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Design and Electrical Characterization of Plant Microbial Fuel Cell (PMFC) Using *Eichhornia crassipes* by Varying the Electrode Distance and Effect Light of the Sun

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Abstract

The Plant Microbial Fuel Cell (PMFC) design using water hyacinth has been successfully created. The PMFC was then treated by varying the distance of the electrode and giving the effect of sunlight. The electrodes used are Cu-Zn pairs where the electrode distance varies, with values of 3, 6, 9, and 12 cm. Furthermore, the data was taken with PMFC conditions placed outside and indoors for 14 days (331 hours). The results showed that PMFC with an electrode distance of 3 cm produced a more excellent value of electrical power than the other electrode distances, which was 0.6786 mW on the second day at the 37th hour or in the afternoon at 13.00 WIB. In general, the electrical characteristics produced by PMFCs, which are affected by sunlight, produce greater electrical power than PMFCs indoors.

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Abstrak

Desain Plant Microbial Fuell Cell (PMFC) menggunakan eceng gondok telah berhasil dibuat. PMFC selanjutnya diberi perlakukan dengan memvariasi jarak elektroda dan memberi pengaruh cahaya matahari. Elektoda yang digunakan adalah pasangan Cu-Zn dimana jarak elektroda divariasi dengan nilai 3, 6, 9, dan 12 cm. Selanjutnya data diambil dengan kondisi PMFC diletakkan di luar dan di dalam ruangan selama 14 hari (331 jam). Hasil penelitian menunjukkan bahwa PMFC dengan jarak elektroda 3 cm menghasilkan nilai daya listrik yang lebih besar dibanding jarak elektroda lainnya yaitu sebesar 0,6786 mW pada hari ke-2 pada jam ke-37th atau di siang hari pukul 13.00 WIB. Secara umum, karakteristik elektrik yang dihasilkan PMFC yang dipengaruhi cahaya matahari menghasilkan daya listrik lebih besar dibanding dengan PMFC di dalam ruangan.

1. Introduction

A fuel cell is an energy conversion device that converts energy from certain fuels into direct current electrical energy using electrochemical principles. This principle utilizes the power of hydrogen as a fuel to convert energy into other forms of energy (Maheswari, 2018).

Fuel cells are classified as Abiotic Fuel Cells and Biological Fuel Cells. The difference between the two cells can be seen in the involvement of living things or biological components in fuel cells (Mahadevan et al., 2014). The subsequent development of the fuel cell is Microbial Fuell Cell (MFC). In its application, MFC uses microbes to break down organic components into electrons and protons. The resulting electrons flow from the anode to the cathode, causing a potential difference in the formation of electricity (Slate et al., 2019).

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The development of MFC has been diverse, including using plants as a medium, called Plant Microbial Fuel Cell (PMFC). PMFC technology can convert solar energy into electricity through photosynthesis with symbiosis regarding nutrients between plants and bacteria. The principle of PMFC is to convert solar energy into electrical energy through the oxidation of rhizodeposits (several organic compounds released by the root surface). Photosynthesis occurs in plant leaves, assisted by solar energy, carbon dioxide, and water, to produce oxygen and organic compounds. Plant organic matter is transferred up to 60% from leaves to roots. The result of photosynthesis carried out by bacteria or microbes anaerobically on the decomposition of carbohydrates produces carbon dioxide (CO2), protons (H+), and electrons (e-) (Prasad & Tripathi, 2018).

Research on PMFC in Indonesia has been initiated to determine the potential of electricity generated from PMFC technology. The main components of a PMFC include a support matrix (bacteria), live plants, and electrodes. These components affect the electrical characteristics of PMFC. For example, PMFC studies are conducted by looking at the influence of the number of plants used (Novelendah et al., 2018), the influence of electrode distance in the PMFC system (Putranto, 2018), and the influence of the use of electrodes as anode-cathode on PMFC (Kadhafi, 2020). PMFC uses water hyacinth with variations in the amount of hyacinth to be produced at a Power Density of 0,772 mW/m with the total amount of water hyacinth (Novelendah et al., 2018).

Based on the explanation above, this study carried out the manufacture of PMFC to determine and analyze two of the electrical characteristics and electrical potential produced by PMFC. The variables used in this study are the electrode distance and the effect of sunlight on the electrical characteristics of PMFC. This study also analyzed the effect of the level of contamination on the electrode by comparing the mass of the electrode before use and after use. The electrode is a Cu-Zn electrode, and the plant is a water hyacinth.

