Thick Activated Carbon Sheet Electrode and Hydrophobic Organic Matter Improve the Performance of Microbial Fuel Cell

Naoki Hayashi, Dang Trang Nguyen, and Kozo Taguchi

***Abstract*—Recently, there are a lot of environmental problems all over the world. Mass-consumption of fossil fuels contribute to depletion of them, emission of large amount of carbon dioxide, and global warming. However, fossil fuels are used everywhere and they are essential for modern life to get energy. A microbial fuel cell (MFC) is one of the new energy resources. This study focused on activated carbon sheet that has property of absorbing organic matter and large surface area. In this study, the experiment was conducted in eight conditions that were combined organic matter, kind of electrode and thickness of the electrode. Biofilm was built on two kinds of anodes that were made of carbon sheet and activated carbon sheet by using glucose or malt powder. The combination of using activated carbon sheet and malt powder produced maximum current density of 220 μA/cm^{2}.**

***Index Terms*—Microbial fuel cell, biofilm, activated carbon, hydrophobic organic matter, baker's yeast, electrode thickness.**

I. Introduction

It is important to reduce carbon dioxide in order to prevent global warming. Therefore, clean and renewable energy without emitting carbon dioxide is needed. Microbial fuel cell (MFC) is one of the new energy resources. MFC is a device that generate electricity by using microbes.

There are two kinds of MFC that are single chamber type and double chamber type. In single chamber type of MFC, the cathode electrode is exposed to the air. It is called air-cathode MFC [1]. Double chamber MFC is divided into two chambers by a proton exchange membrane (PEM) [2]. Usually, potassium ferricyanide is used as oxidant in the cathode chamber of double chamber MFC. In this study, this double chamber MFC was used.

In double chamber MFC, electrons and protons are generated in anode chamber when the microbe decompose organic matter. The electrons travel to cathode chamber through an external circuit. The protons transport through PEM to cathode chamber. Thus, the MFC can convert chemical energy to electric energy (Fig. 1).

In MFC, a mediator was usually used in order to transfer electrons from microbes to the anode electrode [3]. Methylene blue, humic acids and resazurin were used as mediators [4]. Mediators play an important role in this way. However, most mediators have toxic property. Therefore, when the device is operated using mediators, harmful effect might happen. [5] Then, there is a method that uses biofilm instead of adding mediator to the anode chamber. Biofilm is a structured community of surface-associated microbial cells [6], [7]. Biofilm is studied in various fields such as environment, industry, medicine and so on. [8]. In medical field, biofilm is built on medical device and cause various infection. Therefore, there are issues that developing preventative of building biofilm [9]. It does not have only bad aspects but also have good aspects. When biofilm is built in the anode electrode of MFC, electricity is generated without mediator. The electrons that are emitted by microbe's decomposition of organic matter are directly transferred to the anode electrode. Therefore, using biofilm in anode lead to high electricity generation without the need of mediator. It is important to select electrode material when biofilm is built on the electrode.

Metal materials are usually used as the electrode in batteries. Pt is commonly used as the electrode in fuel cells. However, Pt is expensive material. In the MFC, carbon-based materials are commonly used as the electrodes. They are non-metal and has high conductivity. Activated carbon is one of the carbon materials and it has good properties of hydrophilic, abundant pores and large internal surface area [10]. In addition, when biofilm is built on activated carbon material, it enhances biofilm growth [11].

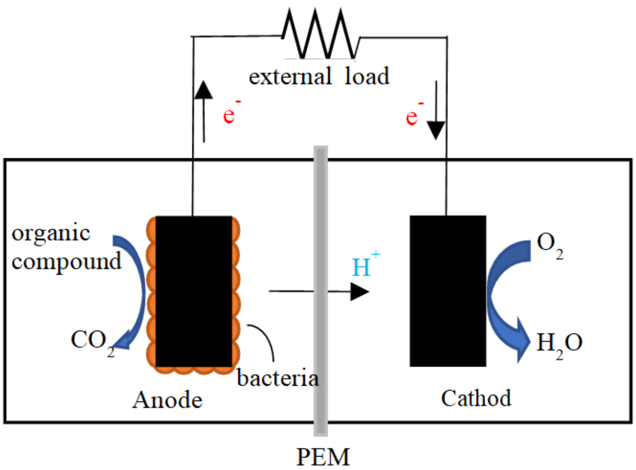

Fig. 1. Operating principle of MFC.

