al Kimiya: Jurnal Ilmu Kimia dan Terapan,
Vol. 9, No. 2 (89-95), December 2022/Jumada Al-Thani 1444

TREATMENT OF ECENG GONDOK WASTE INTO ELECTRICAL BASED ON MICROBIAL FUEL CELL

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Article Information

Received: Oct 26, 2022
Accepted: Dec 26, 2022
Published: Dec 31, 2022

DOI:
10.15575/ak.v9i2.20974

Keywords:
Microbial Fuel Cell; eceng gondok; electrical energy; *Saccharomyces cerevisiae.*

Abstract

The increasing consumption of electrical energy and still dependent on non-renewable energy has encouraged the implementation of effective, efficient, and environmentally friendly technologies to produce electrical energy. *Microbial Fuel Cell* (MFC) is one of the alternative technologies that utilize microorganisms in converting chemical energy from organic compounds under anaerobic conditions to be converted into electrical energy. The study was conducted to determine the potential of electrical energy generated from the treatment of eceng gondok waste (*Eichhornia crassipes*) with variations in the addition of buffer solutions and combinations of electrolyte solutions using the microorganism *Saccharomyces cerevisiae* through *Microbial Fuel Cell* technology. This study consists of three stages and methods, namely sample preparation, MFC media preparation, and analysis of pH, current, voltage, and power density. Measurement of the value of the maximum voltage, maximum current and power density is carried out every 3 hours for 27 hours for each treatment. The results were obtained as follows consecutively: firstly, for variations without the addition of buffers and electrolyte solutions are 0.25 volts; 0.08 mA; 13.05 mW/m^2, secondly, with buffer and electrolyte solution $KMnO_4$ 0.2 M are 1.12 volts; 0.77 mA; 562.92 mW/m^2, and thirdly, with buffer and $K_3Fe(CN)_6$ 0.2 M are 0.47 volts; 0.48 mA; 147.26 mW/m^2. Based on the results of the study, it was concluded that the most optimal variation in producing electrical energy was in the variation in the addition of a phosphate buffer and 0.2 M $KMnO_4$ solution. Eceng gondok waste has the potential to be used as a source of electrical energy.

INTRODUCTION

Electricity became a very important need in life. Many daily activities involve the use of electrical energy. The consumption of electrical energy in Indonesia every year has increased which is accompanied by an increase in population and economic growth. Based on data from the Ministry of Energy and Mineral Resources, Indonesia's electricity consumption reached 1,109-kilowatt hours (kWH) per capita in the third quarter of 2021 [1]. This figure is equivalent to 92.2% of the target set in 2021 of 1,203 kWh per capita [1]. An increase in electricity consumption that is not accompanied by the availability of electrical energy sources will cause an electrical energy crisis. In addition, the source of electrical energy still depends on non-renewable energy. Therefore, technological solutions are needed that lead to the utilization of alternative energy sources that are effective, efficient, and environmentally friendly to produce electrical energy.

Microbial Fuel Cell (MFC) is a technology that utilizes microorganisms in converting chemical energy from organic compounds under anaerobic conditions to be converted into electrical energy [2]. The products produced by the MFC system are products that are environmentally friendly because the substrate used is sourced from organic biomass.

Eceng gondok (*Eichhornia crassipes*) is a type of aquatic plant that grows very quickly and is very easy to grow in water. But as a water-disturbing plant, hyacinth plants can be used to overcome pollution. Eceng gondok plants have roots, stems, and leaves equipped with airbags so that they can float on the surface of the water and can absorb heavy metals that are soluble in water. The chemical components in eceng gondok include cellulose 60%, hemicellulose 7%, and lignin 17% [3]. Cellulose has the potential to be used as a substrate in the MFC system because it is composed of monosaccharides, namely glucose. The process of decomposition of cellulose into monosaccharides (glucose) can be done by using the help of cellulotic bacteria [4].

Microbial Fuel Cell has the same components as fuel cells, namely electrodes, electrical circuits, and membranes (as electrolytes) [5]. MFC performance is influenced by several factors, namely the sensitivity of the MFC components (electrodes and PEM), the type and number of microorganism cultures in the MFC, and the design of the MFC. The comparison between ordinary fuel cells and MFC can be seen in **Table 1**.

