Effect of Electrolytes and Microbial Culture toward Electricity Generation Utilizing Tempe Wastewater in Microbial Fuel Cell

Tania Surya Utami[1*], Rita Arbianti[1], Deni Novitasari[1], Ester Kristin[1] and Astry Eka Citrasari [1]

[1]Chemical Engineering Department, Faculty of Engineering Universitas Indonesia, Depok16424
* Corresponding Author : nana@che.ui.ac.id

ABSTRACT

Demand for electricity has become a crucial requirement of Indonesian society. Resources, which generate electrical energy such as fossil fuel, is predicted to run out within the next dozen years. Microbial Fuel Cell is a development of the latest technology that uses microbes to break down a substrate. This activity will cause potential difference and generate electricity. Microbes which generate electricity could be derived from pure culture and mixed culture. In this study, mixed culture of tempe wastewater microbes is used by adding electrolytes variation which are ammonium chloride-potassium chloride, potassium permanganate, and potassium persulfate in a single chamber reactor. The optimum voltage and power density are 62,09 mV and 3,01 mW/m^2 when using potassium persulfate. Result of this research are compared to others research which using pure culture of *L.bulgaricus* by adding electrolytes variation which are potassium ferrycianide and potassium permanganate. In additional, utilization of potassium permanganat in mixed culture of tempe wastewater microbes and pure culture of *L.bulgaricus* are also compared to each other. The optimum voltage and power density of those comparison are 457 mV and 167,7 mW/m^2 when using potassium permanganat in pure culture of *L.bulgaricus*.

Keywords : Microbial Fuel Cell, Electrolytes, Pure Culture L.bulgaricus , Mixed Culture Tempe Wastewater

1. INTRODUCTION

Fossil fuels such as coal, natural, and hydrocarbon derivatives become a common source of energy generation. One of energy generation from fossil fuels is electricity generation. The shortage of fossil fuels are non-renewable energy and emit CO_2, CH_4 and CO which have adverse effects on the environment. Therefore, an alternative energy need to be developed to avoid an crisis of energy and environmental damage[1].

Microbial fuel cell used role of bacteria to break down organic matter as substrate for this fuel cell. Metabolism of bacteria will produce electrons which flow from anode to cathode and generate electricity current .Besides electrons, this metabolism also produce protons which transfer into cathode chamber through Proton Exchange Membrane (PEM). Bacteria can be derived from pure culture of bacteria in a medium broth as substrate and from the mixed culture of bacteria contained in other materials such as wastewater.

Earlier research used organic matter such as sucrose[2], glucose[3], starch[3]. Type of bacteria used are *Desulfovibrio desulfuricans*, *Clostridium butyricum*, *Lactobacillus plantarum*[4]. While, wastewater that has been used are wastewater of chocolate factory, domestic wastewater, brewery wastewater [5], tempe wastewater [6-8].

As it mentioned before, organic matter donor electron and turn anode into electron acceptor. Afterwards, electron flow from anode to cathode and need new electron acceptor which is electrolyte solution. Soluble electrolyte solution has potential difference value caused by different value of anode and cathode. Electrolyte solutions for this research are potassium ferrycianide, potassium permanganate, and potassium persulfat. Potential difference value of electrolyte solution as follows

$S_2O_8^{2-} + 2e^- \rightarrow 2SO_4^{2-}$ $E^0 = 2,01$ V (1)

$MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$
$E^0 = 1,70$ V (2)

$Fe(CN)_6^{3-} + e^- \rightarrow Fe(CN)_6^{4-}$ $E^0 = 0,43$ V (3)

There are two types of MFC reactor. First, two chamber MFC reactor which is form of two compartments separated by a Proton Exchange Membrane and consists of anode and cathode chamber [4]. Second, single chamber of MFC reactor which has been developed to streamline the design of the earlier MFC reactor. The reactor compartment is not using Proton Exchange Membrane so the anode and cathode are in the same [4]. This type of reactor support the usage of the wastewater substrate due to solids contains in the wastewater effluent which often attached to the membrane[9].

