The effect of addition of vegetable waste on microbial fuel cell performance

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Abstract. In the past few years the fuel cell has become the centre of attention of the scientific community for the possibility of converting organic waste into electricity directly through redox reactions with the help of bacteria or enzymes. The purpose of this study was to determine the value of MFC performance due to the influence of adding vegetable waste. The soil media used is obtained from agricultural areas. The system used in the MFC is a single chamber of a vessel with a volume of 500 mL. The types of electrodes used are carbon fibres with anode thickness of 0.5 cm and cathode 1.0 cm, as well as anode diameter of 8.0 cm and cathode 8.5 cm. Vegetable wastes were given 5 mg / L each in the MFC single chamber. The results showed that the highest power was generated from a microbial fuel cell with spinach vegetable waste. The power produced is 250 mW (49 mW/cm²). The incubation period for MFC can reach 30 days. Variation of the second rinse with a concentration of 499 ppm will have a pH value having a pretty good linear correlation of 0.9536 to the more electric power generated. The power produced by the MFC 6 series circuit is 1.00 mW, while the power generated by the parallel series is 0.831mW.

1. Introduction
Microbes from soil and sediments that contain organic matter are sufficient to show the value of benefits as an alternative energy source in microbial fuel cells (MFC)[1]. MFC performance depends on the ability of bacteria to oxidize organic carbon by producing electrons and then transferred from the anode to the cathode to produce an electric current. Many electrogenic microbes are also known to be able to reduce the Fe³⁺ and Mn⁴⁺ metal ions in the form of reduction, humic acid, and sulfur in sedimentary soils and soils containing many organic compounds[2]. Substrates used for electromagnetic production of MFCs include activated sludge, wastewater, liquid media is enriched in acetate and fumarate, and soils and sediments contain many organic compounds. [3]. The emergence of limitations occurs in MFC systems that use pure culture due to the formation of thick biofilms at the anode. This thick biofilm will reduce the ability of proton diffusion through the membrane to the cathode and the availability and availability of nutrients [4]. These results support the feasibility of utilizing land-based MFCs or sediments, where the potential heterogeneous bacteria of communities that colonize the anode can become potential benefits in preventing the accumulation of inhibited metabolic waste. Soil-based MFCs or deposits are also very cheap to build and maintain, in contrast to pure culture systems.
Starting MFC refers to the process of operating a battery based on the firmness of the power plant. Previous studies of optimal action time mainly focused on maintained and maintained MFCs and explained starting times ranging from 3 days to one month, largely determined by MFC design, electrode material, and operating conditions[5]. Even MFCs have a longer start time (from a few days to a month). This phenomenon is influenced by a complex sediment composition and limited mass transfer in the sediment matrix[6].

One obstacle that inhibits the spread of sediment that can be used as a medium in MFCs is widely low organic matter content. While sediments containing organic material can range from 0.1 to 10% by weight [7], many sediments have a natural content of 0.42.2% [8]. Thus, the concentration of organic matter can prevent it from generating sufficient electricity in some locations. Organic soil seepage has been tested as a potential medium for promoting increased electricity generation due to its higher organic material content [9]. The performance of MFC has also disrupted the emergence of passive anodes due to the accumulation of sulfide oxidation products [9].

In this study, it is proposed to improve the performance of MFCs by adding rice washing waste (first rinse, second rinse, and third rinse) and evaluate the series and parallel arrangement of MFC to get the best operating parameters.

2. Materials and Methods

2.1. Electrodes
Graphite felt cloth (GFC) (Carbon content: 90% ~ 95%, thickness 5 mm, Ash: 0.765%, carbon material Liaoning Jingu Co., Ltd.) is used as an electrode in Microbial Fuel Cells. GFC is soaked in alcoholic solution for five hours, and then rinsed with deionized water. Next, the GFC was immersed and heated in deionized water for five hours and roasted at 110 °C for three hours. GFC is placed in a desiccator for future research use. Later this GFC will be used as an anode. With the same treatment as before, GFC (10 mm thickness and the same specifications) is used as a cathode.

2.2. Sampling of sedimentary soils in rivers
Sediment soil samples were taken in sediment soils at a depth of 0-10 cm (below the sediment-water interface) at the river flow in Sumbersari, Jember City, located in East Java. Subsequently the sediment sample is filtered with a 0.5 cm filter to remove coarse debris and is homogenized manually. All sediment samples are stored in the refrigerator at 4°C so that they do not undergo chemical or physical changes.

2.3. MFC construction and operation
The MFC reactor is tubular and is made of clear plastic with a diameter of 100 mm and a height of 200 mm. Next, the reactor is filled with 10 mm high wet sediment and then the anode that has been connected with a red cable is placed that has been connected with a red wire on it while being pressed down so that the surface is flat. By adding back the wet sediment above the anode as high as 50 mm, this will become an internal connecting medium between the anode and the cathode. and proceed to place the cathode that has a green cable connected to it while being pressed down so that the surface is flat. MFCs are placed in a room at room temperature and the temperature is approximately 25 °C. External circuit use 1000 ohm passive fixed components (resistors). Water removal is carried out through evaporation during routine operations. MFC is operated in a single chamber in each experimental condition [10].