Table 1. Comparison of the condition of the regular fuel cell system with MFC [5].

Operating Conditions	Regular fuel cell	*Microbial Fuel Cell*
Catalyst	Precious metal	Microorganisms/ enzymes
pH	Acidic solution (pH < 1)	Neutral solution (pH 7-9)
Temperature	>200ºC	22-25ºC
Electrolyte	Phosphoric acid	Phosphate solution
Capacity	High	Low
Efficiency	40-60%	>40%
Fuel type	Natural gas	Carbohydrates and hydrocarbons

The efficiency and performance of *a Microbial Fuel Cell* can be influenced by various factors. In *Microbial Fuel Cell* dual chamber optimal growth bacteria require neutral pH. Influential factors include the speed of substrate degradation, the transfer rate of bacterial electrons to the cathode, and the transfer of protons in solution.

The MFC system consists of an anode, a cathode and an electrolyte solution (**Figure 1**). Microbes will metabolize the anode compartment in an anaerobic state decomposing the substrate into protons, electrons, and carbon dioxide [6]. The working principle of MFC is to utilize microbes that metabolize the medium in the anode to catalyze the conversion of organic matter into electrical energy by transferring electrons from the anode through wires and generating current to the cathode. The transfer of electrons from the anode is received by complex ions at the cathode that has free electrons.

The reactions that take place in MFC with a substrate in the form of glucose and oxygen as acceptor electrons are as follows:

$$\text{Anode}: C_6H_{12}O_6 + 6H_2O \xrightarrow{\text{microbe}} 6CO_2 + 24H^+ + 24e^-$$

$$\text{Cathode}: O_2 + 4H^+ + 4e^- \xrightarrow{\text{microbe}} 2\,H_2O$$

$$\text{Overall}: C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{microbe}} 6CO_2 + 6H_2O$$

[8]

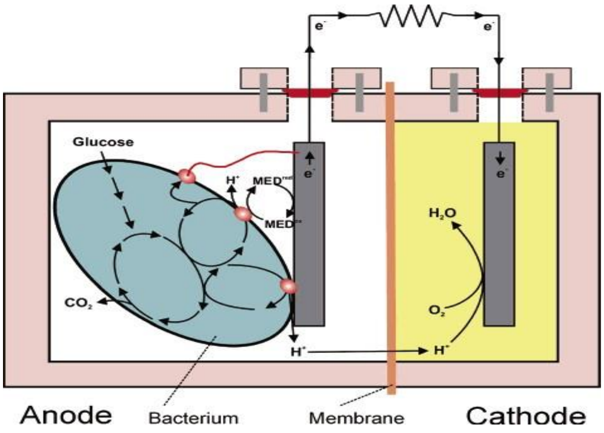

Figure 1. Scheme Principles of MFC work [7].

Research on MFC Double chamber PEM MFC with tapioca liquid waste using *Saccharomyces cerevisiae* yielded 61.62 W/m^2; 0.57 V and 0.12 A [9]. The activity of the bacterium *Saccharomyces cerevisiae* in glucose substrates produced strong currents and voltages of 224 microamperes (µA) and 196 millivolts (mV) [10]. MFC research has also been conducted with tofu whey substrates using the bacterium *Saccharomyces cerevisiae* [11]. This condition allows electrons from the metabolism of microorganisms to be utilized as a source of electrical energy.

Thus, a variety of pretreatment techniques are employed to degrade the lignocellulosic biomass and release the carbohydrates products [12]. Microbial fuel cells (MFCs) may support alternative more economically and environmentally favorable ways of bioenergy production based on their advantage of using waste [13]

Bacteria able to generate current, found in various natural and anthropogenic environments, need simple substrates such as acetate or glucose [14]. However, the present review indicates that fungi can be considered very promising catalytic microorganisms for MFC technology. The highest power density obtained for fungi-based MFCs was 1.5 Wm^{-2}, which provides researchers with a foundation for future investigations, especially with the application of bacteria–fungi mixed consortia in MFCs [15]. Although the MFC techniques have been greatly advanced during the past few years, the present state of this technology still requires to be combined with other processes for cost reduction [16]

Therefore, in this study, the substrate used was eceng gondok waste using the microorganism *Saccharomyces cerevisiae* by varying the addition of a phosphate buffer and electrolyte solution, namely $KMnO_4$ 0.2 M and $K_3Fe(CN)_6$ 0.2 M and using carbon graphite electrodes. The anode and cathode are connected by a salt bridge.