2. Research Methods

This research was conducted to find out the electrical characteristics of the Plant Microbial Fuel Cell (PMFC) in the form of *voltage (V)*, *current (I)*, and *power (P)* as a result of the PMFC design. This study also measured the pH value of the water at PMFC to determine whether or not pH had an effect during the study. In addition, the effect of the corrosion rate on the electrode used will also be observed by comparing the mass of the electrode before and after use. The procedure in this study consists of three stages: research preparation, design and manufacture of PMFC designs, and data collection.

2.1 Research Preparation

At this stage, research preparation consists of a literature review, tools and materials, and preparation of PMFC design. A literature review is done by finding information related to research in the form of journals or information from websites. In the literature review, several journals were selected that were used as references in conducting research. Furthermore, the tools and materials required to research and prepare the PMFC design are carried out. The materials prepared were four plastic boxes, Cu and Zn electrodes, a multimeter and pH meter, a digital scale, scissors, a ruler, and a water hyacinth.

2.2 PMFC Design and Manufacturing

This stage consists of designing the PMFC design and making the PMFC. Electrodes consisting of cathode and anode are placed in a box with a volume of 50 liters, which will be used as a medium to make a PMFC. The cathode and anode are arranged top and bottom inside the box, as shown in **Figure 1**.

Figure 1. Electrode Design (Distance 6 cm).

Before creating a design, the mass of the electrodes used in the study must be measured. Mass measurement was performed by weighing the electrodes using a digital balance. A copper (Cu) plate of size 30 x 20 cm that acts as a cathode is placed on the water's surface that will be filled in the box. For cathode support, cable clamps are installed on the side of the box according to the size of the electrode distance to be used, which is 3 cm, 6 cm, 9 cm, and 12 cm. Then a 30 x 20 cm zinc (Zn) plate that acts as an anode is placed at the bottom of the box. Furthermore, the anode and cathode are connected using a connecting cable (crocodile clamp) and a multimeter. After that, a load in the form of a 100Ω resistor is attached to the PMFC design that has been made. The PMFC design in this study can be seen in **Figure 2**.

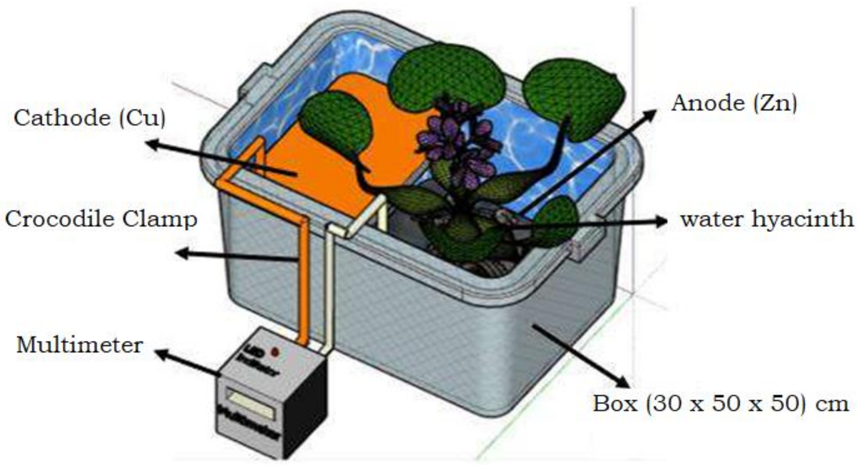

Figure 2. PMFCs Design

Furthermore, PMFC can be used for research data collection by following the design shown in **Figure 3**.