This research compares performance of two types of MFC reactors. Pure culture of *Lactobacillus bulgaricus* with Glucose Yeast Peptone medium (GYP) performed in two chambers reactor. Meanwhile, tempe wastewater by bacterial culture consortium (mixed culture) performed in single chamber reactor. Tempe wastewater is chosen because of its COD value which has high value 4,188.27 mg / L. High COD value indicates that there are a lot of organic matter which can convert into electricity.

Control variables performed to ensure that the mixing of the electrolyte solution with substrates in synergism to produce electricity.

However, MFC only produced little voltage. It causes MFC has not been used for equipment at home. Therefore, this study aims to find the best electrolyte produces a highest voltage in order to MFC can be applied for any equipments.

2. METHODS

2.1 Wastewater as Substrate

Tempeh wastewater (mixed cultures) were incubated for a week at 37 ° C. Optical Density of tempe wastewater was measured using a spectrophotometer at a wavelength of 486 nm.

2.2 Electrolyte Solution

Mixed cultures of bacteria used electrolyte solution of ammonium chloride-potassium chloride (NH_4Cl-KCl) potassium permanganate ($KMnO_4$) and potassium persulfate ($K_2S_2O_8$) with a concentration of 30 mM.

2.3 Operating Condition and Construction of MFC

Volume capacity of reactor up to 500 mL with acrylic glass material. Anode and cathode spaces are not separated by a membrane proton. Electrodes used are graphite electrodes. Anode has an active surface area of 127.75 cm^2. The cathode used was air-cathode, cathode is directly in contact with the outside air. Anode and cathode is connected by copper and resistor of 100 ohm is applied.

2.4 MFC Experiment

Chamber of reactor is filled by artificial tempe wastewater. Tempe wastewater made by boiling soybeans with distilled water at ratio of 3: 5 (Nout et al, 1985). In the first variation of 90 g of soy beans boiled in 225 mL of distilled water and incubated for a week. Afterwards, tempe wastewater is mixed with potassium permanganate (KMnO4) 225 mL, 50 mL of 0.1 M phosphate buffer at pH 7 and observed the voltage with a digital multimeter APPA 109N series for 50 hours. The same steps are also conducted in electrolyte of ammonium chloride-potassium chloride (NH_4Cl-KCl) and potassium persulfate ($K_2S_2O_8$).

2.5 Data Calculation

Data from multimeter is voltage (mV or V). Then, data is processed into current value with a resistor value of 100 ohms used

$$I = \frac{V}{R} \quad (3)$$

where I (A) current, V (V) voltage and R (ohm) resistor.

Then, current data can be used for calculating power density. Powr density can be used for determining energy generated per square meter of anode surface area

$$P\left(\frac{mW}{m^2}\right) = \frac{V\,(volt).I(mA)}{A\,(m^2)} \quad (4)$$

where P (mW/m^2) power density and A (m^2) anode surface area.