This study aims to determine the potential of electrical energy generated from the treatment of eceng gondok waste substrates with variations in the addition of buffer solutions and combinations of electrolyte solutions using *Saccharomyces cerevisiae microorganisms* through *Microbial Fuel Cell* (MCF) technology.

EXPERIMENT

In this study, variations were made in the addition of phosphate buffer solutions and electrolyte solutions to produce electrical energy. The results of voltage and current measurements are carried out every 3 hours for 27 hours. The results of calculating the optimum voltage and current are obtained from power density.

Materials

The materials needed in this research include eceng gondok waste taken under the twin bridges of Gowa Regency, microorganisms *Saccharomyces cerevisiae*, agar swallow, Natrium hydroxide (NaOH) 1 M, HCl 1 M, Salt KCl 1 M, $KMnO_4$ 0.2 M, $K_3Fe(CN)_6$ 0.2 M, phosphate buffer solution, pH paper, and aluminum foil.

Instrumentations

The tools used in this study include the MFC reactor, namely the cathode chamber and anode made of plastic containers connected with salt bridges from PVC pipes, Xenon XN-205 brand Digital multimeters, crocodile clamp cables, carbon graphite electrodes, measuring pipettes, measuring cups, funnels, bulp, erlenmeyer, stirrers, capsule blenders, and hot plate.

Procedures

Sample preparation

Eceng gondok waste is cleaned and cut, then mashed using a capsule blender (adding enough water), transferred to the sample container

Electrode preparations

The carbon graphite electrode was soaked into a 1 M HCl solution for 1 day and then rinsed using aquadest. After that, the electrodes are soaked again into a 1 M NaOH solution for 1 day and then soaked again using aquades. The electrodes are immersed in a solution of aquades until the moment when they are about to be used.

Salt bridge preparation

Dissolved 5 g of agar in 100 mL of water, then add 3 grams of potassium chloride. It is heated to a boil, after which it is cooled. The liquid then was put into the pipe and waited for it to solidify.

MFC Reactor Preparation

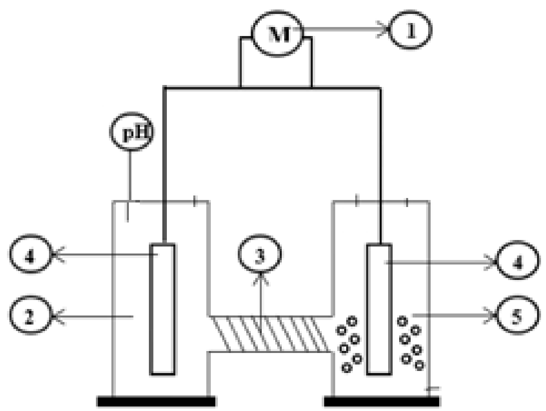

Figure 2. *Microbial Fuel Cell* tool range.

Image caption :
1. Multimeter (voltmeter/ammeter)
2. Anode Chamber (anaerobic) (bacteria and organic waste)
3. Salt bridge
4. Electrodes
5. Cathode Chamber (aerobic) (*electrolyte* solution)

Experimentation Process

The cathode and anode chambers are separated using a salt bridge as in **Figure 2**. The salt bridge used is made of 3% KCl in 5% agar. The cathode chamber is filled with 3 variations, namely (1) without the addition of buffers and electrolyte solutions (2) in the addition of phosphate buffers and electrolyte solutions of $KMnO_4$ 0.2 M and (3) in the addition of phosphate buffers and $K_3Fe\ (CN)_6$ 0.2 M. In the anode chamber filled with microorganisms *Saccharomyces cerevisiae*. Then the electrodes are installed in each chamber and connected by a series of wires and crocodile clamps. Observed the value of the electric current and voltage indicated on the digital screen of the multimeter until it is stable and recorded every 3 hours for 27 hours. Measured the initial and final pH values of measurements in the anode chamber.

