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Full Length Research Paper

Effect of different substrate on performance of microbial fuel cell

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Microbial fuel cells are new technology for the production of bioelectricity. The electrons liberated by microorganisms during consumption of organic substrate are transferred from the anode to the cathode linked by an external circuit and produce electricity under anaerobic conditions. In this study, palm oil mill effluent anaerobic sludge was used as active biocatalyst for bioelectricity generation. Several substrates such as glucose, fructose, sucrose and molasses were examined as electron donors by mixed culture of microorganisms in an anaerobic anode compartment. The maximum open circuit voltage achieved was 460 mV and the highest power and current density were 55.25 mW/m^2 and 208.55 mA/m^2, respectively.

Key word: Biocatalysis, microbial fuel cell, substrate, palm oil, power density.

INTRODUCTION

In recent years, global fossil fuel resources are depleting. Moreover, fossil fuels have detrimental effects on the environment. Use of fossil fuel may create global warming, environmental pollution and climate changing (Gunkel, 2009). Power generation from renewable sources has been growing rapidly and scientists in the world have started to find new alternatives for renewable energies to overcome energy crisis in the future (Lovley, 2006; Strik et al., 2008).

Microbial fuel cells (MFCs) are a biochemical-catalyzed system; electricity was produced by oxidizing biodegradable organic matter in the presence of either fermentative bacteria or enzyme (Liberatore et al., 2002; Chaudhuri and Lovley, 2003). This system can generate clean energy (Liu et al., 2004; Oh et al., 2004; Aelterman et al., 2006). Generated electron pass through anode to cathode with an external circuit and produced protons diffuse through the proton exchange membrane (which separates cathode and anode chamber) into cathode compartment. The potential between the respiratory system and electron acceptor generates the current and voltage needed to make electricity (Rahimnejad et al., 2009).

The performances of MFCs may be increased by several important process parameters which are critical in MFCs operation. These parameters are: (i) Metabolism of microorganisms, (ii) transfer of produced electron, (iii) proton exchange membrane performance, (iv) external and internal resistances, (v) cathode oxidation and (vi) electron donors or substrate (Rabaey et al., 2004; Logan, 2007; Rabaey and Verstraete, 2005).

Traditional MFCs have two chambers, an aerated cathode and anaerobic anode compartments separated by cation exchange membrane such as nafions or salt bridge (Rahimnejad et al., 2005; Najafpour et al., 2009). Membrane or salt bridge allows hydrogen ions generated in the anode chamber to be transferred into cathode chamber (Luo et al., 2009).

The electron donors, as a key parameter influences the integral composition of the bacterial community in the anode biofilm, and the performance of MFC including the

