

# Power Generation From Pre-treated Empty Fruit Bunch Using Single Chamber Microbial Fuel Cell

Nik Azmi Nik Mahmood<sup>a</sup>, Loke Kwong Thong<sup>a</sup>, Kamarul' Asri Ibrahim<sup>b</sup>,  
 Jong Boor Chyan<sup>c</sup>, Nazlee Faisal Ghazali<sup>\*a</sup>,

<sup>a</sup>Department of Bioprocess Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia.

<sup>b</sup>Department of Chemical Engineering, Faculty of Chemical Engineering, Universiti Teknologi Malaysia., 81310 Johor Bahru, Malaysia.

<sup>c</sup>Agrotechnology and Biosciences Division, Malaysian Nuclear Agency (Nuclear Malaysia), Ministry of Science, Technology and Innovation, Bangi 43000 Kajang, Selangor, Malaysia.  
 nazlee@cheme.utm.my

The utilization of lignocellulosic biomass (LB) as the substrate in Microbial Fuel Cell (MFC) have been receive growing interest due to the vast amount of abundant LB side-product that are generated yearly from agriculture field. In this paper the author will be discussing the utilization of Empty Fruit Bunches (EFB), which is one of the LB waste generated from palm oil industry in single chamber MFC (SCMFC) to generate bioelectricity. The microbes used in this study were equivalent volume mixtures of Gram-positive *Bacillus* E1 and *Clostridium cellulolyticum* (CC). To enhance the efficiency of the microbes to utilize the EFB for bioelectricity generation, the EFB used were pre-treated first with several pre-treatment method which include physical pre-treatment, hot water pre-treatment and alkaline pre-treatment. Different amount of EFB were tested which include 1.5 g, 3.5 g and 5.5 g of EFB under similar condition with total working volume of 250 mL for anode chamber. Resistor of range 100 - 100,000  $\Omega$  was connected to the MFC to calculate the current and power generated from the system. Results indicate maximum power was achieved at the value of up to 0.7 W/m<sup>2</sup> at above 1.0 A/m<sup>2</sup> for all pre-treated EFB tested. The highest power was achieved at 100  $\Omega$  using lower concentration of EFB with a value of 0.678 W/m<sup>2</sup>. In conclusion, EFB is a feasible substrate for MFC and more studies on improvement of the power generation in progress for larger scale application.

## 1. Introduction

World energy consumption demand is predicted to increase by 41 % from 2012 to 2035 (BP, 2014). However, most of the required energy will still be supplied from fossil fuels, with around 6 % being from nuclear sources and about 8 % from other renewable energy sources (EIA, 2008). Furthermore, with the widespread usage of fossil fuels (coal, oil, and natural gases), carbon dioxide (CO<sub>2</sub>) emission become a threat and contributes the greenhouse gases.

Meanwhile, empty fruit bunch (EFB), which is an abundant biomass, produced during harvesting of oil palm fruits, has been focused on recycling it, for example composting (Watida et al., 2011), bio-methane (Nuntiya et al., 2009) and bio-ethanol production (Yanni et al., 2013). In addition, several lignocellulose biomass candidates such as algae as cathode (Araceli et al., 2014) and as anode (Sharon et al., 2009), steam-exploded corn stover (Xin et al, 2009) and other aquatic plant such as *canna indica* (Guo et al., 2010) have been reported of their utilization as fuel in MFC. Yet, EFB that contains largely cellulose and hemicelluloses could be extended (Hamzah et al., 2011) for more than just biogas or bioethanol production.

MFC utilized cellulose degradation process and produce large amount of power. For example, wheat-straw was pre-treated using steam and acid hydrolysis (Yifeng et al., 2009) and liquid hydrolysate was used as fuel in a dual chamber MFC containing wastewater to produce 123 mW/m<sup>2</sup> of power density. The microbial communities developed from the biofilm on the anodic electrode were investigated to consist of largely *Bacteroidetes* family of bacillus species. Similar microbial communities were found in other lignocellulose-fed

air-cathode MFC with aquatic plant (Guo et al., 2009) and corn stover (Xin et al., 2010) but there is some evidence that clostridium sp. emerged during the long period of acclimation process of the hydrolysate in MFC that may also contribute to cellulose degradation (Xin et al. 2010).