Measurement of Voltage, Current, and Power Density

The digital multimeter is connected at both electrodes, with a positive pole at the cathode and a negative pole at the anode chamber. Readings of voltage and electric current are recorded every 3 hours for 27 hours. From the data on current and voltage strength, a power density value (mW/m^2) can be obtained, that is, power per unit electrode surface area [17]. Power density can be calculated using the following equation:

$$\text{Power Density } \left(\frac{\text{mW}}{\text{m}^2}\right) = \frac{\text{I (mA) x V (volt)}}{\text{A (m}^2\text{)}}$$

RESULT AND DISCUSSION

The Microbial Fuel Cell used in this study consists of anode and cathode chambers with separate models, which are filled with each of these chambers with carbon graphite electrodes and then connected by a salt bridge. This study was carried out by measuring the voltage, current, and power density of hyacinth substrates from the influence of variations in electrolyte solutions, namely $KMnO_4$ 0.2 M and $K_3Fe(CN)_6$ 0.2 M in the cathode chamber and also the addition of a phosphate buffer solution to maintain the environmental pH condition of the microorganism *Saccharomyces cerevisiae*. The range of MFC equipment in this study can be seen in **Figure 3**.

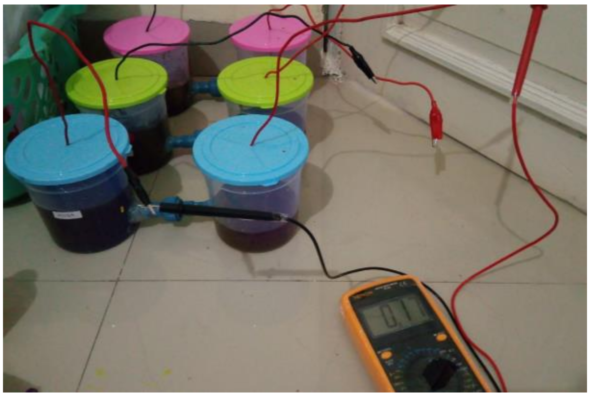

Figure 3. MFC Equipment Series on Eceng Gondok Waste.

Hydrogen is formed from there-action of glycolysis that occurs at the anode, while oxygen and $KMnO_4$ and $K_3Fe(CN)_6$ catalysts are present at the cathode. The salt bridge is used as a catalyst capable of passing protons to the cathode and holding electrons in the anode. If the anode and cathode are connected to a resistor, there will be a flow of electrons from the anode to the cathode, causing an electric current. Furthermore, protons and electrons will reduce Mn^{7+} to Mn^{4+} in the electrolyte solution of $KMnO_4$, and reduce Fe^{3+} to Fe^{2+} in the electrolyte solution $K_3Fe(CN)_6$ [18].

Measurement of value voltage and current

The results of voltage and current measurements obtained every 3 hours for 27 hours using a substrate of hyacinth and microorganism *Saccharomyces cerevisiae* for variation without addition, the addition of $KMnO_4$ + buffer phosphate, and addition of $K_3Fe(CN)_6$ + buffer phosphate are shown in **Figure 4** and **Figure 5**.

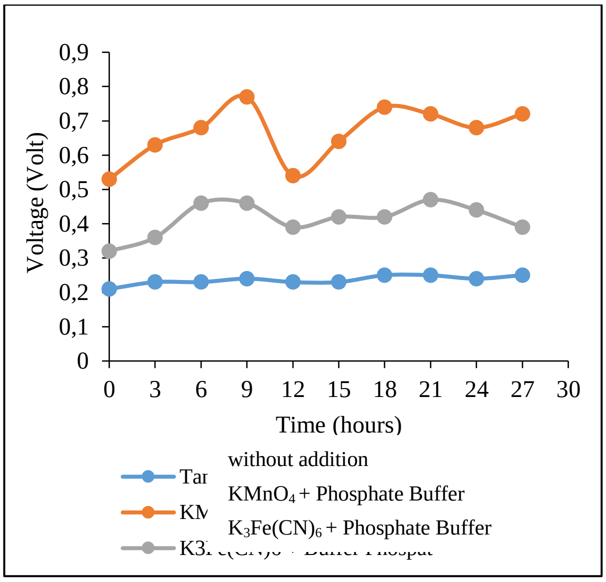

Figure 4. Measurement of Voltage Value Eceng Gondok waste methode MFC.