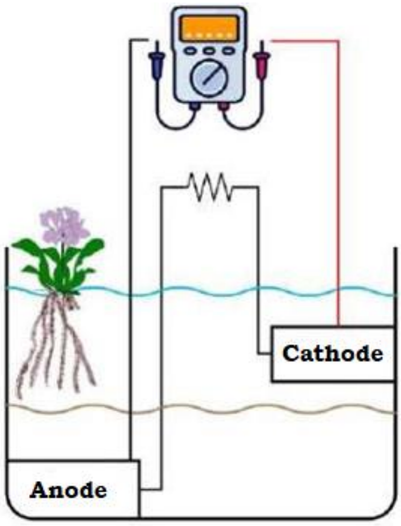

Figure 3. Data Collection Design

2.3 Data Collection

PMFC testing and data collection were conducted for 14 days (2 weeks). The first week of testing was outdoors (influenced by sunlight) with variations in the distance between the two PMFC electrodes. The same thing was done for PMFC indoors (no sunlight) in the second week. In addition to measuring electrical characteristics, pH and dissolved oxygen (DO) in water were also observed to see their effect on PMFC electricity. Furthermore, the rate of corrosion that occurs at the electrodes is also analyzed by calculating the values of mass loss (M) by subtracting the initial mass (m_0) from the final mass (m_a), as shown in **equation 1**.

$$M = (m_0)(m_a) \tag{1}$$

Corrosion rate can be calculated using equation 2, with CR = Corrosion Rate (mm/years), K = Unit Constant mm/years (8,76 x 10^4), M = mass loss (g), A = Surface area (cm^2), t = time (o'clock), and d = Density (g/cm^3).

$$CR = \frac{K\,M}{A\,d\,t} \tag{2}$$

3. Results and Discussions

Research on the manufacture of Plant Microbial Fuel Cell (PMFC) has been carried out, where this study focuses on knowing the amount of electrical power produced by PMFC with the variation of electrode spacing and the effect of the sun. Using natural processes around the roots, PMFCs can produce sustainable electricity using living plants (Kadhafi, 2020). Plants produce organic matter from sunlight and carbon dioxide through photosynthesis. The process of breaking down organic matter is carried out with the help of *Electrochemically Active Bacteria* (EAB) in the roots and soil to produce electron donors. Furthermore, the process results are captured by electrodes and channeled into electricity (Wiranti, 2017).

Observational research investigated the influence of electrode distance variation and sunlight exposure on the resulting electrical characteristics. The type of electrode used is the Cu-Zn electrode. Analysis was carried out on the value of voltage, current, and electric power of PMFC, the effect of pH, oxygen content (DO), and the effect of corrosion rate on PMFC. The plants used in this study are water hyacinths, with spacing variations of 3, 6, 9, and 12 cm. The research was conducted in two places, outdoors and indoors. Current, voltage pH and dissolved oxygen were measured in each PMFC reactor. The anode and cathode poles of the PMFC are connected with a multimeter to measure the voltage and current of the PMFC (**Figure 3**). Measurements of electric current, voltage, and pH were carried out in the morning, afternoon, and night with a time interval of 6 hours, at 07.00 WIB, 13.00 WIB, and 19.00 WIB. At the same time, the measurement of DO (oxygen level) is only done at night. Before data collection, the tools used were first calibrated. Data collection lasted for 14 days for outdoor PMFC. Then, proceed with PMFC data collection in the room.

3.1 Electrical Characteristics of PMFCs

The electrical characteristics of PMFC measured in this study are voltage, current, and electrical power. PMFC voltages and currents were obtained from measurements taken during 28 days of data collection, with 14 days outdoors and 14 days indoors. Meanwhile, the electric power of the PMFC is obtained from the calculation results by multiplying the voltage and electric current. The maximum and minimum values of voltage, current, and electrical power located outdoors can be seen in **Table 1**, and those located indoors can seen in **Table 2**.

Table 1. Maximum and minimum values of PMFC electrical characteristics located outdoor

Reactor	Maximum Values			Minimum Values		
	V (V)	I (mA)	P (mW)	V (V)	I (mA)	P (mW)
1	0.261	2.60	0.6789	0.171	1.73	0.2954
2	0.199	1.95	0.3881	0.166	1.65	0.2775
3	0.184	1.85	0.3404	0.150	1.50	0.2250
4	0.181	1.77	0.3203	0.142	1.42	0.2016

Table 2. Maximum and minimum values of PMFC electrical characteristics located indoor

Reactor	Maximum Values			Minimum Values		
	V (V)	I (mA)	P (mW)	V (V)	I (mA)	P (mW)
1	0.170	1.79	0.2924	0.140	1.40	0.1960
2	0.159	1.59	0.2528	0.136	1.36	0.1849
3	0.154	1.56	0.2402	0.134	1.34	0.1975
4	0.152	1.52	0.2301	0.130	1.30	0.1704

Reactors 1, 2, 3, and 4 are PMFC reactors with electrode distances of 3 cm, 6 cm, 9 cm, and 12 cm, respectively. Of the four distances used in the study, the maximum values of voltage, current, and electric power were produced by the PMFC with a closer electrode distance, which is 3 cm. The highest electric power output occurred at the 37th hour, precisely at noon on the second day of data collection. The heightened photosynthesis levels can elucidate this phenomenon during daylight hours (Khadafi, 2020).