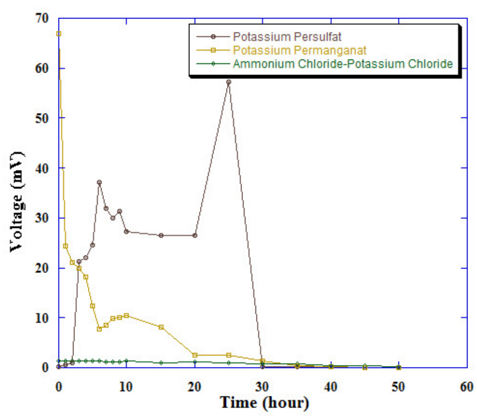
3. RESULTS

3.1 Effect of Electrolyte Solution Towards Electricity Energy In Mixed Culture

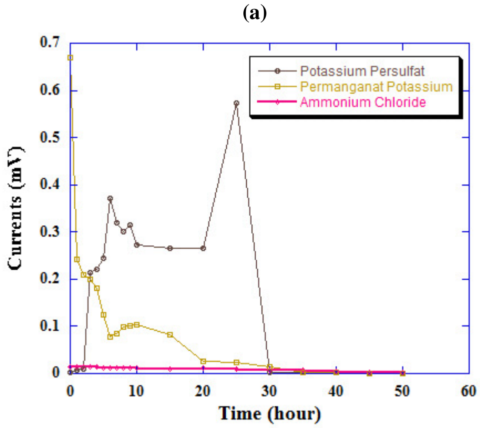
As can be seen from Fig 1a,1b, and 1c the highest electricity energy were owned by $K_2S_2O_8$ with value 62.09 mV, 0.621 mA and 3.01 mW/m^2. Average voltage of potassium persulphate is higher than the other electrolyte. It is happen due to potassium persulphate's potential standard higher than other electrolyte's potential standard. Potential standard connected by redox potential or ability to change oxidation numbers of atoms in potassium persulphate [10]. Besides potassium persulfat and permanganat, ammonium chloride-potassium chloride also can be used as electrolyte solution because it has electrical conductivity [11],[12]. Standard potential of ion are shown at equation (5) and (6)

$S_2O_8^{2-} + 2e^- \rightarrow 2SO_4^{2-} \quad E^0 = 2{,}01\ \text{V}$ (5)

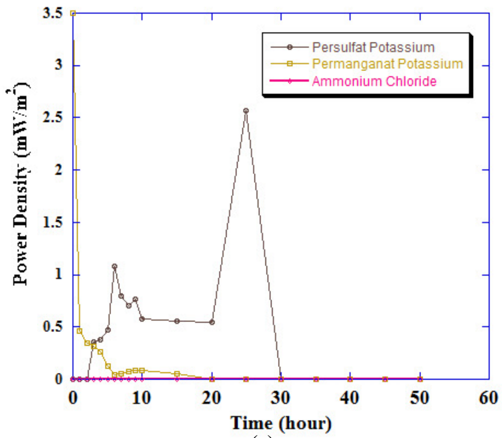
$MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O\ E^0 = 1{,}70\ \text{V}$ (6)



(a)



(b)



(c)

Fig 1 voltage (a), currents (b) and power density (c) at different electrolyte solution in mixed culture

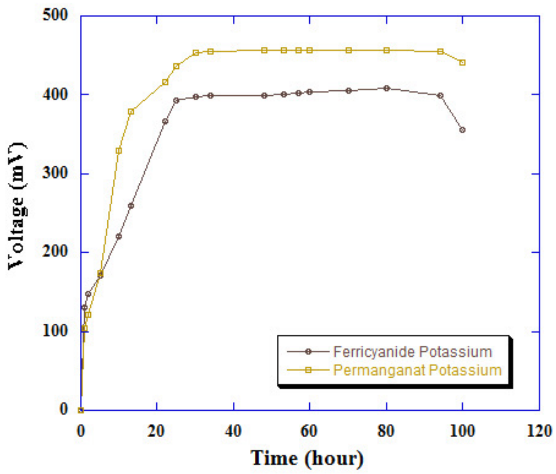
Besides electrolytes, oxygen is also become electron acceptor at cathode. However, redox potential of oxygen is smaller than potential redox of electrolyte but it still cause enough potential difference between anode and cathode. Sometimes, diffused oxygen from cathode encounter difficult way to contact with electrons [13]. The absence of oxygen will decrease potential difference thus electricity generation also decrease.

Control variables were also conducted as a comparison. Control variables were performed using tempe wastewater without electrolyte and using electrolyte without tempe wastewater. Conducted control experiment aims to see how much electricity can be generated if only using electrolyte and tempe wastewater. Compounding tempeh wastewater and the electrolyte solution can increase the voltage of electricity up to 85% higher than control variables only. This condition happened because compounding substrate and electrolyte turn anode into more negative value if compared to using only tempe wastewater[14]. Anode values becomes more negative because the accumulation of NADH from bacterial metabolism. Besides that, control experiment proves that the existence of electrolyte is necessary to capture the electrons in cathode and reduces oxygen diffuses through the cathode. Despite of the economic side of electrolyte which is quite expensive.