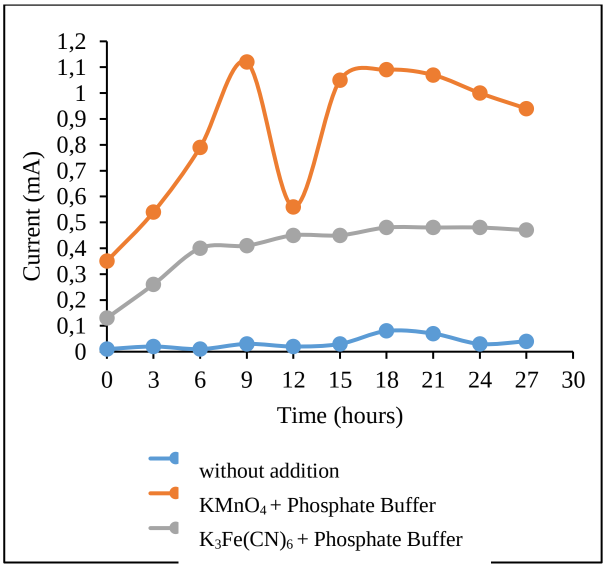

Figure 5. Measurement of Current Value Eceng Gondok waste methode MFC.

In **Figure 4** and **Figure 5**, the voltage values in each variation show a pattern of energy rise and fall, which is due to the activity of microorganisms in the system [19]. The energy expended through the outer membrane of microbes is partially used for metabolic processes. From a total of 27 hours of voltage and current measurements, the maximum value of each variation was obtained, namely for no addition in the results of voltage measurements at the 18th, 21st, and 27th hours of 0.25 volts while the current measurement at the 18th hour time was 0.08 mA. For the addition of $KMnO_4$ + buffer, the results of voltage and current measurements at the 9th hour time are 0.77 volts and 1.12 mA. As well as for the addition of $K_3Fe(CN)_6$ + buffer phosphate the result of measuring voltage and current in the 21st hour time of 0.47 volts and 0.48 mA. Along with the growth phase of microorganisms namely the slow phase, exponential, stationary phase, and death phase [19]. This is also because, the substrate used is cellulose, as it is known that cellulose will be more easily broken down by bacteria into glucose [20].

The decrease in current strength is also caused by the presence of hydrogen as a result of metabolism at the anode, which causes the longer the concentration of hydrogen will increase and cover the entire surface of the electrode at the anode so that the process of transferring electrons from bacteria to the electrode becomes obstructed. Besides that, the voltage drop is caused by the formation of biofilms on the salt bridge so that the activity of bacteria in the anode is inhibited. Biofilm has a bad impact on the mass transfer process that occurs on the membrane and can block the transfer of protons from the anode to the cathode. Retained protons will cause pH changes in the anode and disrupt bacterial life. The voltage drop is also caused by a decrease in the activity of $KMnO_4$ and $K_3Fe(CN)_6$ as electron acceptors at the cathode. This is following the reaction equation that the longer the concentration of the two potassiums is used, the more it decreases due to the incomplete redox process by oxygen, causing a decrease in electrical energy in the MFC system.

In **Figure 4** and **Figure 5**, the measurement results can be seen with variations in electrolyte solutions in $KMnO_4$ solutions producing a maximum voltage and current of 0.77 volts and 1.12 mA, this value is higher than the result of $K_3Fe(CN)_6$. This is because $KMnO_4$ is a strong oxidizer that has a fairly high standard reduction potential of 1.70 V, especially in acidic conditions, while $K_3Fe(CN)_6$ only has a standard reduction potential of 0.36 V.