Moreover, microbe and organic matter are important elements for MFC operation. Saccharomyces Cerevisiae is a common baker's yeast that generate electrons by decomposing organic matter in MFC [12]. The baker's yeast is able to decompose glucose that is commonly used as organic matter in MFC. Yeast bacteria and glucose are used in food industry. In addition, baker's yeast decompose malt

Manuscript received November 13, 2018; revised January 4, 2018.

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doi: 10.18178/ijcea.2019.10.1.732

powder that is one of the organic matter. Malt powder is hydrophobic organic matter and include starch and amylase that converts starch to glucose. Thus, in this study, we focused on hydrophobic property of malt powder and adsorption property of activated carbon. We assumed that when activated carbon sheet and malt powder were used, biofilm quality and electricity generation were promoted.

II. MATERIAL AND METHODE

A Construction of the MFC

The MFC was constructed with an anode chamber, a PEM, and a cathode chamber as shown in Fig. 2. Each chamber was made by silicon. The volume of anode chamber was 3.5 cm×3.5 cm×0.5 cm and cathode chamber was 3.5 cm×3.5 cm×0.3 cm. Anode and cathode electrode materials were carbon sheet or activated carbon sheet. Each electrode size was 1cm×1cm. Carbon sheet or activated carbon sheet, that was built biofilm, was used as the anode electrode.

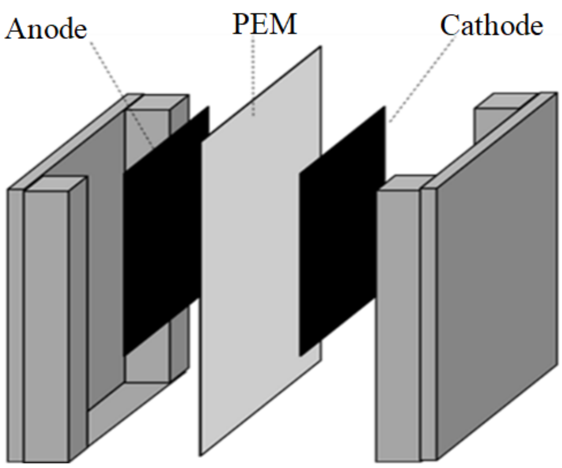

Fig. 2. Construction of the MFC.

B Biofilm

In this study, biofilm was built on activated carbon sheet and carbon sheet using baker's yeast. Furthermore, when yeast was cultured, glucose or malt powder were used as organic matter. The biofilm was built as follows. Firstly, solution of 70 g/L baker's yeast was made. Secondly, solution of 50 mL pure water, 0.5 mL "Hana koujo" (nitrogen: 5%, water-soluble phosphorus: 10%, water-soluble potassium: 5%, water-soluble magnesium: 0.08%, water-soluble manganese: 0.004%, water-soluble boron: 0.016%), 1 g malt powder or glucose, 1 g additive-free bouillon, the 0.3 mL was made. Then the two solutions were mixed together. Carbon sheet or activated carbon sheet were put into a cup contained 50 ml of the final solution [13]. Finally, the cup was put in an incubator at 30 degrees.

C Operation of the MFC

Anode chamber was fed with 5 ml medium that consisted of 1 mL "Hana koujo", 0.1 g malt powder and 4 ml pure water. 2 types of carbon sheet (thickness: 0.2mm 0.6mm) and activated carbon sheet (thickness:0.2mm 0.6mm), that were formed biofilm, were used as the anode electrode. Biofilm of baker's yeast was built in two ways that added glucose or malt powder as organic compound. Cathode chamber was fed with 5 ml of 300 mM potassium ferricyanide solution, and activated carbon sheet and carbon sheet was used cathode electrode [14]. The MFC was operated in batch mode. Voltage was measured by open circuit and then the device was connected to external resistor of 10 kΩ and 1 kΩ [15]. Then current density was calculated using Ohm Law .

D Condition of the Experiment.

In this study, the experiment was conducted in eight conditions (Table I). Thickness of the electrodes was also a variable factor in our experiment. Thickness of the electrode was 0.2 mm and 0.6 mm. The anode and cathode electrodes were used same materials. In addition, same organic matter was used for culturing the microbes and measuring voltage.