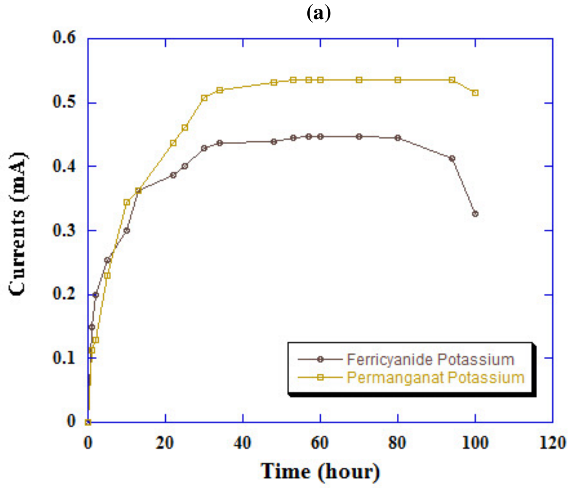
3.2 Effect of Electrolyte Solution Towards Electricity Energy In Pure Culture of *L.bulgaricus*

Another study has been conducted MFC experiment using pure culture of *L.bulgaricus*. Fig 2a, 2b and 2c shows the highest electricity energy were obtained from potassium permanganate with value 457 mV, 0.536 mA and 167.7 mW/m^2. Utilization of potassium permanganate generate electricity energy higher than the potassium ferricyanide due to the high redox potential of permanganate if it compared with ferricyanide, as seen in Eq. 6-7.

$MnO_4^- + 4H^+ + 3e^- \rightarrow MnO_2 + 2H_2O$ $E^0 = 1{,}70$ V (6)
$Fe(CN)_6^{3-} + e^- \rightarrow Fe(CN)_6^{4-}$ $E^0 = 0{,}43$ V (7)

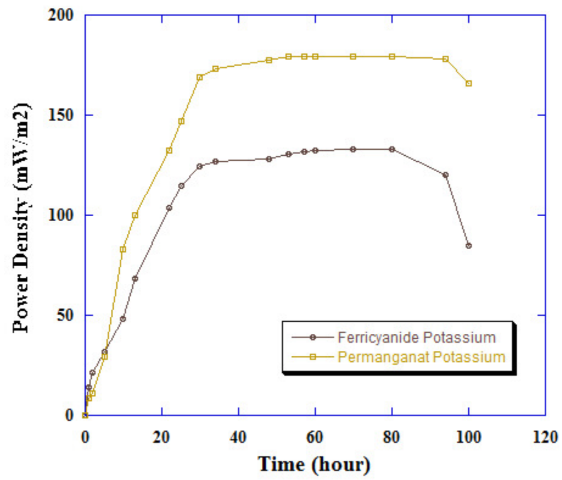


(a)



(b)

Potential of anode is generally determined by several factors, such as the rate of substrate conversion and electron transfer rates of microorganisms to anode. Meanwhile, potential of cathode depends on the type of cathodic electron acceptor. Assuming the redox potential of the NAD + / NADH in anode is constant (-0.32 V), the cell voltage will depend only on the performance of the cathode. Permanganate has a high redox potential resulting in a greater potential difference between the anode and cathode. As a result, generation of electrical energy will also increase [15].

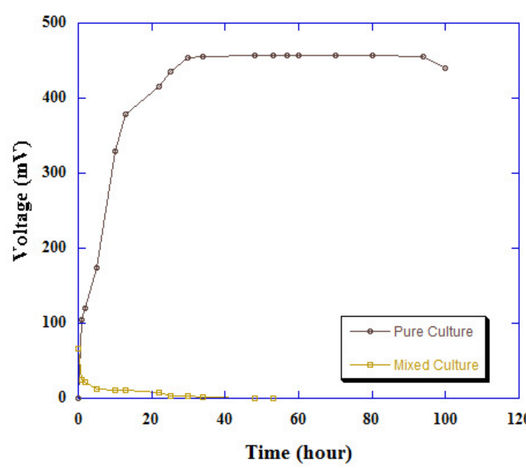


(c)