In the present research, investigation has been conducted using EFB as fuel in a single chamber MFC (SMFC) to produce power. In addition, one bacilli species microbe, which was isolated previously (Nik Azmi et al., 2013) and a known-cellulose degrader, *Clostridium cellulolyticum* have been combined as the machineries to promote both electron transfer and biomass degradation.

## 2. Materials and methods

### 2.1 EFB preparation

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 subjected to crushing before manually sieved to collect between 250 to 400 mm sizes. Subsequently, the crushed EFB was treated with the pre-treatment procedure adapted from Hamzah et al. (2011). Briefly, crushed EFB was soaked in distilled water in a water bath at 80 °C. The water was filtered and 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 EFB was then filtered to separate from alkaline solution and mixed with sodium hypochlorite solution (6 - 14 % active chlorine) for bleaching process. This will break most of the lignin present and the process should be continued until the pH of the filtrate became 3 (EFB became almost white in color). Next, the EFB fiber produced was washed several times with running tap water until reaching neutral pH. The pre-treated EFB fiber was used directly for MFC operation. The EFB fiber was analyzed for cellulose, hemicellulose and lignin according to the analysis provided by Nomanbhay et al. (2013).

### 2.2 Inocula preparation

The microorganisms used were maintained in 10 % (w/v) glycerol stock solution in -80 °C. *Bacillus* E1 and *C. Cellulolyticum* were directly plated on nutrient agar plates, and single colonies were chosen and transferred to a fresh 5-mL Luria-betani broth, which was supplemented with 1.0 % (w/v) carboxymethyl cellulose to enhance growth of both microbes. After 24 h of pre-incubation the pre-cultures were transferred to 100 mL of the same medium and incubated for another 24 h or until the optical density of 600 nm achieved more than 1.0. The microbial cells were harvested and dissolved in 15 mL each prior to use in MFC.

### 2.3 MFC design

MFC assembly comprised Perspex elements that were connected together as a single chamber MFC (Figure 1). One anode compartment with a main stainless steel holder for one 4 x 5 cm<sup>2</sup> graphite reticulated cloth as anode electrode. The cathode side was exposed to air with a stainless steel mesh wire to hold the cathode electrode, which was made from the same material as anode and surface area of (28.3 cm<sup>2</sup>). The cathode connection consists of stainless steel material that has a screw that touched the cathode electrode surface and acted as a connector platform to the multimeter as shown in Figure 1.

### 2.4 MFC operation

The EFB was added into the anodic compartment together with 250 mL of modified pH 7.0 medium consists of (g/L): 1.0 g KH<sub>2</sub>PO<sub>4</sub>; 1.0 g K<sub>2</sub>HPO<sub>4</sub>; 0.5 g MgSO<sub>4</sub>·7H<sub>2</sub>O; 0.5 g KCl; 0.5 g NH<sub>3</sub>Cl; 0.01 g FeSO<sub>4</sub>·2H<sub>2</sub>O; 2.0 g Yeast Extract. 30 mL of mixture of both microbes E1 and CC was added or otherwise specified. The anode medium was then flushed with nitrogen gas for 15 min to create anaerobic condition before MFC operation. The EFB was varied in terms of weight per 250 mL medium, which include 1.5 g, 3.5 g and 5.5 g in a separate MFC. It was important that the MFC was initially operated without any external resistance to ensure that the microbes were acclimated in the medium environment for almost 3 days before the open circuit voltage (OCV) became constant and at the maximum average value.

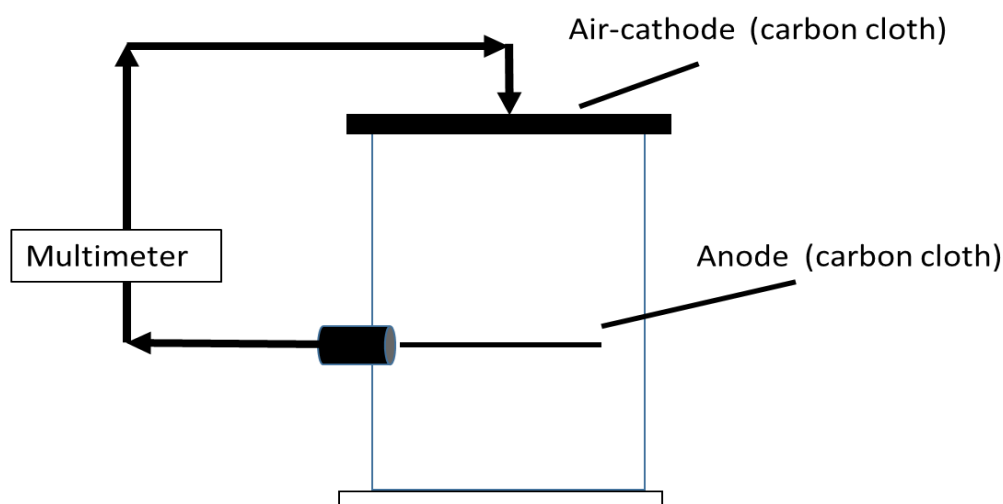


Figure 1: Schematic diagram of single chamber microbial fuel cell.

### 2.5 Power analysis

Measurements of voltage were performed using an auto-logged multimeter (Fluke, USA) and was monitored automatically for every 90 min. Meanwhile for closed circuit set up, external resistant, R from 100 to 1,000 K Ohm was applied to measure voltage produced and power output was calculated as  $P = I \times V$  and I was deducible as  $I = V \times R^{-1}$ .

## 3. Results and discussion

### 3.1 EFB composition

The EFB has been analyzed and estimated for its three major component before and after pre-treatment using alkaline solution. Table 1 shows the proximate analysis of cellulose, hemicellulose and lignin.

Table 1: Proximate analysis of treated and untreated EFB

Condition	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)
Before treatment	42	33	25
After treatment	38	18	7

The cellulose remains intact as the highest yield composition in EFB compared to other components with or without treatment. However, it is known that lignin is a barrier for any enzymatic attack or microbial degradation due to its molecular structure. In contrast, via alkaline treatment, lignin was reduced tremendously and this condition provides more access for cellulose degradation. The following MFC trials were done with alkaline-treated EFB.

### 3.2 Open circuit voltage during acclimatization

The MFC was initially acclimatized for approximately 3 d, which also the period for the designated microbes to adjust to their new environment. The hypothesis was that CC will initiate the cellulose degradation and glucose produced will eventually used up for both growth and also power generation. However, as depicted in Figure 2, the OCV for individual CC and mixed of both microbes achieved more than 0.5 V but not E1. The achievable OCV was very low approximately maximum average value of 0.26 V. Bacillus E1 was previously tested for cellulose degradation using agar containing 0.1 % Carboxymethyl cellulose and did not show high degradation compared to CC (data not shown). In contrast, there were no reports of CC to be able to perform electron transfer directly though one microbe of the *Clostridia* family, related to *Clostridium butyricum* (Hyung et al., 2001) in a dual chamber MFC. The high OCV of MFC operated with CC only was comparable to the one with mixed microbes. The availability of cellulose degradation product, which mainly consists of glucose, was the most important aspect in the MFC system. In CC based and mixed based MFC, large amount of glucose

was available for electron recovery to be transferred to anodic electrode for power production. In E1 based MFC, glucose limitation could reflect the low OCV obtained. In any case, power performance was evaluated by varying the resistance, R for the mixed culture as discussed below.

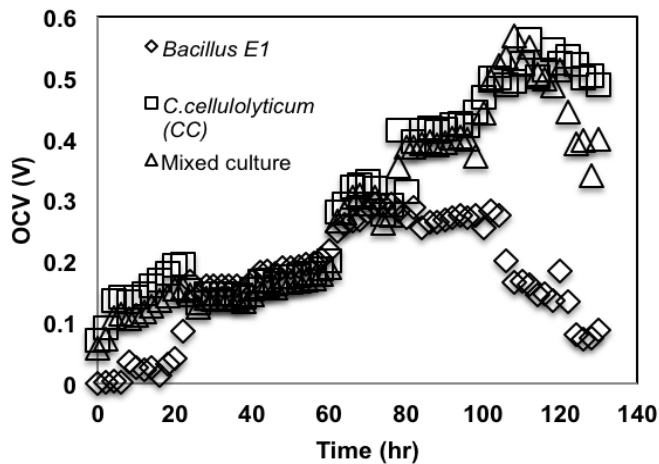


Figure 2: Open circuit voltage (OCV) profile. Maximum achievable OCV observed for E1, C.Cellulolyticum and mixed culture were  $0.294 \pm 0.04$ ,  $0.564 \pm 0.014$  and  $0.569 \pm 0.011$

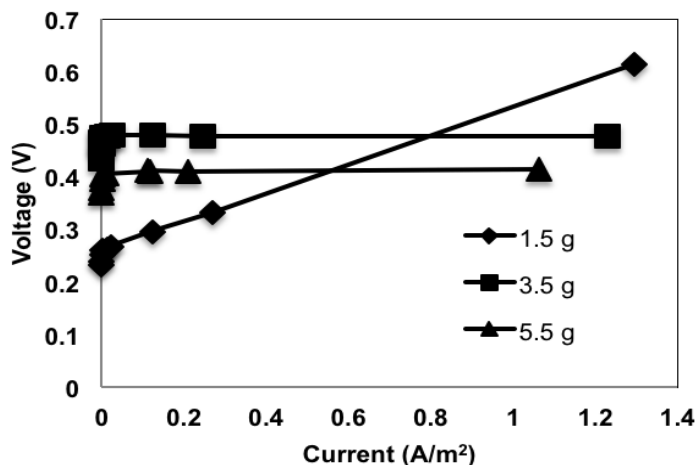


Figure 3: Polarization curve for mixed culture using different EFB concentration. Voltage was measured by varying external resistance every 30 min.

### 3.3 Polarization curve and power curve

Changing the external resistance of the circuit for all MFC set-ups generated polarization curves. A polarization curve is used to characterize current as a function of voltage. The polarization curve pattern shows a decrease at lower current value but gradually increase and stabilized at higher current. This kind of polarization pattern was thought to be some kind of power overshoot phenomenon. At the moment this cannot be explained due to the fact that tests for such phenomenon can only be elucidated if the polarization curve data was measured at much longer days (Valerie et al., 2011). However, MFC with the present of pre-treated EFB immediately produced high power at higher current for all EFB concentrations (above  $1.0 \text{ A/m}^2$ ) and up to  $0.7 \text{ W/m}^2$ . In addition, at low concentration (1.5 g of pre-treated EFB) at 100 Ohm, achieved higher power value of  $0.678 \text{ W/m}^2$ , compared with 3.5 g and 5.5 g, the maximum power value of 0.56 and  $0.42 \text{ W/m}^2$ . Geung et al. (2003) did look into the effect of substrate concentration in a mediatorless MFC and determined that an increment of substrate concentration gave higher power till it reached a plateau or saturation point at

certain concentration. However, the concentration was not enough to elucidate the substrate effect and even wider range of external resistance is needed to obtain more data on the power performance.

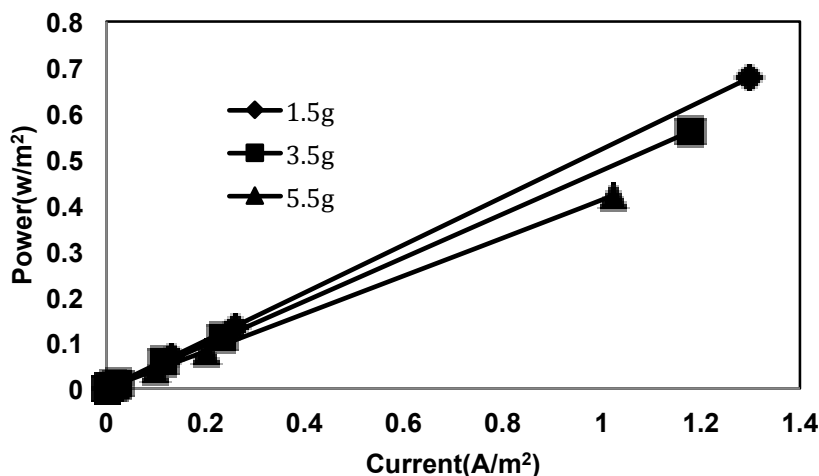


Figure 4: Power curve for different concentration of pre-treated EFB.

#### 4. Conclusion

The study proved that pre-treated EFB could be utilized for power generation using MFC-based process. In addition, high power was obtained at lower concentration of pre-treated EFB and showed limiting effect if substrate concentration is increased. Yet, the effect of concentration remains elusive and more data needed to support concentration effect.

#### Reference

- Aracelli G.D.C., Justo L., Pablo C., Manuel A.R., Francisco J.F, 2014, Cathodic optimization of a MFC for energy recovery from industrial wastewater. *Chemical Engineering Transactions*, 41, 145 – 150.
- BP Energy Outlook 2035. 2014, <[www.bp.com/content/dam/bp/pdf/Energy-economics/Energy-Outlook/Energy\\_Outlook\\_2035\\_booklet.pdf](http://www.bp.com/content/dam/bp/pdf/Energy-economics/Energy-Outlook/Energy_Outlook_2035_booklet.pdf)> accessed 24.02.2015.
- Energy Information Administration (EIA), 2008, Annual Energy Outlook: with Projections to 2030. <[www.eia.doe.gov/oiaf/aeo](http://www.eia.doe.gov/oiaf/aeo)> accessed 24.02.2015
- Geung C.G., In S.C., Byung H.K., Mia K., Jae K.J., Hyung S.P., Hyung J.K 2003, Operational parameters affecting the performance of mediator-less microbial fuel cell. *Biosens. Bioelectron.* 18. 327 – 334
- Guo L.Z., Guo P.S., Zhong H.T., Xian, W.L., Shao X.T., Wen W.L., Hab Q.Y. 2010, Direct electricity recovery from *Canna indica* by an air-cathode microbial fuel cell with rumen microorganisms. *Environ. Sci. Technol.* 44(7). 2715 – 2720.
- Hamzah F., Idris A., Shuan T.K. 2011, Preliminary study on enzymatic hydrolysis of treated oil palm (Elais) empty fruit bunches fibre (EFB) by using combination of cellulase and beta-1-4-glucosidase. *Biomass. Bioenergy.* 35. 1055 – 1059.
- Hyung S.P., Byung H.K. Hyo S.K., Hyung J.K., Gwang T.K., Mia K., In S. C., Yong K.P., Hyo I.C., 2001, A Novel Electrochemically Active and Fe (II) reducing Bacterium Phylogenetically Related To *Clostridium butyricum* Isolated from Microbial Fuel Cell. *Anaerobe.* 7, 297 – 306.
- Nik Azmi N.M., Nazlee F.M.G., Kamarul' A.I., Nur Muhammad E.Q.M.N., 2013, Electricity generation from Citronella Bagasse (CB) using microbial fuel cell (MFC), *Pertanika J. Sci. Technol.*, 21(2), 581 – 588.
- Nuntiya P., Anop N., Warinthorn S., 2009, Bio-methane potential of biological solid materials and agricultural wastes. *As. J. Energy Env.*, 10(1), 19 – 27.
- Valesquez-Orta, S.B., Curtis, P.T., Logan B. E., 2009, Energy from algae using microbial fuel cell. *Biotechnol. Bioeng.*, 103(6).1068 – 1076.
- Valerie J.W., Bruec E.L., 2011, Analysis of polarization methods for elimination of power overshoot in microbial fuel cell. *Electrochem. Commun.* 13, 54 – 56.

- Watida K., Thunwadee T., Chaisri S., 2011, Biochemical changes during oil palm (*Elaeis guineensis*) empty fruit bunch composting with decanter sludge and chicken manure. *ScienceAsia*, 37, 17 – 23
- Yanni S., Dyah S., Eka T., Sudyarmanto Kiki C.S., Yosi A., Haznan A., Min H.H., 2013, Utilization of biomass waste empty fruit bunch fiber of palm oil for bioethanol production using pilot-scale unit. *Energy Procedia*, 32, 31 – 38.
- Yifeng Z., Booki M., Liping H., Irini A., 2009, Generation of electricity and analysis of microbial communities in wheat straw biomass-powered microbial fuel cells. *Appl. Environ. Microbiol.*, 75(11). 3389 – 3395.
- Xin W., Yujie F., Heming W., Youpeng Q., Yanling Y., Nanqi R., Nan L., Elle W., He L., Bruce E. L. 2009. Bioaugmentation of electricity generation from corn stover biomass using microbial fuel cell. *Environ. Sci., Technol.* 43, (15). 6088 – 6093.