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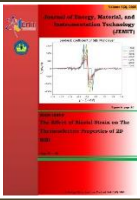

Electrical Design and Characterization of Plant Microbial Fuel Cell (PMFC) Using Water Hyacinth Plants with Variation of The Amount of Water and The Effect of Sunlight

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Abstract

Research on Plant Microbial Fuel Cells (PMFCs) has begun to develop, and various types of plants have been used. This research has realized PMFC using hyacinth plants by diversifying the amount of water and the effects of sunlight. The electrical properties of PMFCs aim to determine the effect of variations in the amount of hyacinth and sunlight on the power generated. In the reactor, the electrodes used are Cu and Zn plates. Data were collected by placing three reactors outdoors for 14 days or 331 hours. Based on the study's results, PMFC in reactor c, containing three clumps of hyacinth, obtained greater electrical power than in reactors A and b. The maximum electrical power is 6.31 mW on the 61st hour or 3rd-day measurement at 13.00 WIB. PMFC produces greater electrical power in external conditions than in internal conditions.

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Abstrak

Penelitian mengenai Plant Microbial Fuel Cell (PMFC) mulai banyak dikembangkan dengan berbagai jenis tanaman yang digunakan. Penelitian ini telah direalisasikan PMFC menggunakan tanaman eceng gondok dengan memvariasikan jumlah eceng dan pengaruh cahaya matahari. Karakteristik elektrik PMFC bertujuan untuk mengetahui pengaruh variasi jumlah eceng gondok dan cahaya matahari terhadap daya yang dihasilkan. Pada reaktor, elektroda yang digunakan berupa plat Cu dan Zn. Pengambilan data dilakukan dengan meletakkan 3 reaktor di luar ruangan selama 14 hari atau 331 jam. Berdasarkan hasil penelitian, PMFC pada reaktor c yang berisi 3 rumpun eceng gondok memperoleh daya listrik yang lebih besar dibandingkan reaktor a dan b. Daya listrik maksimal sebesar 6,31 mW pada pengukuran jam ke-61 atau hari ke-3 pukul 13.00 WIB. PMFC di kondisi luar ruangan menghasilkan daya listrik yang lebih besar dibandingkan di kondisi dalam ruangan.

1. Introduction

The need for energy is increasing due to population growth and development. If we continue to use fossil-based electricity, this will impact the energy crisis. Using fossil energy increases greenhouse gases, making the climate unstable, increasing the temperature of the earth's emissions, and raising sea levels (Pertamina, 2020). The energy crisis can be anticipated by using alternative electricity. Therefore, an environmentally friendly renewable energy-based power source is needed.

A fuel cell is an energy conversion device that uses an electrochemical process to convert chemical energy into electricity (Horri et al., 2012). It produces few emissions (Demirbas, 2007), making it environmentally safe. Plant Microbial Fuel Cell (PMFC) is one fuel cell used in this research. PMFC uses plants as a medium to produce microorganisms that operate as biocatalysts. Plants convert CO2 emissions into biomass through photosynthesis. This process is one strategy to produce alternative energy that does not release toxic substances into the environment. It also serves as a solution to the long-term environmental problems arising from the use of fossil fuels.

The results of the PMFC research that has been carried out by Kadhafi (2020) through the manufacture of PMFCs by diversifying the types of Al/Cu, Zn/Cu, and Al/Pb electrodes to produce the highest power on the Al/Cu electrodes. Furthermore, the study of making PMFCs by varying the anode-cathode distance between 10 cm and 20 cm. The results obtained show that PMFC with a distance of 10 cm (using a zinc anode) produces greater power than

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a distance of 20 cm (Hendawan, 2020). Then, research on the electrical potential of PMFCs by diversifying the number of hyacinth plants, ¼, ½, and the reactor produces maximum power in a reactor full of hyacinths (Novelendah et al., 2018)

The main components of PMFC are plants, substrate, and electrode pairs. Based on previous research, the best pair of electrodes is Cu and Zn, so this study uses a pair of Cu and Zn electrodes. Meanwhile, the plant used is water hyacinth (*Eichhornia crassipes*) because of its high cellulose content, which microorganisms can break down into simple sugars that serve as an energy source in the microbial fuel cell system. Water hyacinth is an invasive aquatic plant that grows rapidly, often causing environmental problems such as waterway blockage and oxygen depletion. Utilizing this plant in PMFCs generates electricity and helps control its overgrowth, providing energy and ecological benefits (Halim et al., 2021; Firmansyah et al., 2022). The electrical characteristics of PMFC are the objectives of this study, where the effect of diversifying the amount of water hyacinth and the effect of sunlight are research variables.