The voltage, current, and electrical power of the PMFC system generated by each reactor during the 14-day outdoor and 14-day indoor tests decreased in value. PMFC generates the most significant electrical power with an electrode distance of 3 cm, which is 0.15 mW, placed outdoors. At the same time, the lowest electrical power is generated by PMFC with an electrode distance of 12 cm of 0.17 mW, with the location of PMFC indoors. The decrease in voltage, current, and electric power due to the influence of microorganisms or EAB found in plant roots is in the adaptation stage to the reactor environment (Hendrawan, 2020). In addition, the decrease in PMFC voltage and current is also due to the plants used in the PMFC study experiencing a decrease in growth, which is shown by the dryness of the leaves and plant stems, causing the photosynthesis process that occurs in the leaves to be less than optimal (Khadafi, 2020). The data obtained in the study were then plotted into a graph, as shown in **Figure 4** and **Figure 5**.

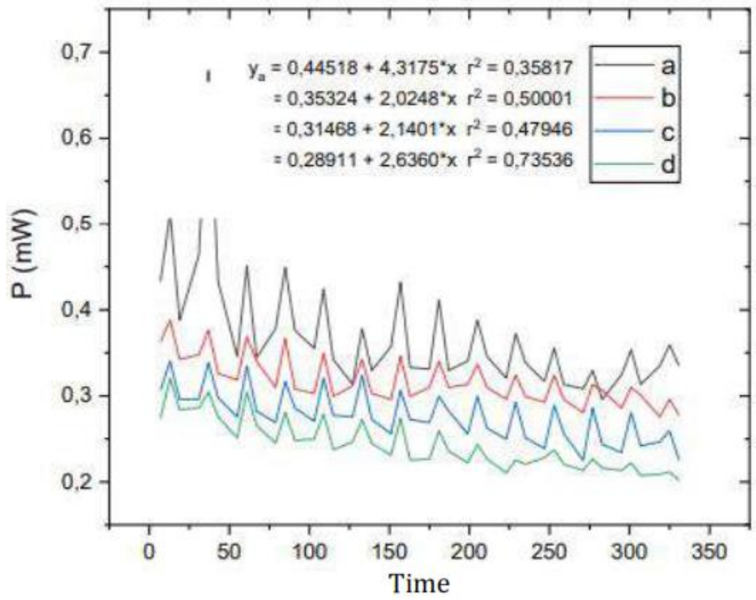

Figure 4. Electrical power obtained by PMFC located outdoors for 331 hours

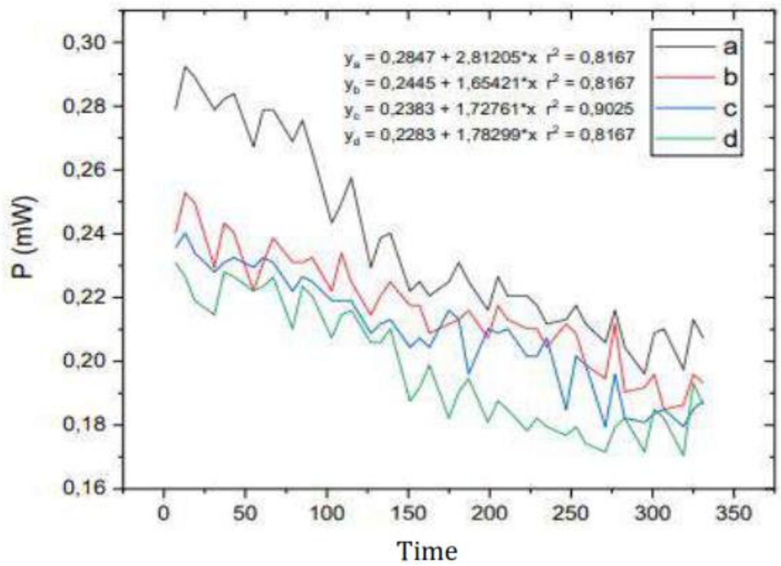

Figure 5. