The Effect of Multiple Electrode Pairs to Electricity Potential of Ceramic-Based and Tempe Waste Microbial Fuel Cell

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Abstract. Ceramic is low-cost separator membrane has widely applied in dual-chambered Microbial Fuel Cell (MFC). Its big pores and other chemical and physical advantages make it suitable to substitute expensive exchange separator membranes. The purpose of this study is to enhance electricity of ceramic-based microbial fuel cell by using various number of carbon electrode pairs. This study uses tempe waste as anolyte and KMnO4 as its catholyte to gain electricity. Three variety of electrode pairs data of electricity result is processed statistically to examine significant difference of voltage, current, and power density as parameters. The result of this study shows that electricity of three-electrode pairs has a higher average of power density with the number 1447.91 mW/m², the difference between three and two electrode pairs is around 588 mW/m² and between three and one electrode pairs is 910 mW/m². It has significant difference between one, two, and three-electrode pairs in the parameters.

1. Introduction

Recently, renewable energy has been popular because its sustainability towards the environmental system. Electricity that gained from coal is no longer relevant nowadays because its harms and limitlessness. Environmental problems that occurs in the world have threatened the society for health issues, clean water, pollution, and others. Microbial Fuel Cell (MFC) is a promising renewable energy that can gain electricity and reduce environmental problems at the same time [1].

Wastewater is a common problem in every country. Maintaining wastewater is a crucial thing to establish a good environmental system. Many local home industries do not understand the maintenance, often skip their wastewater treatment. Production of tempe is a popular local home industry in Indonesia that produces liters of water of soaked soy every day [2]. It contains high organic matters that might worse the environmental system. Using organic wastewater to run the MFC may decrease the waste’s Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) to become more environmentally friendly [3].

MFC is a bioelectrochemistry technology that gaining electricity from microbes that oxidize organic substrate such as glucose, acetate, or organic wastewater in the anode chamber. This oxidation process releases proton and electron. The electron flow in the external circuit from the anode to cathode chamber to produce electricity. The proton flow through separation membrane to the cathode chamber to unite with electron in cathode chamber [4].

Research on MFC has grown rapidly focusing on its low cost and effectiveness. The things that affect the cost and effectiveness are plenty, including separator membrane, electrode materials, chamber materials, and others. Dual-chambered MFC is a simple design on MFC that has anode and cathode...
chamber separated by Proton Exchange Membrane (PEM) that let proton flow from anode to cathode chamber. PEM that is usually used in MFC is Nafion that costly and limits the application of MFC. Many other materials have been used to exchange costly Nafion such as salt bridge, fiberglass, ceramic, and many others. Ceramic has superiority in environmentally friendly and its resistance for long time usage. The initiation of ceramic-based MFC has done by Park and Zeikus in 2003 using 100% kaolin porcelain in single-chamber MFC [5]. In 2010, Behera et al. use a ceramic pot that was made from 56-68% kaolinite, 15-26% illite, and 5-9 % smectite and produce a power output of 168 W/m$^3$ without catholyte that harmful to the environment [6]. Environmentally friendly catholyte that used by Behera et al. still produce lower power density than KMnO$_4$, as conventional catholyte. However, Behera et al. has succeeded to construct low cost MFC with ceramic based separator. Ceramic modification has also been applied by Sudarlin et al. using montmorillonc2, compared by non-modification ceramic pot, and shows that power density is higher for 0,163 mW/cm$^2$ than the non-modification ceramic pot [7].

Andika use tempe wastewater ceramic based MFC compared with salt bridge MFC, both of them use carbon as the electrodes [8]. The results show that ceramic based MFC is better than the salt bridge MFC with maximum power density is 2197,343 mW/m$^2$, but there are more result have higher power density. Chen et al. has done single chambered MFC and gained power density 2676 mW/m$^2$ [9]. Kumar et al. has also done research with power density 3359 mW/m$^2$ that higher than Andika and Chen et al. [10]. In order to maximize the electricity of Andika’s MFC using the same waste, this research is conducted.

According to Sadeqzadeh et al., larger surface area of electrodes might boost the electron transfer and increasing electricity in the external circuit [11]. Sadeqzadeh et al. used different electrode surface area with the amount 12, 16, 20, and 24 cm$^2$. The result shows 20 cm$^2$ has the highest power density, with the number 76,5 mW/m$^2$. Sinaga et al. also used different electrode surface 13,29 cm$^2$, 26,58 cm$^2$, 39,87 cm$^2$, and 53,16 cm$^2$ and show that 53,16 cm$^2$ has the higher potential difference with the number 40,67 mV/100 mL for whey wastewater [12].

Ibrahim et al. also tried variation of electrode surface area by increase the amount of electrode pairs [13]. Ibrahim et al. use one, two, three, and four electrode pairs for wastewater from fish industry. The result shows that two electrode is the maximum electrode pairs for dual chambered MFC that used in this research. There is no significant difference between two, three, and four electrode pairs. This research used salt bridge as its separator membrane. BOD and COD as wastewater treatment result of the four MFC systems were decreased in the same amount. There is no effect of multiple electrode pairs to wastewater treatment. There is even no slight difference between those four MFC systems.

