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Potential bioelectricity generation from mangrove sediments

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ABSTRACT

Bioelectricity has gained a lot of attention in order to fulfil the demand for clean and renewable energy source. The demand is increasing rapidly worldwide. Therefore, new energy source need to be explored in order to overcome the energy deficiency. In this study, the potential of bioelectricity generation from mangrove sediments were investigated. The experiments were conducted by using two-chamber microbial fuel cell that consists of an anode and cathode compartment. The mangrove sediments were collected from two different areas, the salt flat area and live mangrove forest area. The effects of mangrove sediments concentration as the electrolyte on electricity generation were measured. The parameters including different type of catholyte, resistor and effect of pH of the sediments on bioelectricity generation were tested. Salt flat area sediment produced higher electricity compare to live mangrove area with 310 mV and 234 mV respectively. Phosphate buffer act as better catholyte compare to distilled water. Higher electricity was produced at pH 9.2 compared to pH 6.5. The Power density obtained by salt flat area sediment was 0.30 µW/cm^3 with external load 14 kΩ while for live mangrove forest area sediment area 0.17µW/cm^3 with external load 19 kΩ.

Keywords:
Microbial fuel cell, Bioelectricity, Mangrove sediments

1. Introduction

Fossil fuels have been the backbone in the industrialization and economic growth of the world. The increase in demand for fuel had caused depleting in source of fossil fuel. Besides that, the main energy productions of the world also include oil, natural gas and coal. The source of fossil fuel can support the need for at least 100 years or more [1], but the overuse of fossil fuel clearly will not support the demand for oil in ten or twenty years from now [2]. Moreover, the unbalanced consumption and management of energy has called in serious awareness among gloal community to developed alternative energy production by using eco-friendly and renewable source. Thus, several

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renewable energy research has been done to overcome this energy crisis such as biohydrogen [3], bioelectricity [4], hydroelectic, geothermal, biomass, wind and wave energy [5].
In recent years, scientists already found the existence of organism naturally found in the environment and have the ability to react with minerals to convert organic nutrients into biological fuel such as biohydrogen [3] or bioelectricity [4]. Bioelectricty is a conversion of chemical energy into electricity by using biocatalysts [4]. Usually microbes will act as catalyst. These microorganisms are called exoelectrogenic microbes. Exoelectrogenic microbes are the type of microbes that convert organic matter into electrical current. The current are produced by gaining the electrons from the metabolism of microbes [6]. These microorganisms have been proved to be the agent for electricity generation [7].

Mangrove forests are very unique natural ecosystem which consider robust and highly tolerant to the environment within warm, tropical and sub-tropical sea because of their adaptable to the daily change of tidal temperature, water and salt exposure [8]. It is also the accumulation site of sediments, nutrients and contaminants. This rich in organic matter ecosystems has undergoes major nutrient transformations due to the microbial activity [9]. Recent study has shown the potential of sediment in generating electricity by implementing Benthic Microbial Fuel Cell [10]. In this study, the presences of exoelectrogenic microbes in these highly nutrient mangrove sediments will be asses in order to determine the capability to produce electricity by comparing the mangrove sediment found in salt flat area and live mangrove forest area.

2. Methodology

2.1 Sampling of mangrove sediments

The samples of mangrove sediments were taken from Tanjung Piai National Park located in Tanjung Piai, Johor, Malaysia. The sediments were taken in two different areas which is salt flat area and live mangrove forest area. The areas of sampling were 5-10 cm deep and $1m^2$ area. The sludge was stored in 16L container and was sealed with parafilm. The container was placed in the fridge with 4^oC for 3 months.

2.2 Bioelectricity production by mangrove sediments

In this study, dual chamber microbial fuel cell (MFC) set up as Fig. 1 was used to determine the bioelectricity productions by the mangrove sediments from the salt flat area ad live mangrove forest area. For the MFC, graphite rod was chosen as the electrode with a 5 cm salt bridge connected to the anode and cathode chamber. Several parameters were tested for the electricity generation such as effects of dilution, catholytes, pH and external loads. The electricity generation was collected by using a digital voltmeter.

2.2.1 Effects of Mangrove Sediments Concentrations

Both of the salt flat area and live mangrove forest area samples were diluted with distilled water in different concentrations. The concentrations are 100%, 80%, 60%, 40% and 20%. For the control, the samples were autoclaved at 121^oC and then removed at room temperature for cooling.

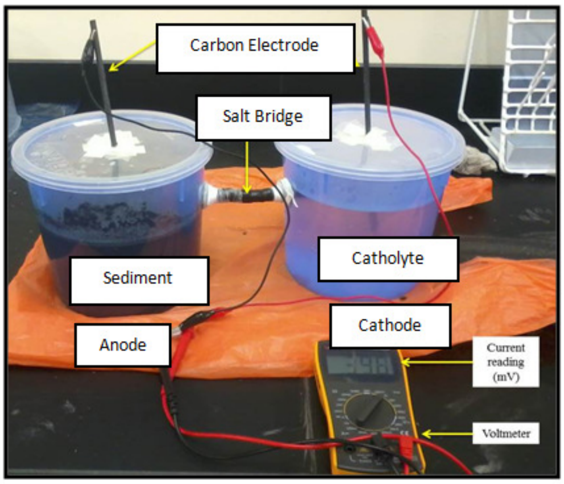


Fig. 1. Set up of Microbial Fuel Cell (MFC)

2.2.2 Effects of catholytes

Two different catholyte was used as the electrolyte for the cathode chamber in assessing electricity generation by mangrove sediments. The catholytes used for the open circuit voltage (OCV) of the sediments was distilled water and phosphate buffer.

2.2.3 Effects of external loads

External loads were introduced into the circuit for the electricity productions in close circuit voltage (CCV). In this set up, phosphate buffer was used as catholyte and different range of external load were added. The values of external load used were resistor with value of 3kΩ, 4kΩ, 9kΩ, 14kΩ and 19kΩ. The reading was recorded three times with 10-minute interval.

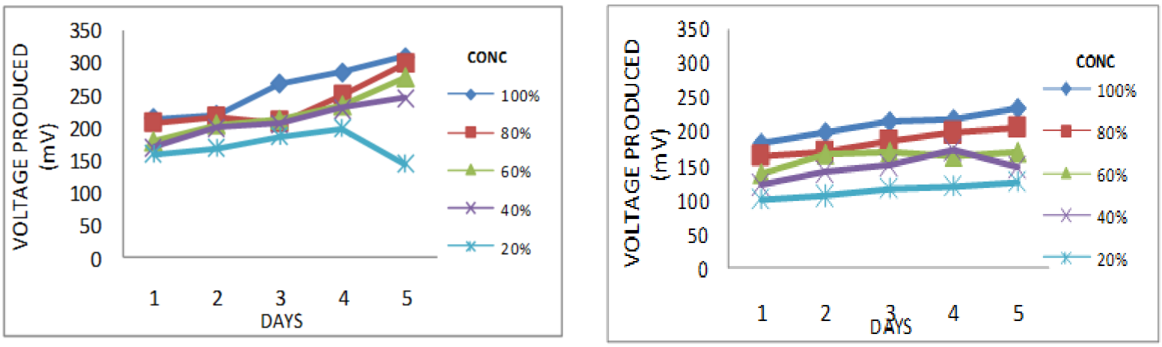
2.2.4 Effects of external pH

The mangrove sediments pH in the anode chamber was adjusted between 6.5 and 9.2.by using Hydrochloric acid (HCl) and sodium hydroxide (NaOH). The electricity production of the sediment was assessed in open circuit voltage (OCV).

3. Results and discussions

3.1 Effects of mangrove sediments concentrations

The reading of current flow for each sediments were taken by using voltmeter. The reading were taken each day for a total of five days. Fig. 2 (a) shows the open circuit voltage of salt flat area sediments. The graph shows that 100% concentration of the sediment have the highest value with 310 mV. On the other hand, the 20% concentration of sediments shows the lowest current flow of 145 mV. For concentration range of100%, 80%,60% and 40% show significantly increase by days. While on the last day 20% concentration of sediments show the depletion in current flow. On Fig. 2(b) it shows the open circuit volatage of live mangrove forest area sediments. Live mangrove forest sediments shows the same result as salt flat area where 100% concentration show the highest current flow with 234 mV. The open circuit voltage for 20% concentration show the lowest reading with 100 mV.



(a) (b)

Fig. 2. Open circuit voltage of salt flat area sediments (a) and live mangrove forest area sediments (b) by MFC

The higher the concentration of the sediments, the higher the reading of current flow of the open circuit voltage. Mangrove sedimentd provide a very unique diversity to various microorganism. Previous study proved that mixed culture can perform better in the electricity generation compare to single culture [11]. There are different types of microbial that exists in mangrove sediments ecosystem which are bacteria, fungi and actinomycetes [12].They also reported that there are various types of bacteria in the sediments like nitrogen fixation bacteria, phosphate solubilizing bacteria, sulfate reducing bacteria, photosynthetic anoxygenic bacteria, methanogenic bacteria and enzyme producing bacteria. For example, sulfate reducing bacteria can degrade organic matter up to 53% [13]. They also have the ability of using organic matter in their metabolism like lactate, acetate, propionate, butyrate and benzoate [14]. There are large amount of organic carbon that mixed in the mangrove ecosytem. Organic matter is important in MFC because they need to be oxidize by microorganism and release electrons through metabolic reactions [15]. The organic matter and the mixed culture in mangrove sediments play the roles in the sediments to produce electricity.

From the graph we can compare that salt flat area sediments produce higher current flow compare to live mangrove forest area. The reason for this is because of the presence of burrows in the live mangrove area but absent in the salt flat area [16]. Durimh hight tide, the water in the burrows is being flush away [17]. Thus, at the same time flusing away the salt accumulated in the sediments. This will make the sediments around the live mangrove area decrease and reduce the salinity of the sediments. Salinity play the important role in the elctrical conductivity. This is why salt flat area sediments show higher current flow.

3.2 Effects of mangrove sediments catholytes

Catholyte is the electrolyte used in the cathode chamber. Different catholyte were used in each open circuit voltage which were phosphate buffer and distilled water. Fig. 3(a) is the result of voltage produce by using phosphate buffer as the catholyte. On the other hand, Fig. 3 (b) show the voltage produce when distilled water was used as catholyte. From both graph we can conclude that circuit that using phosphate buffer produced higher voltage compare to the one that used distilled water as the catholyte.

Phosphate buffer provide the suitable pH for bacteria to generate electricity and this will increase the conductivity in MFC [18]. Protons relatively have slower transport rate compare to other cations like K^+ and Na^+. in two-chamber MFC, this factor actually can reduce the pH in the anode solution and increase the pH in cathode solution [19].The increase of pH in the cathode solution can reduce the permeability of protons towards cathode chamber.Previous study state that when distilled water is used as catholyte, the pH of electrolyte in cathode chamber increased gradually [20]. These will cause the huge different of pH in both chambers.

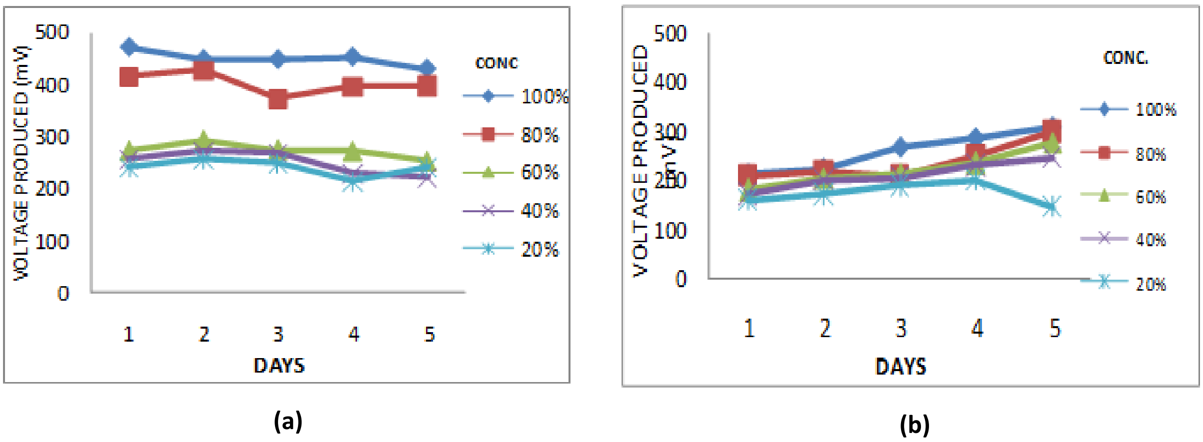


Fig. 3. Voltage produce by using phosphate buffer (a) and distilled water (b) as the catholyte

From the result show that the rate of proton transport to the cathode chamber is lower compare to its productions. Despite providing the optimum temperature for microbial activities, phosphate buffer can also increase the transport rate of proton tranfer to cathode chamber [20]. The microbial activity and the transfer of electrons to electrode are slower due to the limited supply of protons to the cathode chamber.