2. Research Methods

The tools and materials used in this research are multimeters, scissors, digital scales, pH meters, rulers, laptops, plastic boxes, Zn plates, Cu plates, jumpers, water, deposition, LEDs, hyacinths, and 100 resistors.

2.1 Overall Tool Design

Figure 1 shows the tool's design in Plant Microbial Fuel Cell (PMFC) research, which was done using SketchUp. The PMFC measurement method is shown in **Figure 2**.

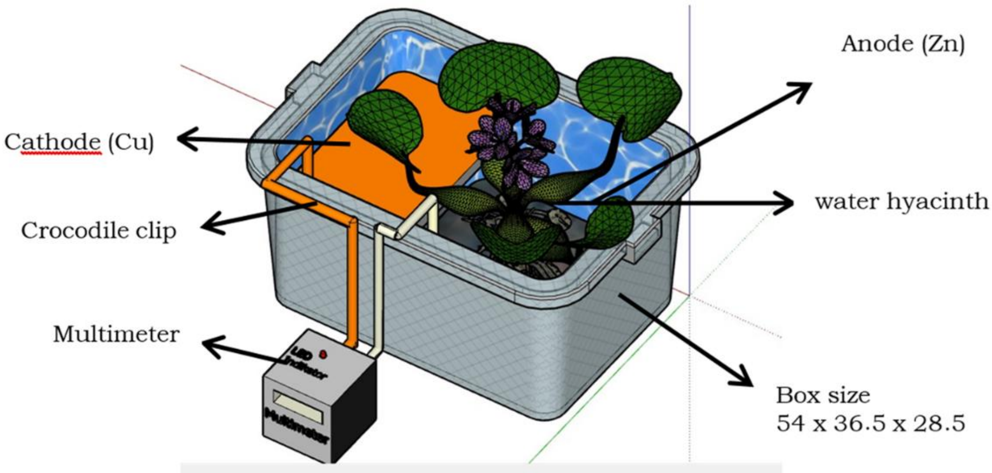

Figure 1. PMFC Design

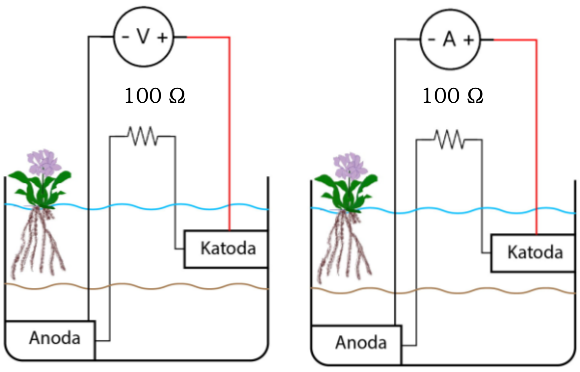

Figure 2. PMFC Measurement Method

The PMFC design refers to the research of Kabutey et al. (2019), as shown in Figure 2. Measurements on the PMFC are carried out every 07.00, 13.00, and 19.00 WIB for 14 days. Three PMFC reactors are placed outside the room to be exposed to sunlight. The results obtained are electric voltage, electric current, and water pH. This data calculates the electric power using the Eq (1).

$$P = V \times i \tag{1}$$

where V is the electrical voltage, and i is the electric current obtained from the measurement.

3. Results and Discussions

3.1 Design Implementation

The PMFC reactor with variations in the amount of water hyacinth is realized, as shown in Figure 3.

Figure 3. PMFC reactors

Figure 3 shows three reactors, each containing a pair of Cu-Zn electrodes connected to a resistor (100 ohms). The PMFC reactor measures 54 x 36.5 x 28.5 cm. Each reactor contains 15 liters of water with water hyacinth clumps between 250-300 gr. The reactor was named Reactor (A), containing one water hyacinth clump; Reactor (B), containing two water hyacinth clumps; and Reactor (C), containing three water hyacinth clumps. Data were collected by measuring the electrical characteristics of the reactor every day at 07.00, 13.00, and 19.00 WIB for 14 days or 331 hours.

3.2 Data Collection and Analysis

Data on the reactor's electrical characteristics were taken during 331 hours of outdoor exposure to direct sunlight. The output produced by PMFC is voltage and electric current, which is indicated by the LED flame connected to the reactor. The working voltage on the LED is 1.7 volts, so to turn it on, two reactors and LEDs in series are needed. The state of the LED at night is shown in Figure 4.