Guerrero-Rangel also compared the performance of electrolyte solutions at the cathode using aluminum permanganate, potassium ferricyanide, and potassium dichromate. From Gurrero-Rangel's research, it was again obtained that the highest electrical energy was produced by potassium permanganate, which was 1.07 V. This value was greater by about 33% against potassium ferricyanide and 48% against potassium dichromate [21].

Value Power Density

Based on the maximum values of voltage and current at each variation of the electrolyte solution with a phosphate buffer. Then it can be calculated the efficiency value of Power Density (mW/m^2) which is the power per unit surface area of the electrode. The electrode area in this study was 15.32 cm^2. The power density (mW/m^2) values in each combination can be seen in **Table 2**.

Table 2. Large Power Density at each combination of electrolyte solution with phosphate buffer material.

Variable	Power Density (mW/m^2)
No Additions	13.05
$KMnO_4$ and phosphate buffer	562.92
$K_3Fe(CN)_6$ and phosphate buffer	147.26

From the calculation results based on variations in electrolyte and buffer solutions, the power density value on the eceng gondok waste without electrolyte solution and buffer was obtained at 13.05 mW /m^2, at the addition of KMnO 4 electrolyte solution of 562.92 mW/m^2 and at the addition of electrolyte solution $K_3Fe(CN)_6$ of 147.26 mW/m^2. So the combination that produces the highest *Power density* is in the addition of the electrolyte solution $KMnO_4$ and the phosphate buffer which is 562.92 mW /m^2.

Based on research conducted by Maminska et al who use cellulose substrates, the *Power Density* (mW/m^2) value was obtained, which was 44 mW/m^2 [22], and the research conducted by Lisa Utami et al using banana peel substrate obtained a *Power Density* value (Mw/m^2) of 31.9 Mw/m^2[23]. The results obtained, shows that *the Power Density* (Mw/m^2) value using an eceng gondok waste produces a higher *Power Density* (mW/m^2) value. This is thought to be due to the use of an electrolyte solution of $KMnO_4$ combined with a solution of phosphate buffer corresponding to the substrate and bacteria used in the MFC system. The difference in Power Density results is also due to the cellulose content of the substrate, the cellulose content of bananas is only 14.56% [24] while the eceng gondok substrate is 60% [3].

Thus, the use of an electrolyte solution with the addition of an appropriate buffer material can affect the current value, potential difference and *Power Density* (mW/m^2) value produced by the MFC system. In addition, the use of buffer materials also plays an important role in maintaining the stability of the pH of the bacterial environment so that the energy produced can increase. From this study, the combination of the highest suitable results was obtained between the electrolyte solution $KMnO_4$ and the phosphate buffer solution with voltage, current and *Power Density* (mW/m^2) values obtained successively the maximum yield of 0.77 V, 1.12 mA, and 562.92 mW/m^2. This is because in addition to $KMnO_4$ has a standard reduction potential value of 1.70 V compared to $K_3Fe\ (CN)_6$ with a reduction potential price of 0.36 V. Phosphate buffer solution also acts as a source of nutrients needed by bacterial growth so that the energy produced is higher. The more active a bacterium is in metabolism, the more free electrons it produces. The resulting power density on average experienced a decrease with increasing operating time. This results in increased resistance in the anode causing a decrease in power density [25].

CONCLUSION

Based on the results of the study it can be concluded that hyacinth waste can be used as a substrate for the production of electrical energy using MFC technology. The results of the measurement of the maximum voltage value, maximum current, and power density carried out every 3 hours for 27 hours were obtained for variation without the addition of buffers and electrolyte solutions of 0.25 volts; 0.08 mA; 13.05 mW/m^2, buffer and electrolyte solution $KMnO_4$ 0.2 M is 1.12 volts; 0.77 mA ; 562.92 mW/m^2 , buffer and $K_3Fe(CN)_6$ 0.2 M is 0.47 volts; 0.48 mA; 147.26 mW/m^2 with *Power Density* maximum 562.92 mW/m^2.

ACKNOWLEDGMENT

Thank you are conveyed to the Ministry of Education and Culture, Research and Technology (Kemdikbudristek) for providing funding support.

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