3.3 Effects of pH

The pH of mangrove sediments in the anode chamber was adjusted. In this circuit the pH of the sediment was adjust to pH 6.5 and pH 9.2. Fig. 4 shows that pH of 6.5 produce higher current flow compare to pH 9. The acid and neutral MFC are more efficient in producing current compare to basic pH.This is due to the effect of internal resistance happen in the circuit [21]. They also state that higher pH will produce insufficient concentration of hydrogen ion (H^+) that will cause slower electron discharge to the electrode and thus producing low current flow. Dissolved oxygen in the anode chamber is important in producing protons that will be pass to the cathode [22].

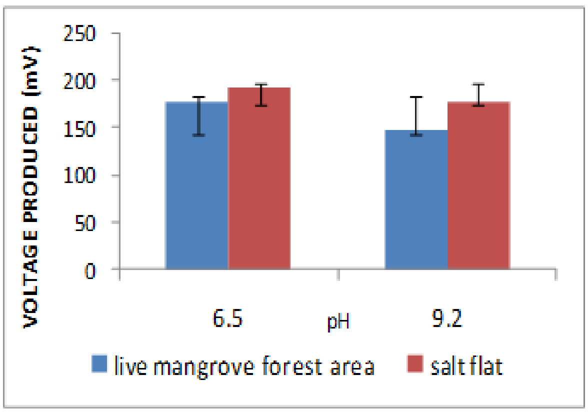


Fig. 4. Open circuit voltage for different pH of the mangrove sediments by using carbon rod electrode

Higher oxygen concentration has the abilities to neutralized the protons that being produced during the metabolic reaction before being pass to the cathode [23]. Thus, low concentration of dissolved oxygen can provide the good condition of electrons and protons transfer in MFC operations. This conclude that, the result for pH 6.5 having the higher release of electrons due to the low dissolved oxygen in anode. It is presumed that the concentration of dissolved oxygen is low due to the acidc codition of the sediments. This is because the HCl that being added in the sediments dissolved the dissolved oxygen present in the sediments [24].

3.3 Effects of External Loads

The current flow for both sediments were measured when external load was added into the circuit. The best power density was selected between different values of external load. Power density is the amount of power produce per unit volume. This is to measure that the sufficient current produced even though external load is added.

From Table 1, the sediment from salt flat area produced higher power density compare to the live mangrove forest area. The highest power density was obtained from salt flat area when 14 kΩ of external load been added with value of 0.30μW/cm^3. While for the live mangrove area sediment, the highest power density recorded was when 19 kΩ was added to the circuit with power density of 0.17μW/cm^3.

Table 1
Maximum open circuit voltage (OCV), power density, current density and external load values for salt flat and live mangrove forest area sediments.

	Maximum Open Circuit Voltage (V)	**Power Density (W/m^3)**	**Current Density (mA/m^3)**	**External Resistor Value (kΩ)**
Salt flat	0.472	2.96x10^{-7}	5.38x10^{-6}	14
Live mangrove forest	0.241	1.66 x 10^{-7}	3.46 x 10^{-6}	19

4. Conclusion

In the study, the salt flat area sediments produced higher current flow compare to the live mangrove forest area sediment with 472 mV and 241mV respectively. 100% of the concentrations of the sediment produce highest voltage compare to other concentrations. This is because the concentration on the mixed culture of bacteria presence in the sediments. When the catholyte of the MFC is changed, we can see that MFC that used phosphate buffer produce higher voltage generation compare to distilled water as catholyte. The effect of pH of the sediments also will affect the internal resistance of the circuit. More acidic sediment with pH 6.5 produces higher current flow compare to pH 9.2. External loads were added to the circuit to calculate the power density produced by the circuit. Power density is to determine the ability of the circuit to produce current when resistor is added. The salt flat area sediments show higher power density compares to the live mangrove forest are with 2.96x10^{-7}W/m^3 and 1.66 x 10^{-7}W/m^3 respectively. Electricity generation of MFC from local mangrove sediments in this study show an effective performance as predicted. Possible diversity of bacteria in the sediments does have the ability to act as electroactive microorganism. The efficiency of electricity generation was influenced by the concentration of sediments, type of catholyte and pH of the sediments. Mangrove sediments have the potential in producing bioelectricity but further study need to be conducted to minimize the exploration of mangrove forest.

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