Figure 4. LED conditions at night outdoors

Figure 4 shows outdoor conditions at night when PMFC can turn on 2 LEDs. Voltage and electric current measurements were carried out in each PMFC reactor. The anode and cathode poles connected with wires are then connected directly to the multimeter. The results of the voltage and electric current measurements of each reactor are shown in **Figure 5**.

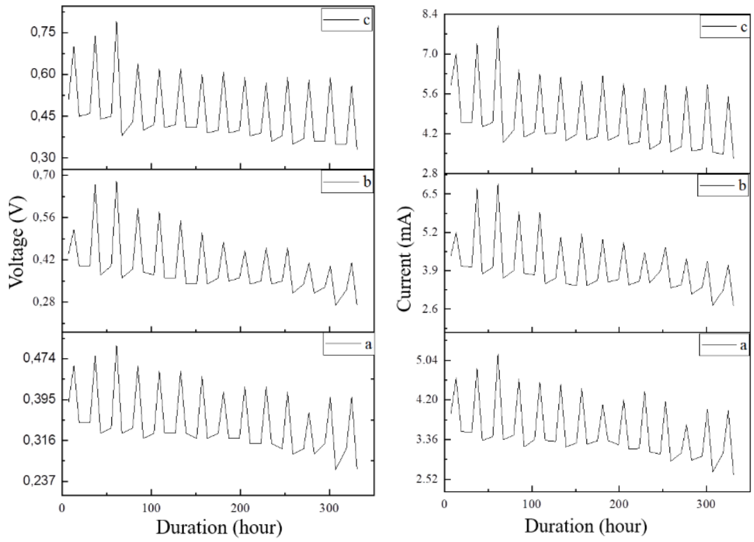

Figure 5. Graph of voltage and electric current versus time characteristics for the reactor: (a) water hyacinth 1, (b) water hyacinth 2, (c) water hyacinth 3

Figure 5 shows 331 hours or 14 days of measurements that produce fluctuating voltage and electric current. The voltage and electric current values from morning to noon increase and then decrease at night. This is influenced by plant photosynthesis. The peak photosynthesis rate occurs at noon without weather disturbances (Susanty, 2014). Without sunlight, plants cannot perform photosynthesis (Zahara & Fuadiyah, 2021). That way, voltage, and electric current values at night and in the morning are constant.

Figure 5 shows each reactor's maximum and minimum voltage and electric current values in **Table 1**.

Table 1. Maximum and minimum values of voltage and amperage

Reactor	Maximum value		hour-	Minimum value		hour-
	V (V)	I (mA)		V (V)	I (mA)	
a	0.5	5.18	61	0.26	2.61	307 dan 331
b	0.68	6.85	61	0.27	2.71	307 dan 331
c	0.79	7.99	61	0.33	3.33	331

Based on **Table 1**, the maximum voltage value was obtained at the time of measurement on the 61st hour of noon on the third day. This can happen because the number of plants' roles in producing electricity differs. In addition, the tendency of voltage increase on the first to third day can be influenced by the adaptation of plants to the reactor; plant roots, as a habitat of electrochemically active bacteria (EAB), begin to multiply. (Kurniawati dkk., 2017). The voltage value decreases until the 331st hour. The decay in the leaves can cause this decrease in stems, which results in photosynthesis not being passed to the roots, so the roots lack energy, resulting in root rot. With root decay, the life of the EAB is disrupted.

Based on the voltage and electric current values generated, electrical power in PMFC can be calculated using **Equation 1**. This study also measures the pH of the water in each reactor. The results of the calculation of electrical power and pH of PMFC water are shown in **Figure 6**.

Figure 6 shows the resulting electrical power and pH fluctuations. Electrical power is influenced by voltage and electric current. In addition, the electrical power generated is also influenced by the pH of the water. Overall, the pH value increased from the first to the last day, although not significantly. An increase in pH affects the resulting output. If the pH of the solution is low, the number of conductive ions will increase and vice versa. The more ions produced, the better the ability to transmit electrons, producing a larger output. However, the higher the pH of the ionic solution produced, the less and the weaker the electron conductor capacity will be, so the resulting output will be smaller (Pauzi et al., 2022). This is evidenced by the reduced electrical power generated and the increase in the pH of the water. The maximum and minimum power generated by PMFC are presented in **Table 2**.

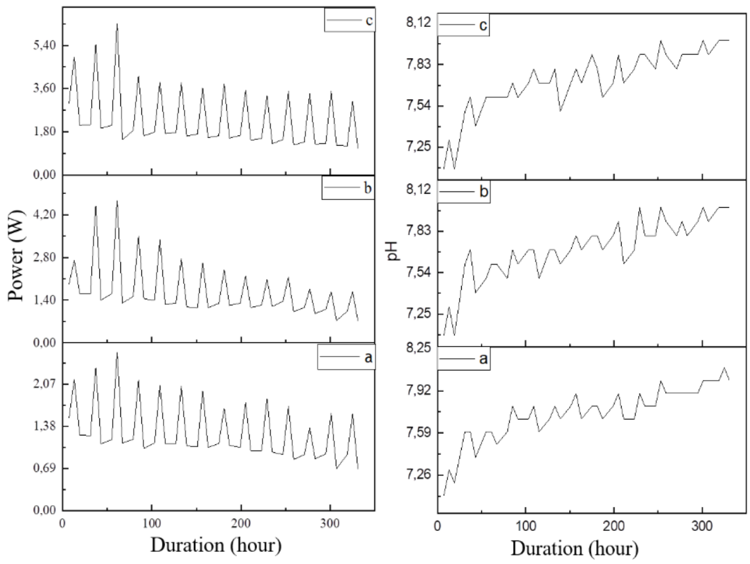

Figure 6. Characteristics of electrical power and pH produced by PMFC for the reactor: (a) water hyacinth 1, (b) water hyacinth 2, (c) water hyacinth 3

Table 2. PMFC maximum and minimum power

Reactor	P_{max} (mW)	Time (hour)	P_{min} (mW)	Time (hour)
a	2.59	61	0.68	307 & 331
b	4.66	61	0.73	307 & 331
c	6.31	61	1.10	331

Based on **Table 2**, the maximum power produced is reactor c, which contains more hyacinth clumps. At the same time, the minimum power is produced by a reactor containing at least a clump of hyacinths. Maximum power is obtained at noon during the 61st hour because photosynthesis is very effective during the day. At the same time, the minimum power produced at night is 307 and 331 hours because photosynthesis does not occur in plants.

From the PMFC test, by varying the amount of hyacinth, it was found that reactor (c) produces a higher current and voltage than reactors (b) and (a). This suggests that reactors containing hyacinths produce more electrical energy because they have many roots (Novelendah et al., 2018).

3.3 Electrode Corrosion Rate of PMFC

The corrosion rate was obtained by measuring the mass of the electrode before and after use. Table 3 shows the results of Cu and Zn electrode mass measurements.

Table 3. Electrode mass measurement

Reactor	Before use		14 days use	
	Cu (g)	Zn (g)	Cu (g)	Zn (g)
a	55	55	45	50
b	55	55	45	50
c	55	55	45	50

The mass of the Cu and Zn electrodes decreased on 14 different days of use. The Cu electrode as cathode decreased in mass by 10 grams, and Zn decreased by 5 grams. With a decrease in mass, it is possible to calculate the corrosion rate using **Equation 2**.

$$CR = \frac{(\Delta W \times K)}{(\rho \times A \times t)} \tag{2}$$

with *CR* as corrosion rate (mm/year or mpy), ΔW is Weight loss of the corroded metal (grams), K is Constant (534 for mpy, 87.6 for mm/year), ρ is density of the metal (g/cm^3), A is surface area of the corroded electrode (cm^2) and t is exposure time (hours), so that the corrosion rates at the Cu and Zn electrodes are obtained as in **Table 4**.

Table 4. Electrode corrosion rate

Reactor	Outdoor Environment	
	Cu (mm/y)	Zn (mm/y)
1	0.3637	0.0228
2	0.3637	0.0228
3	0.3637	0.0228

Based on **Table 4**, it is known that the corrosion rate of Cu is greater than that of Zn. Cu is one of the hardest to corrode electrodes because it has a higher potential value than hydrogen. However, in this study, Cu is used as the cathode, which is an oxygen-rich region. It is known that corrosion occurs when metals react with oxygen and air to form rust. If the corrosion rate is low, the electrode will be more easily damaged. It is evidenced by plate rust and damage to the connector clamps on the copper electrodes. Lower electrode corrosion rates effect higher electrical energy output. In addition to being affected by oxygen, corrosion can also be influenced by air pH and temperature.

4. Conclusions

PMFCs with hyacinths can generate electricity, with a maximum electrical power of 6.21 mW in outdoor conditions exposed to sunlight. The PMFC feature, with variation in the amount of hyacinth, produced the highest voltage and current in reactor c, which contained more hyacinths, with a voltage of 0.79 V and a current of 7.99 mA. The highest corrosion rate on the Cu plate was 0.3637 mm/y in the external PMFC condition.

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