TABLE I. CONDITION OF THE EXPERIMENT

Electrode	Thickness (mm)	Organic matter
carbon sheet	0.2	glucose
activated carbon sheet	0.2	glucose
carbon sheet	0.2	malt powder
activated carbon sheet	0.2	malt powder
carbon sheet	0.6	glucose
activated carbon sheet	0.6	glucose
carbon sheet	0.6	malt powder
activated carbon sheet	0.6	malt powder

III. EXPERIMENTAL RESULT

Baker's yeast was cultured using glucose for three days and biofilm was built on 0.2 mm thickness activated carbon sheet and carbon sheet in the 3^{th} day. Experimental result was shown in Fig. 3. When biofilm was formed on the 0.2 mm carbon sheet (CS) and using glucose, OCV was about 0.4 V that is the higher value than that of the activated carbon sheet (AC). However, when external resistance was connected, the voltage was decreased significantly. Especially, the voltage, that was measured over 1 kΩ, was about 2 mV. It indicates that carbon sheet electrode generates hardly electricity. That is because when carbon sheet was used in MFC, the internal resistance was high.

When 0.2 mm activated carbon sheet and glucose was used, OCV was about 0.2 V that is about a half value of using carbon sheet. However, unlike carbon sheet, the voltage across 10 kΩ resistor was about 0.18V that was similar value to the OCV. Moreover, when external resistor of 1 kΩ was connected, the voltage was about 50mV that is higher value than using carbon sheet.

Next, the experiment was conducted changing glucose to malt powder cultured time was 3 days (Fig. 4). The graph of each voltage that was measured using malt powder was almost similar to the graph using glucose (Fig. 3). When carbon sheet and malt powder were used, voltage across 1 kΩ resistor was about 2mV that was lower value than activated carbon sheet.

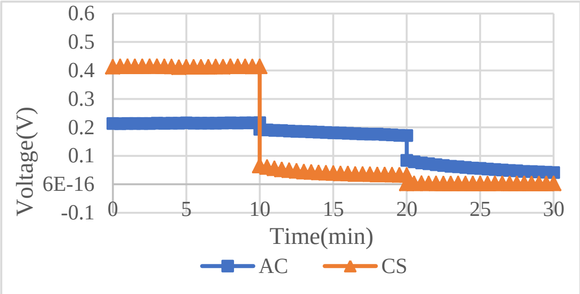

Fig. 3. Experimental result of using 0.2 mm thickness electrode and glucose in the 3th day. (AC: activated carbon sheet, CS: carbon sheet).

OCV and voltage across 10 kΩ resistor that were measured using activated carbon and malt powder were about 0.25V and 0.2V. Compared with using glucose, that were higher value. Voltage across 1 kΩ resistor was almost the same as the case using glucose.

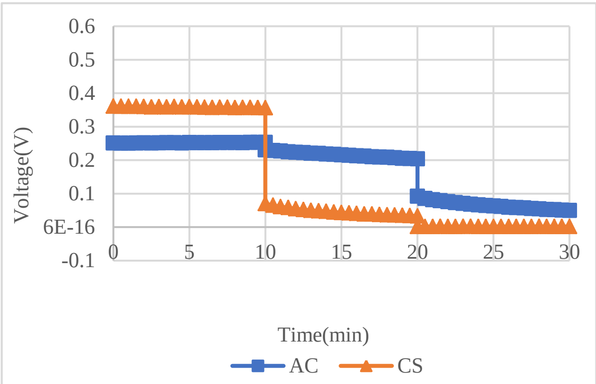

Fig. 4. Experimental result of using 0.2 mm thickness electrodes and malt powder in the 3th day.

Fig. 5 and Fig. 6 shows that a daily transition of each voltage that was measured using 0.2 mm thickness carbon sheet and glucose or malt powder. When glucose was used, each voltage was almost constant value for three days. On the other hands, when malt powder was used, OCV was increased day after day and about 0.4 V that was similar value to using glucose at the 3rd day. The voltage across 10 kΩ and 1 kΩ resistor were same result as using glucose for all three days.

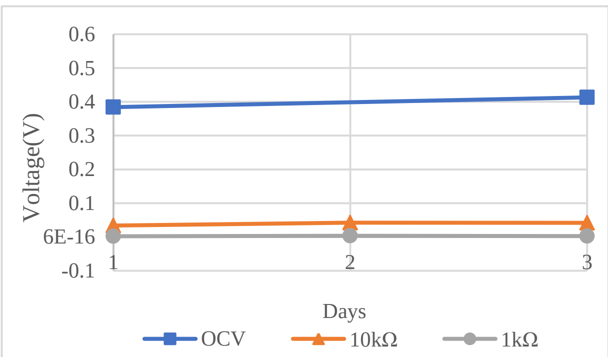

Fig. 5. A daily transition of each voltage that was measured using 0.2 mm thickness carbon sheet and glucose.

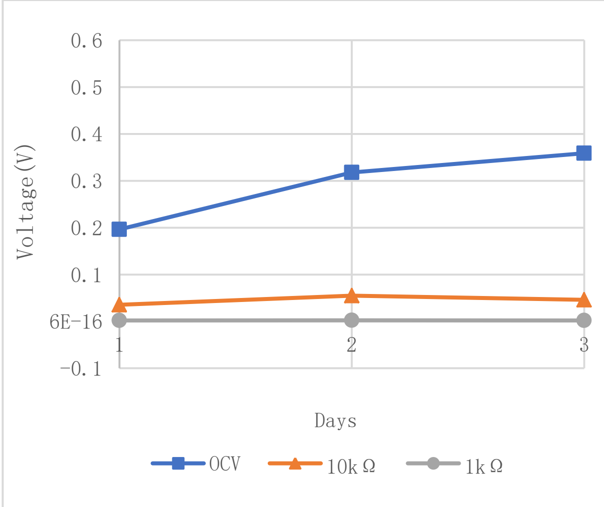

Fig. 6. A daily transition of each voltage that was measured using 0.2 mm thickness carbon sheet and malt powder.

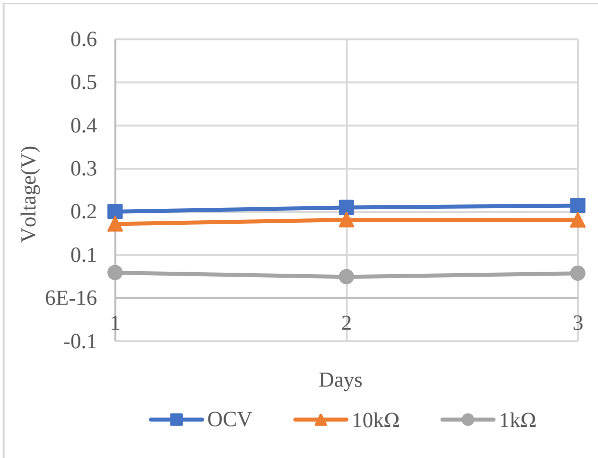

Fig. 7. A daily transition of each voltage that was measured using 0.2 mm thickness activated carbon sheet and glucose.

Fig. 7 and Fig. 8 show daily transition of each voltage that was measured using 0.2 mm thickness activated carbon sheet and glucose or malt powder. For three days, use of carbon sheet as electrode generated higher value of OCV than activated carbon sheet. However, when the device was connected to external resistor, the voltage that measure using activated carbon sheet was higher value than using carbon sheet in all the times.

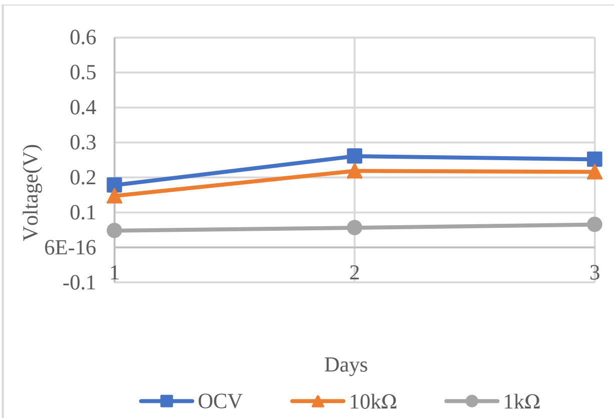

Fig. 8. A daily transition of each voltage that was measured using 0.2 mm thickness activated carbon sheet and malt powder.

Next, the result of the experiment, that used 0.6mm thickness electrode, shows in following graphs (Fig. 9 and Fig. 10).

When biofilm was formed and grown by using glucose on 0.6mm thickness carbon sheet, OCV was about 0.45 V that is higher value than using 0.6mm thickness activated carbon sheet and glucose. However, when external resistor was connected to the device that electrode is 0.6mm thickness carbon sheet, the voltage was decreased significantly. Especially, the voltage that was measured connecting external resistance of 1 kΩ was about 5 mV. It indicates that electrode of 0.6mm thickness carbon sheet generates hardly electricity. That is because when carbon sheet was used in MFC, the internal resistance was high. Unlike carbon sheet, when activated carbon was used, the voltage across 10 kΩ resistor was similar value to OCV. In addition, the voltage across 1 kΩ resistor was about 0.2 V that was higher value than using 0.6mm thickness carbon sheet.

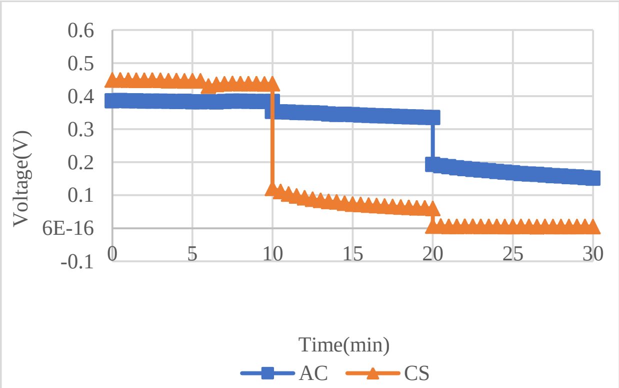

Fig. 9. Experimental result of using 0.6 mm thickness electrode and glucose in 15th day.

Fig. 10 shows the result of the experiment that used 0.6mm thickness electrode and malt powder in culturing yeast for nine days. Experimental result of the device that used 0.6 mm thickness carbon sheet and malt powder were almost the same as result of using 0.6 mm thickness carbon sheet and glucose. When 0.6mm thickness activated carbon sheet and malt powder were used, OCV and the voltage across 10 kΩ and 1 kΩ resistor was highest value compared to the other conditions.

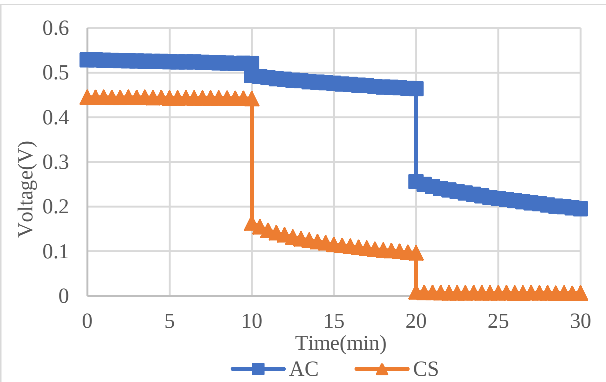

Fig. 10. Experimental result of using 0.6 mm thickness electrode and malt powder in the 9th day.

Fig. 11, Fig. 12 and Fig. 13 show a daily transition of each voltage that was measured using 0.6 mm thickness electrode and culturing microbes for about twenty days. Fig. 11 shows the result of the experiment that used 0.6 mm thickness carbon sheet and malt powder and culturing for twenty days. OCV and voltage across 10 kΩ resistor were increased to the 9th day. However, the voltage across 1 kΩ resistor was about 6 mV all the time due to its high internal resistance.

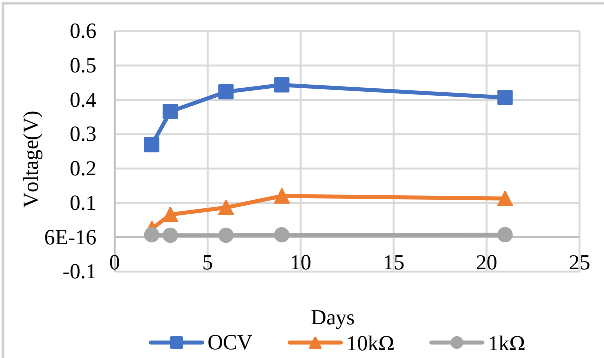

Fig. 11. A daily transition of each voltage that was measured using 0.6 mm thickness carbon sheet and malt powder.

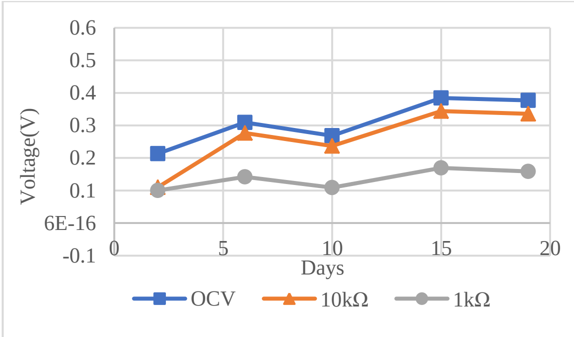

Fig. 12. A daily transition of each voltage that was measured using 0.6 mm thickness activated carbon sheet and glucose.