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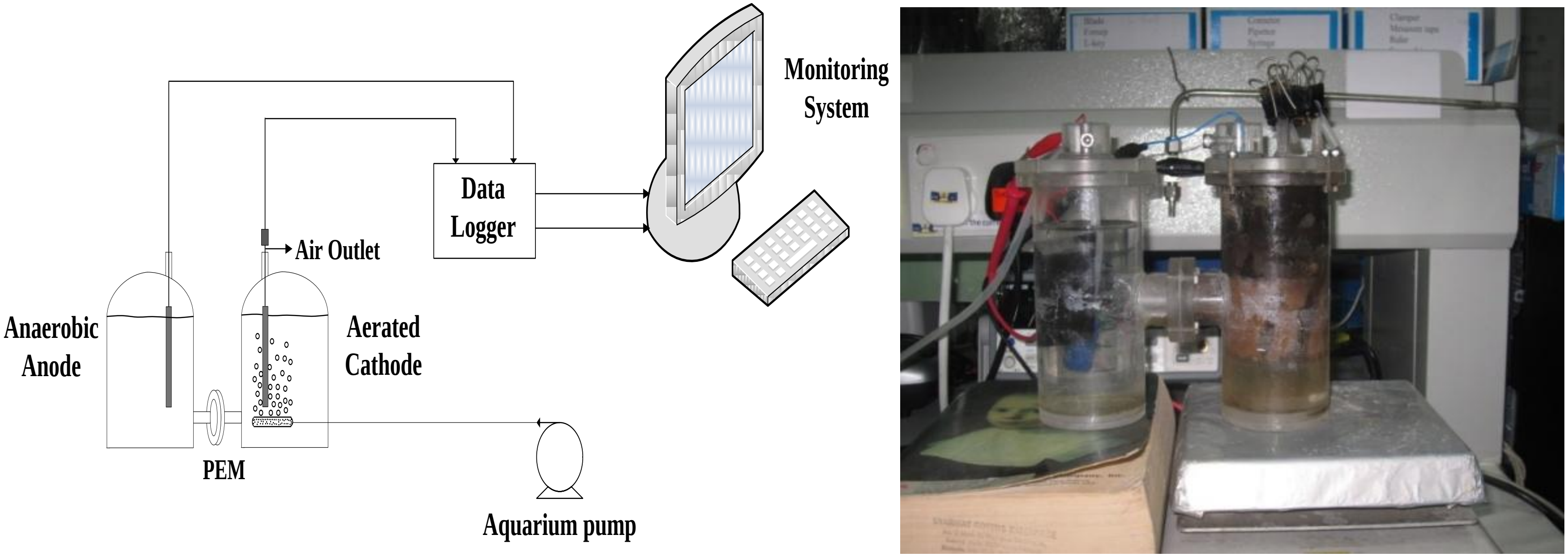


Figure 1. Schematic and photograph image of fabricated MFC.

generated power and coulombic efficiency (Pant et al., 2010). Different kinds of substrate, simple organic and inorganic substrate or waste water as mixed combination of several materials can be used in MFCs as electron donors (Habermann and Pommer, 1991).

The purpose of the present research was to use mixed culture of microorganisms as active biocatalyst without using any electron mediators for bioelectricity production in dual chamber MFC. Also, effect of source of electron donors was investigated.

MATERIALS AND METHODS

MFC construction and operation

Two cylindrical and H-shaped chambers were constructed using Plexiglas material with a diameter of 6.2 cm and a length of 14 cm and were separated with Nafion 117 (Sigma Aldrich, USA), which acted as the proton exchange membrane (PEM). Oxygen was fed to the cathode continuously by an air pump (80 ml/min). Both the cathode and anode surface areas were 12 cm^2 and MFC was operated in ambient temperature and neutral pH (6.5 to 7) in anode and cathode (Zhao et al., 2005; Kim et al., 2002). The pH was adjusted by the phosphate buffer solution. Plain carbon paper was used as the anode and cathode electrode. The schematic and figure of MFC is shown in Figure 1.

Microorganism and cultivation

Palm oil mill effluent (POME) anaerobic sludge (Selangor, Malaysia) was used to inoculate the reactor in the anode chamber. The media contained 5 g of glucose, 0. 5 g of yeast extract, 0.2 g of KCl, 1 g of $NaH_2PO_4.4H2O$, 3 g of NH_4Cl, 4 g of $NaHCO_3$ (all from the Merck company), 10 ml solution of Wolfe's mineral and 10 ml of Wolfe's vitamin solution added per liter (Trinh et al., 2009).

Analysis and calculation

The current and power produced by the system was calculated by using equations 1 and 2:

$$I = \frac{V}{R} \quad (1)$$

$$P = R \times I^2 \quad (2)$$

Where, I is the current (amper); V is the voltage (volt); R is the external resistance (ohm) and P is the power (watt) produced by the system.