2.4. Analyses
The voltage generated by MFC during the study was recorded at 30 minute intervals using a PC precision multimeter and a data logger system (Sanwa PC 7000, Japan). To get the polarization curve, the anode and cathode in the MFC are connected to resistors that are 4 - 2000 ohms [11], [12]. Information obtained from the polarization curve is in the form of power density as a function of current density. The current density and power density are calculated based on the surface area of the anode. [13]. Electric current
(I) is obtained directly from a digital multimeter reading [1]. Power density (P) is calculated according to \( P = I \text{ (mA)} \times V / \text{electrode surface area (m}^2\)). Internal resistance can be obtained from determining the slope by the polarization method [14].

3. Results and Discussion

3.1. Measurement results of power for each chamber

Data were obtained from observations for 38 days with chambers 4, 5, and 6 as controls and the addition of nutrients to chamber 1 using washing water first flushing vegetable, chamber 2 using washing water the second rinse vegetable, and chamber 3 using washing water the third rinse vegetable. Each concentration used is tabulated in table 1. The results of the graph are shown in figures 1 and 2. Based on Figure 1 An information can be seen that the value of power in each chamber has increased every day. On the third day, microbes have adapted to the MFC system so that microbial growth tends to increase. However, on the 31st day, the value of electricity generated has decreased. This is due to the decrease in the availability of nutrients in the soil media, so this causes the growth of microbes into the phase of death.

Table 1. Variations of concentration.

| Label    | Rinse variations | Concentration (ppm) |
|----------|------------------|---------------------|
| Chamber 1 | 1                | 872                 |
| Chamber 2 | 2                | 499                 |
| Chamber 3 | 3                | 281                 |

![Figure 1](image1.png)

Figure 1. Power Graph with Variations of Control over time.

![Figure 2](image2.png)

Figure 2. Graph of power with variations in nutrition addition vs. time.
Figure 2 shows that the addition of nutrients causes an increase in power after the provision of nutrients every week. Nutrient concentration in rice washing water affects the level of the graph surge. It can be seen that the second rinse has a more significant increase in power compared to the first and third rinse rice washing water. Concentration on rinses dramatically affects the survival rate of microorganisms and will cause microorganisms to pause for a moment because the conditions are too acidic. The slow increase in electric power generated is due to microbes need time in terms of degrading complex compounds, including starch, which is abundant in the water remaining from the rice washing process [10]. The increase relates to the concentration of rice washing water. In the second rinse has a level of 499 ppm, meaning that it is not watery and not concentrated compared to the first rinse of 872 ppm, and the third rinse is dilute with a concentration of 281 ppm. Giving rinses of rice washing water is done every 7 days for 30 days of measurement.

3.2. Electrical energy measurement results in series systems

The data obtained in series system measurements are voltage and current. In this study, a series system of MFC units was measured. The series system is divided into 2, the series system consists of 3 chambers, and the series system is composed of 6 chambers. The purpose of this variation is to determine the effect of the arrangement of the MFC chamber series on the electrical energy produced. The characteristics of current to power and voltage can be seen in Figure 3.

Based on graph 3, the current to power will have a maximum peak where the voltage produced if multiplied by the maximum current will provide optimum power. The maximum power for a series of 3 chamber circuits is 0.4135 mW, and 6 chambers is 0.9531 mW. The increase that occurred in the series 3 chamber to 6 chamber is a voltage increase of 20.87%, current 31.02%, and power 56.61%.

Electricity generated by MFC arranged in series generally has a large voltage and power value where the more chamber units arranged in series, the higher the voltage and power values. In the principle of a series circuit, the total voltage is the sum of the voltage from each power source, the MFC reactor. The results of research data that have been done produce an average electricity 0.834 V and 0.169 mA for 3 chambers, 1.521 V and 0.310 mA for 6 chambers. On the graph, the comparison between I to V will decrease until it reaches the minimum limit depending on the external resistance given.
3.3. Electrical energy measurement results in the design of parallel systems
The preparation of a parallel system is a combination of MFC units that will form a series according to Figure 5. This parallel system is divided into 2 parallel 3 chamber units and 6 chamber units. The purpose of designing a parallel system is to determine the effect of the order on the strength of the current and voltage produced.

![Figure 4](image1.png)

**Figure 4.** Characteristics of I-V and I-P in a parallel circuit consisting of 3 and 6 chambers.

The current and voltage strength data produced in Figure 4 shows that the MFC circuit is arranged in parallel so that a higher current strength will be generated. The electrical data of a parallel system consisting of 3 chambers produces an average value of voltage, current, and power, respectively 0.328 V; 0.126 mA and 0.299 mW. Meanwhile, the parallel circuit with its 6 chamber constituents experienced a voltage increase of 25.62% (0.441 V), a current of 9.35% (0.139 mA), and power of 64.01% (0.831 mW). From these results, indicate that the voltage arranged in parallel in each branch will tend to approach the same or the value is not much different, the total voltage generated is the voltage at each branching. Unlike the case with the entire current generated by a parallel system, the value of the electric current is higher if the MFC reactor is arranged in parallel, because the total current generated is the sum of each MFC reactor. The more chambers, the more power is generated.