Fig. 12 shows that when the microbes were cultured in the first 15 days, voltage increases gradually. Compare Fig. 11 to Fig. 12, OCV that used 0.6 mm thickness carbon sheet was higher than using 0.6mm thickness activated carbon sheet. However, when the device was connected to resistors, the voltage that was measured using 0.6mm thickness activated carbon sheet was higher than using 0.6 mm thickness carbon sheet.

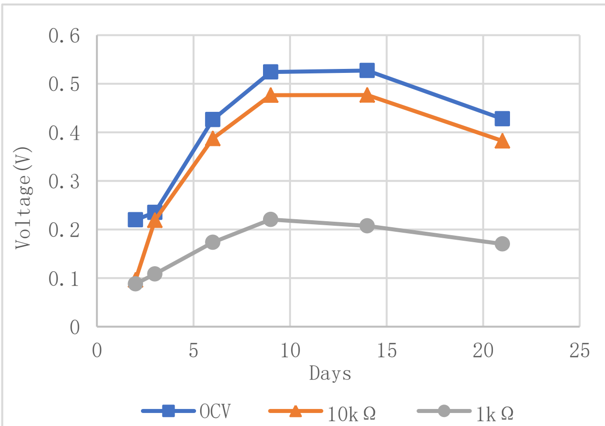

Fig. 13. A daily transition of each voltage that was measured using 0.6mm thickness activated carbon sheet and malt powder.

Fig. 13 shows daily transition of each voltage value that was measured using 0.6 mm thickness activated carbon sheet and malt powder. On the first day, OCV was about 0.2 V and voltage across 1 kΩ and 10 kΩ were about 0.1V that was almost the same value. Each voltage was increased until the 9th day. The voltage values were almost unchanged between the 9th day and the 14th day and decreased from the 14th day. Compared with other conditions, this condition, that used 0.6mm thickness activated carbon sheet and malt powder, produced the highest voltage.

TABLE II. CALCULATED CURRENT DENSITY

Electrode	Thickness (mm)	Organic matter	Current density (μA/cm²)	
			10 kΩ	1 kΩ
CS	0.2	glucose	4.2	2.3
AC	0.2	glucose	18.2	55.2
CS	0.2	malt powder	4.6	1.9
AC	0.2	malt powder	21.6	65
CS	0.6	glucose	7.9	5.3
AC	0.6	glucose	34	169
CS	0.6	malt powder	12	6.8
AC	0.6	malt powder	48	220

Table II shows current density that was calculated from the voltage and the resistor under each condition. Current density of the cases using activated carbon sheet was higher than the cases using carbon sheet. Furthermore, 0.6mm thickness was better than 0.2mm thickness. Because 0.6mm thickness electrode has larger surface area than 0.2mm electrode. Moreover, large surface area contribute to building good quality biofilm and low internal resistance. Similarly, using malt powder is better than using glucose in most cases. In particular, when 0.6mm thickness activated carbon sheet is used, the difference between result of using malt powder and glucose is significant. In addition, current density of 220 $\mu A/cm^2$ was the highest in our experiments when the conditions were 0.6mm thickness activated carbon cultured using malt powder and connected to 1 kΩ external resistor.

IV. CONCLUSION

In this study, anode material, anode thickness and culture medium were investigated. When carbon sheet was used as the electrodes, OCV was higher than using activated carbon sheet. However, the voltage over external resisters was lower than using activated carbon sheet, due to the high internal resistance of carbon sheet. Activated carbon sheet has larger surface area, which leads to its lower internal resistance. When 0.6mm thickness substrate was used, it took about 10days to sufficiently build biofilm. Moreover, using 0.6mm thickness activated carbon sheet was better than 0.6mm carbon sheet. Finally, hydrophobic malt powder contributed to higher voltage output than using glucose. Especially, when 0.6mm thickness activated carbon sheet and malt powder were used, the voltage was higher than other conditions. Using carbon sheet as electrode led to low current density due to its high internal resistance. On the other hands, using activated carbon sheet contributed to high current density. Therefore, using the combination of 0.6 mm thickness activated carbon sheet and malt powder led to an improvement of the MFC's performance.

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