Columbic efficiency can be calculated by division of total coulombs obtained from the cell and theoretical amount of coulomb that can be produced from glucose (Equation 3):

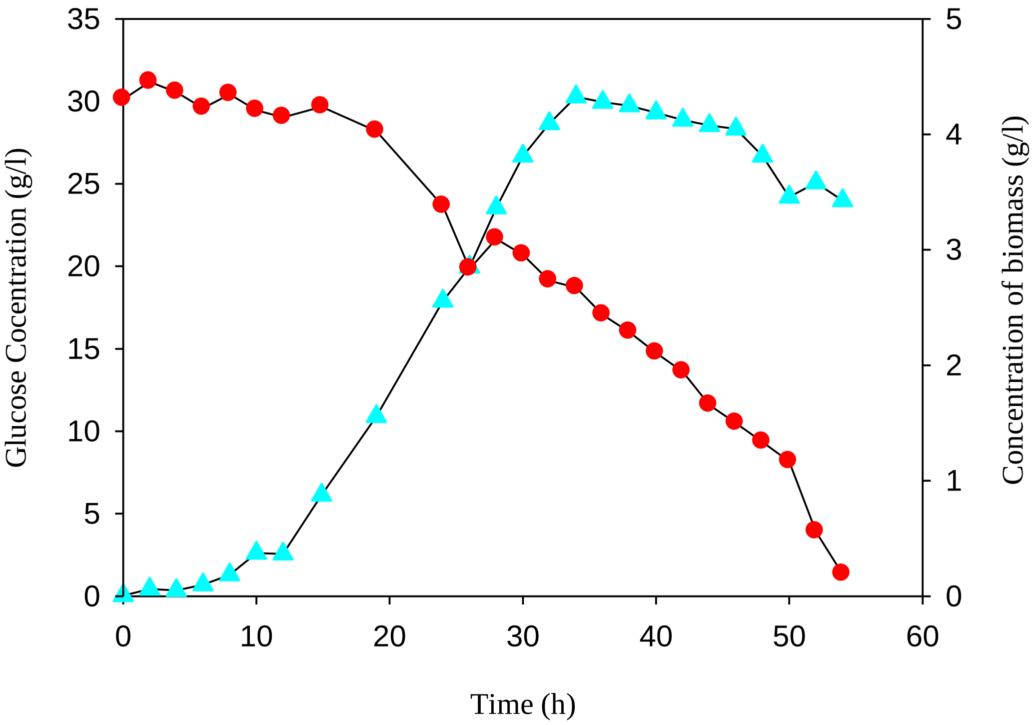


Figure 2. Cell growth profiles and glucose consumption by active biocatalyst in an anaerobic anode compartment.

$$CE = (C_p/C_T)\times 100 \qquad (3)$$

Total coulombs was obtained by integrating the current over time (C_p), where C_T is the theoretical amount of coulombs that can be produced from carbon source, calculated as follows:

$$C_T = (FbSV.M^{-1}) \qquad (4)$$

Where, *F* is the Faraday's constant; b is the number of moles of electrons produced per mole of substrate (24 mol of electron was produced in glucose oxidation in anaerobic anode chamber); *S* is the substrate concentration and *M* is the molecular weight of used substrate (for glucose, *M* = 180.155 g.mol^{-1}).

Scanning electron microscope (SEM)

SEM was used to show the surface of the anode electrode. The sample was coated with gold and observed with a microscope (Phillips XL30, Holland). Finally, images of the samples were taken under SEM at 5000 magnifications.

Cyclic voltammetry

Cyclic voltammetry (Ivium CompactStat, Ivium Technology, Netherland) was carried out to characterize the oxidation and reduction of thionin on the electrode. A conventional three-electrode system was employed with the anode as the working electrode, cathode or platinum mesh (Platinum, gauze 100 mesh, Sigma Aldrich) as the counter electrode, and an Ag/AgCl reference electrode (0.195 V corrected to a normal hydrogen electrode; NHE). The potentials were shifted from -400 to 1000 mV at a scan rate of 50 mV/s.

RESULTS AND DISCUSSION

In the MFCs, the electricity was produced by the microbial growth in anaerobic anode compartment, while the substrate was consumed by active microorganisms or enzymes. Glucose consumption and cell growth with respect to incubation time is shown in Figure 2. Figure 2 demonstrates that selected mixed culture of microorganisms had the good possibility for consumption of substrate at anaerobic condition and produced bioelectricity. Fixed incubation time and enriched media was used. The media consist of yeast extract, glucose, K_2HPO_4, $MgSO_4$ and $MnSO_4$ with concentrations of 3, 30, 0.2, 0.2 and 0.05 gL^{-1}, respectively.

Glucose, sucrose, fructose and molasses were individually implemented as carbon source for electricity production in the fabricated MFC. Maximum generated bioelectricity was obtained from molasses as electron donors. Maximum obtained power and current were 55.25 mW/m^2 and 208.55 mA/m^2, respectively. These achieved power and current were more than that of obtained power and current from the other used substrate at the same concentration (Figure 3).

Figure 4 depicts an OCV recorded by online data

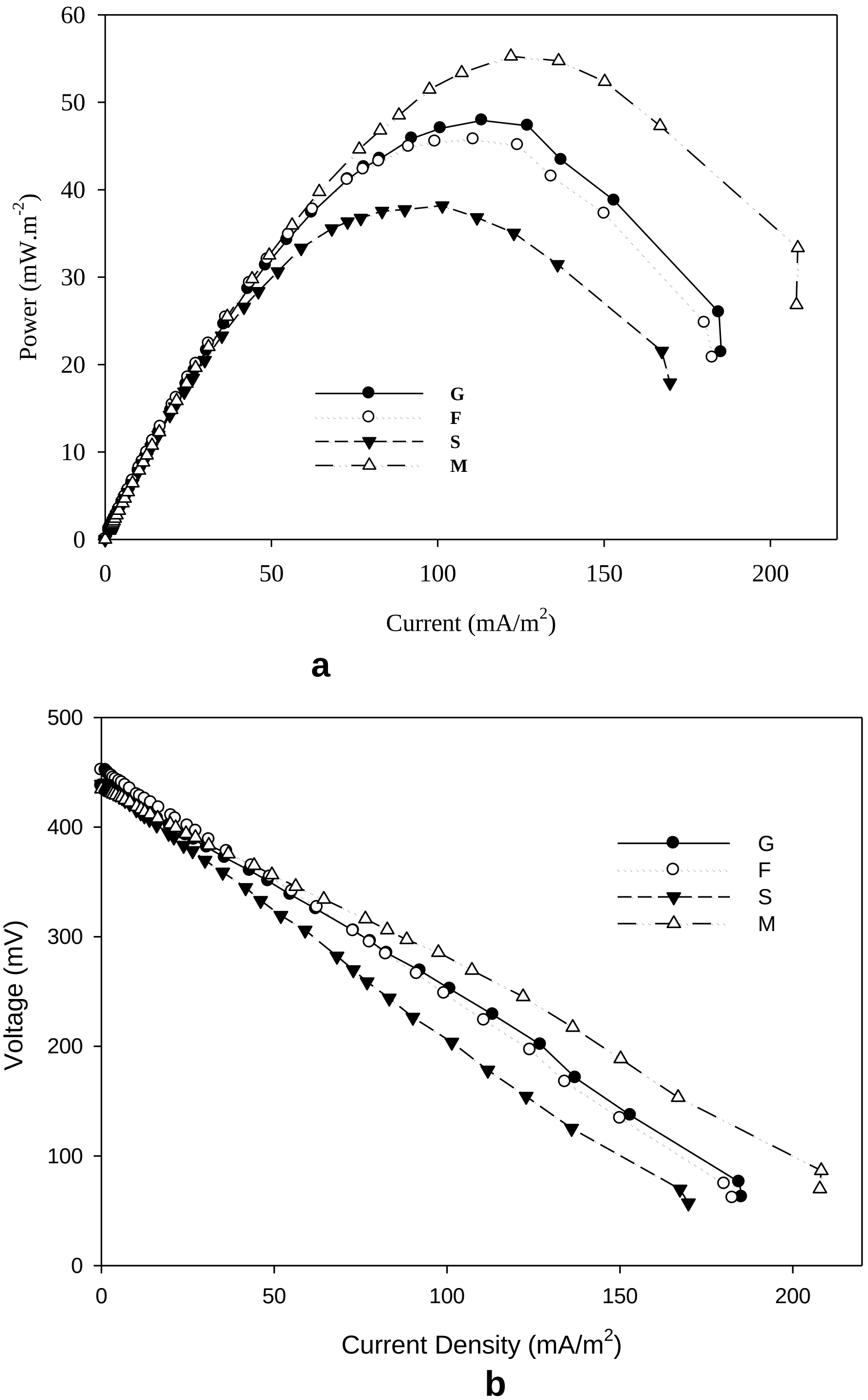


Figure 3. Generated power density (a) and voltage (b) as function of current density of different kinds of substrates.

acquisition system connected to the MFC for duration of 72 h. At the beginning of the experimental run, the voltage was less than 250 mV and then the voltage gradually increased. After 28 h of operation, the OCV reached a maximum and stable value of 480 mV. The OCV was quite stable for the entire operation (duration of 72 h).

Graphite was selected in the fabricated MFC as electrode. The normal photographic image of the used electrode before employing the MFC as anode

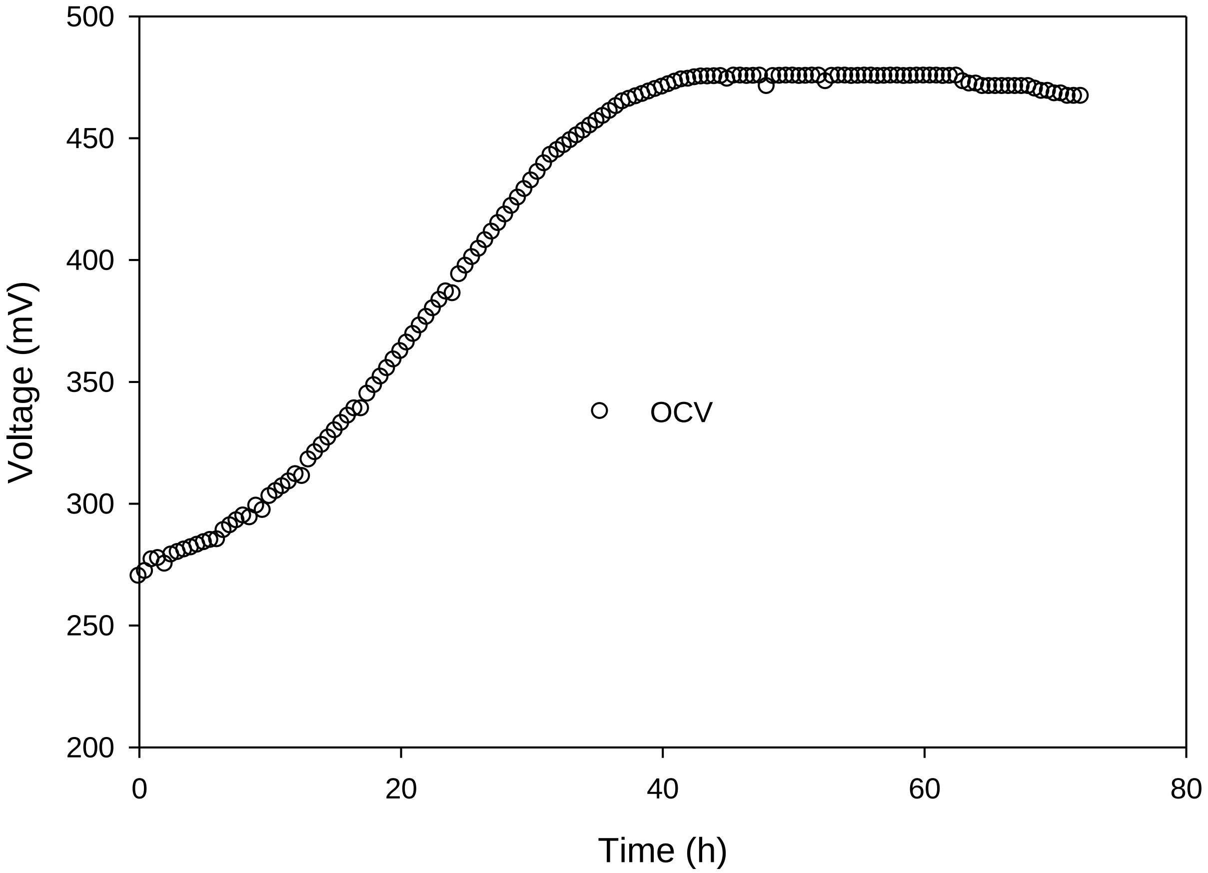
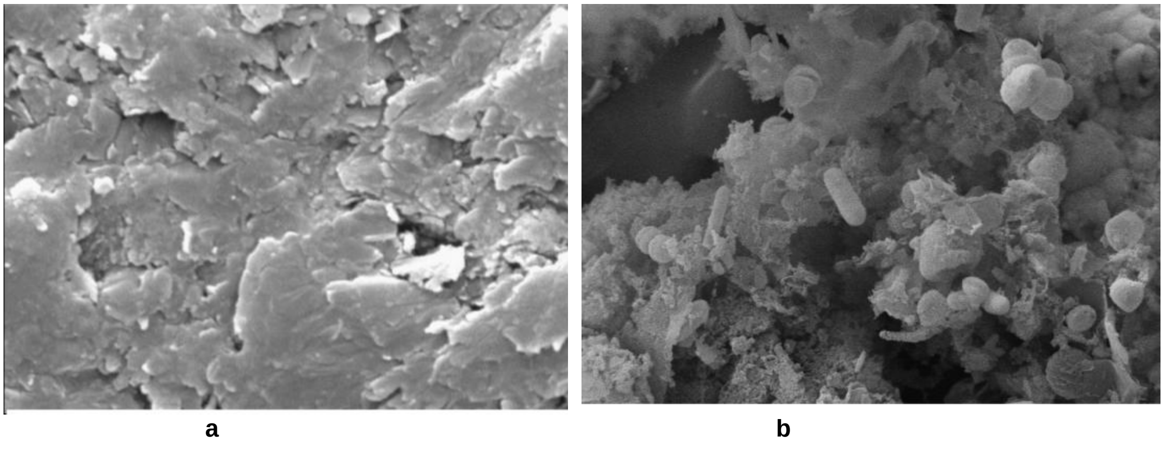


Figure 4. Stability of OCV.OCV recorded by online data acquisition system connected to the MFC for duration of 72 h.


a

b

Figure 5. Attached microorganisms on anode surface at the end of the period. Scanning electron microscopy of the biofilm observed on the surface of anode electrode with magnification of 5000.

compartment is shown in Figure 5a. Scanning electronic microscopy technique has been applied to provide surface criteria and morphological information for the anode surface. The surface images of the graphite plate electrode were successfully obtained by SEM. The image from the surface of graphite electrode before and after experimental run was taken. The sample size was 1.5 × 1.5 cm for SEM analysis. Figure 5a and b show the outer surface of the graphite electrode prior to and after use in the MFC, respectively. These obtained images demonstrated that microorganisms were grown on the graphite surface as attached biofilm.