This research try to maximize the effectiveness of ceramic based MFC by finding the effect of the multiple electrode pairs to its electricity. Electrodes that used in this research is carbon, with variation of one, two, and three electrode pairs. The substrate that used in this research is tempe wastewater that has been used in MFC before. Kristin used the tempe wastewater with dual chamber MFC using salt bridge as separator, comparing various incubation time of the substrate and addition of glucose to the wastewater. Substrate with glucose addition shows higher power density, and one week incubation of wastewater shows highest power output than one hour and one month incubation time. Arbianti et al. also used tempe wastewater for membraneless MFC to compare COD reduction of various MFC volume. The research from Andika in 2020 that expanded in this research also use tempe wastewater as explained above. In order to increase the electricity and effectiveness of MFC, multiple electrode pairs are investigated.

Parameters that affect the electricity effectiveness of MFC are voltage, current, and power density [14]. The higher electrode pairs should produce higher electricity because the high surface area. This research used carbon as the electrode materials. Carbon shows good performance and has been common usage as electrode in electrochemistry field [15]. These electrode pairs combine with ceramic separator in dual chamber MFC using tempe waste as substrate and KMNO$_4$ as catholyte.

2. Method
The method of this research is divided into three sections, separation, running, and analysis. Preparation section includes the method to prepare substrate, catholyte, electrodes, MFC construction. Running
section is the method for observation during MFC running system. Statistical test that is used in this research is explained in analysis section.

2.1. Preparation
Tempe wastewater is taken from local tempe home industry and incubate for 24 hours before usage. BOD and COD of the substrate was checked before running to see its reduction. The wastewater becomes substrate in ceramic based anode chamber with 1 cm thickness and 1 L volume that was put inside plastic cathode chamber. KMnO₄ 0,1 M was added into cathode chamber to surround the ceramic based anode chamber. Carbon electrodes are soaked in HCl 0,1 M for 24 hours and then in NaOH 0,1 M for 24 hours before use. External circuit was made with cables that unite the electrodes for electron transfer from anode to cathode. One, two and three electrode pairs MFC was built with the same format as in figure 1.

![Figure 1. Illustration of MFC construction.](image)

2.2. Running
The running of the MFC is 48 hours with voltage and current check every two hours with multimeter. Three multiple electrode pairs MFC run in the same time to avoid other unexpected variables. The MFC should run in anaerobic condition to keep the bacteria works as planned.

2.3. Analysis
Voltage and current data from the MFCs were processed with statistical analysis with ANOVA test to see the significant difference. Power density were calculated and also processed in ANOVA test. Power density was calculated with the equation below.

\[
Power Density = \frac{V \times I}{A}
\]

(1)

\(A\) is \(\pi \times D^2\), and \(D\) is electrode diameter [2].

BOD and COD were measured before in the preparation and after the running. The measurement result were processed with t-test to see the significance of decreased number to analyze the effectiveness of MFC system to wastewater treatment.

3. Result and Discussion
MFC produce electricity and do wastewater treatment at the same time. Both of these MFC utilities from this research are reported in two section, electricity and wastewater treatment. The main focus of this research is to boost electricity of the previous ceramic-based MFC. Parameters for the electricity are current, voltage, and power density.
3.1. Electricity
Electron transfer from microbes to electrodes involve electrode surface area where microbes can form biofilm to transfer their electron to the anode [16]. Higher electrode pairs should have higher electron transfer because their ability to have wide space for biofilm than fewer electrode pairs, and high electron transfer means higher electricity that flow in the external circuit. This electron flow was measured by multimeter to perform current.

![Current from one, two, and three electrode pairs](image)

**Figure 2.** Current from one, two, and three electrode pairs.

Figure 2 show the graph of current from one, two, and three electrode pairs MFC during 48 hours running. The fluctuation of the current is caused by microbe activities that impact to the electron production and transfer. One electrode pair show the lowest track of current than two and three electrode pairs. There is no exact point when current of one electrode pair is higher than the other in the same measurement time. Three electrode pairs dominated the highest current than one and two electrode pairs almost in all measurement time with the highest current average of 2.51 mA. The highest current also comes from three electrodes with the number of 9.72 mA. Two electrode pairs has lower current average from three electrode pairs with the number 1.56 mA. The lowest current average of 0.51 mA is from one electrode pairs. This result shows that the higher number of electrode pairs produce higher current in ceramic-based dual chamber MFC. This is happened because the wide electrode surface area to maximize the possibility of physical contact and electron transfer from microbes to anode [17].

Figure 3 show the voltage measured from one, two, and three electrode pairs MFC in 48 hours running system. The voltage difference between three MFC is not as wide as current difference. It can be seen from voltage average, 0.080 V for one electrode pair, 0.085 for two electrode pairs, and 0.126 for three electrode pairs. This is happened because three MFCs used the same size and thickness of anode chamber that also turn to separator membrane or PEM. Voltage in MFC can be described as potential difference between the anode and cathode chamber [18]. If the PEM that was used in three MFCs that in charge of separate and connect the anode and cathode chamber have the same ability to transfer proton to keep the electricity flow, then it should be no major difference in the voltage numbers. Although the difference is not big, but voltage average still increased from one until three electrode pairs. There are many things that may affect this rise. This research conducted multiple electrodes that differentiate one and other MFC. The most possible answer for the difference is the effect of high electron transfer from higher number of electrode pairs that can stimulate proton transfer to be faster to balance with massive electron transfer from the anode.
Power density that was calculated from voltage and current measured every 2 hours in 48 hours running system can be seen in figure 4. Power density averages are 536.36 mW/m² for one electrode pair, 859.98 mW/m² for two electrode pairs, and 1447.91 mW/m² for three electrode pairs. The rise of power density according to number of electrode pairs shows that multiple electrode pairs boost the electricity although there are only slight difference in voltage. Combination of three electrode pairs with ceramic separator membrane produced the highest power density of 15258.38 mW/m² at 44th hour of running system. This is caused by high current measured in the time with the number 9.72 mA.

![Figure 3. Voltage from one, two, and three electrode pairs.](image1)

![Figure 4. Power density from one, two, and three electrode pairs.](image2)

Current and voltage data were processed with ANOVA test and show significant difference with P-value less than 0.05 [19]. It means multiple electrode pairs affect significantly towards the electricity parameters. Power density also tested with ANOVA and show significant difference. It strengthens the
positive effect of multiple electrode pairs. Higher number of electrode pairs produce high electricity of dual chamber ceramic-based MFC.

3.2. Wastewater Treatment

Organic wastewater contains microbes that breakdown organic matter for their metabolism process. This process needs oxygen and produce carbon dioxide after. If organic wastewater with high microbes in it directly thrown to the environment, then it will consume the oxygen from water and increase the level of carbon dioxide. It might harm living things that using the water such as plants and fish that live in it. Anaerobic system of MFC can prevent the microbes using oxygen from the air because there will be oxygen from the catholite in cathode chamber. Inside the MFC, microbes breakdown and decrease the amount of chemical organic matters that might harm the environment. This decrease is measured by COD. The microbes in the wastewater decreased after some time because organic matters as their food has been decreased too. This decreased microbes is measured by BOD [20].

| Table 1. BOD and COD before and after MFC running system. |
|-----------------------------------------------------------|
| Before MFC Running | After MFC Running |
| (mg/L) | (mg/L) |
| BOD | 46200 | 30500 |
| COD | 119750 | 13320 |

This research used tempe wastewater and check the BOD and COD before and after MFC running system. Multiple electrodes in this research did not affect the wastewater treatment, same as treatment results from Ibrahim et al. that also used multiple electrodes [13]. Table 1 shows the decrease of BOD and COD of the tempe wastewater in this research. BOD decreased from 46200 mg/L to 30500 mg/L and COD decreased from 119750 mg/L to 13320 mg/L. Although the BOD and COD are dropped for about 33.98% and 88.88%, the final amount of BOD and COD still doesn’t meet the criteria for maximum BOD and COD for tempe wastewater treatment, 150 mg/L for BOD and 300 mg/L for COD, that regulated by Indonesian Government, The Ministry of Environment and Forestry. However, these results show that MFC can do wastewater treatment and produce electricity at the same time. That is why the MFC is one of promising renewable energy in this era.

Previous study that using low-cost MFC separator membrane and multiple electrode pairs is Ibrahim et al. in 2017 with salt bridge to change Nafion in dual chamber MFC. Electricity result of Ibrahim et al. shows maximum electricity in two electrode pairs from four multiple electrode pairs that was used in the research [13]. Andika in 2020 compare MFC using tempe wastewater with salt bridge membrane and ceramic-based membrane, the result show that ceramic-based MFC is better than salt bridge membrane MFC with the maximum power density 2197.343 mW/m² [3]. Andika used carbon as electrodes for his research. In order to maximize the electricity of this ceramic-based MFC, this research was conducted.

Ceramic-based MFC from Andika shows great power density number. There are two research before from Chen et al. and Kumar et al. with higher maximum power density, 2676 mW/m² and 3359 mW/m² [9][10]. This research has the higher result than those research with maximum power density 15258.38 mW/m². Electricity that gained from ceramic-based with the same thickness as Andika with three electrode pairs in this research has major difference with the previous study using tempe wastewater.

4. Conclusion

Ceramic-based MFC has been popular in this decade. Combination of multiple electrode pairs and ceramic separator membrane on dual chamber MFC for tempe wastewater was never done before. This research initiate the combination to produce high maximum power density of 15258.38 mW/m² with three carbon electrode pairs. This MFC construction also decreased the number of BOD and COD of the wastewater. BOD dropped from 46200 to 30500, and COD dropped from 119750 to 13320. There is no difference of wastewater treatment of one, two, and three electrode pairs MFC, but the decreased
amount of after BOD and COD has significant difference with before. This research does not compare and explain whether single electrode that has same surface as the multiple electrode will result any difference. That is why further research of promising renewable energy ceramic-based MFC should be conducted for higher electricity and better wastewater treatment.

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