Fig 2 voltage (a), currents (b) and power density (c) at different electrolyte solution in pure culture

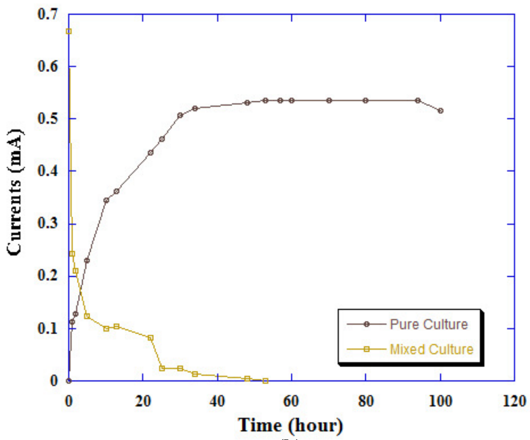
Similar results were obtained by Guerrero-Rangel, who compared the use of potassium permanganate, potassium ferricyanide, and potassium dichromate, with the highest electrical energy is produced when using potassium permanganate as an electrolyte.

3.3 Effect Bacterial Culture Toward Electricity Energy.

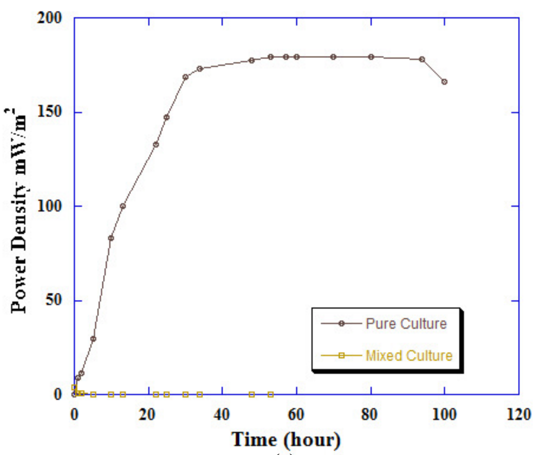


Based on part 3.1 and 3.2 can be taken electricity generation data of potassium permanganate electrolyte combined with bacterial cultures variation. Fig.3a, 3b and 3c shown a comparison between mixed culture of tempe wastewater and pure culture of *L.bulgaricus* using same electrolyte solution which is potassium permangat.

(a)



(b)



(c)

Fig 3 voltage (a), currents (b) and power density (c) in different culture

It can be conclude from figures 3a, 3b and 3c that experiment used pure culture of L.bulgaricus produced higher electricity energy than mixed culture of tempe wastewater. This result contrary to result belong to Hassan, 2012. In his study, electricity generation from pure culture of *Nocardiopsis* sp and *Streptomyces enissocaesilis* lesser than mixed culture of soil microbial which degrading cellulose. That condition happen because mixed culture has more various strain bacteria inside than pure culture which only has single strain bacteria [16].

Comparison in this study has different result because it can not be determined the ability to degrade glucose of bacteria inside tempe wastewater. The possibility is the ability of pure culture of L.bulgaricus in degrading glucose higher than the ability of mixed culture of tempe wastewater.

4. CONCLUSION

MFC experiment utilizing tempe wastewater has been successfully conducted and produced electricity energy although it has not been applied in home equipment yet. MFC using mixed culture of tempe wastewater was found to produce optimum output of 62.09 mV and 3.01 mW/m^2 when using potassium persulfat ($K_2S_2O_8$) as electrolyte solution. While, result of MFC experiment using potassium permanganat ($KMnO_4$) reach output 66.84 mV and 3.49 mW/m^2.

This study also compared to pure culture of *L.bulgaricus* while using this culture increase electricity energy up to 85%. Optimum ouput was produced by pure culture of *L.bulgaricus* using potassium permanganat as electrolyte solution.

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