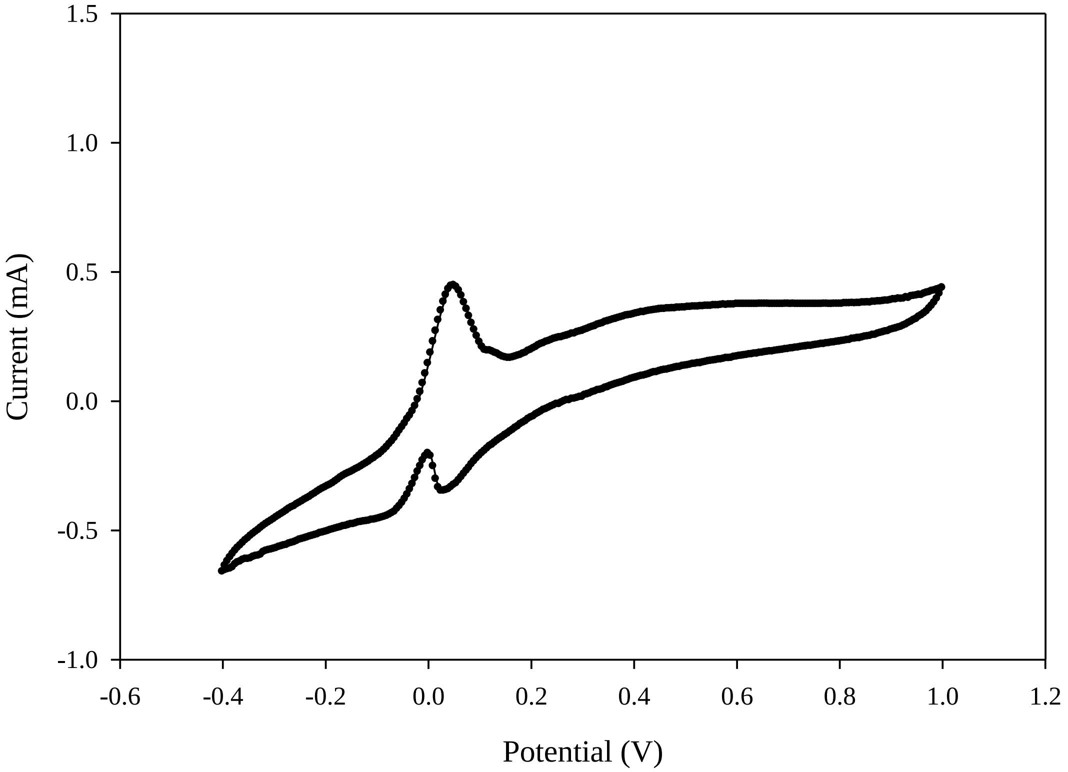


Figure 6. Cyclic voltammograms of the anode electrode under anaerobic condition.

In the next stage, surface of anode electrode with attached microorganisms was investigated with CV test. The system was analyzed in anaerobic anode chamber. Before formation of active biofilm on anode surface, oxidation and reduction peak was not observed in CV test. Current-potential curves by scanning the potential from negative to positive potential after formation of active biofilm are shown in Figure 6. Two oxidation and one reduction peak was obtained with CV test.

Conclusion

This study revealed that palm oil mill effluent anaerobic sludge has good ability for oxidation of substrate and production of bioelectricity. Fermentation of four different substrate such as glucose, fructose, lactose and molasses for power production was successfully carried out in the duel chamber of fabricated MFC. An interesting point was that sources of electron donors have important role in the efficiency of microbial fuel cell. Obtained result showed that the two chambers MFC successfully produced bioelectricity from different kinds of substrate without using any mediator and oxidizer in anode and cathode compartment. The maximum obtained current and power density were 208.55 mA/m^2 and 55.25 mW/m^2, respectively. When the initial molasses concentration was 30 g/L, the maximum obtained voltage was 480 mV. This produced voltage was quite stable for the entire operation time (duration of 72 h).

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