3.4. Optimum power measurement results
The optimum power data is obtained by polarization methods such as series and parallel measurements. Resistors are needed to regulate current and adjust voltage levels through a series circuit. Microbial fuel cell electrical measurement results are listed in table 2.

| Table 2. Optimum power in each chamber. |
|----------------------------------------|
| Chamber | Resistor (Ω) | Voltage (V) | Current (mA) | Power (mW) | Power Density (mW/m²) |
|---------|--------------|-------------|-------------|------------|---------------------|
| 1       | 47           | 0.212       | 1.412       | 0.299      | 59.6                |
| 2       | 100          | 0.296       | 1.461       | 0.432      | 86.1                |
| 3       | 47           | 0.171       | 1.102       | 0.188      | 37.5                |
| 4       | 100          | 0.298       | 1.296       | 0.386      | 76.9                |
| 5       | 200          | 0.263       | 1.299       | 0.342      | 68.0                |
| 6       | 100          | 0.305       | 1.467       | 0.447      | 89.1                |
The results show that the optimum power is in the range of resistors 47 $\Omega$ and 100 $\Omega$, with an optimum power range of 0.3 mW - 0.45 mW. If resistance is installed too large, then the voltage generated will be small, it will automatically affect the power generated.

3.5. Results of measurement pH

The degree of acidity or pH is the state used to express the acidity or basicity of a solution. In this study, pH measurements were carried out every day by determining the position and depth of the same soil so that the measurement results were more accurate. The pH measured in each chamber is not always the same every time the measurement. When the pH condition decreases, this is due to the decay of organic matter that has died by bacteria. This decay process releases acid into the nutrient solution. According to [15], in MFC dual chamber, the highest current strength is achieved at a neutral pH between 6.5-8. Based on research that has been done, pH can affect the performance of MFC, and if the pH obtained is close to neutral pH, the MFC performance will be better. The results of this study show a range of pH values 6-9. This means that as long as the pH is maintained, microbes can produce electrical energy. Here is a pH chart in chamber 2 and chamber 6.

![Figure 5. Results of pH measurements in chamber 2 and chamber 6.](image)

3.6. Short-term power production as a function of pH

pH is one of the essential parameters in MFC in the electricity production process. Also, pH is a critical factor for all microorganism-based operations. pH does not only affect the course of metabolism and bacterial growth but also affects the transfer of protons and cathode reactions so that it has implications for MFC performance. Most MFCs operate at near-neutral pH to maintain optimal growth conditions of the microbial community involved in electricity generation [16]. Low pH (pH 5 and 6) results in lower electricity production, and low pH in MFCs may have inhibitors of electrogenic bacterial activity. Other researchers have also observed that acidic pH in the anode chamber reduces electricity production [17], [18]

The above observations are following the research conducted. It can be seen in Figure 6 that the relationship between pH and power produced by MFC has a linear correlation value of 0.9536, which means that pH and power are related to each other. Electricity decreases when the pH drops due to the degradation of wastewater from rice washing to produce acidic compounds. pH in chambers 4, 5, and 6 obtained a pH range of 7-9; it is due to the absence of outside interference that can interfere with the reproduction of microorganisms. The optimum pH of microorganisms will produce the highest power, with an average optimum pH value of 8. Table 3 shows that all MFC chambers have linear correlation values with a range of 0.80 to 0.94, meaning that pH affects the power.
Table 3. Relationship between pH and MFC electric power in each chamber.

| Label of MFC | Linear Correlation Value | The range of pH |
|--------------|--------------------------|-----------------|
| Chamber 1    | 0.8577                   | 5.0 - 8.5       |
| Chamber 2    | 0.9536                   | 5.5 - 8.0       |
| Chamber 3    | 0.8646                   | 5.0 - 8.5       |
| Chamber 4    | 0.8518                   | 7.0 - 9.0       |
| Chamber 5    | 0.8085                   | 7.0 - 9.0       |
| Chamber 6    | 0.9464                   | 7.0 - 9.0       |

![Figure 6. Relationship between pH and pH on the Label chamber 2.](image)

\[
y = 34.597x - 193.6 \\
R^2 = 0.9536
\]

4. Conclusion

Based on the description above, we conclude as follows: The addition of nutrients has benefits for maintaining survival and increasing power in the MFC. The concentration of 499 ppm rice washing waste produces the best power compared to the concentration and below. Rice washing water has the potential to be used as a nutrient for microorganisms in the MFC system. The more chamber units arranged in series, the higher the voltage value. In a parallel order, the value of the voltage obtained is close to the same; the strength of the current obtained will be even more significant with the number of units arranged together. The incubation time of MFC will affect the value of the generated power, i.e., the value will increase with the length of incubation time. Optimum power is achieved on the 30th day, but on the 31st day (control chamber), the strength of energy will decrease because microorganisms do not have enough nutrients to maintain life activities. Variation of the second rinse with a concentration of 499 ppm will have a pH value having a pretty good linear correlation of 0.9536 to the more electric power generated.

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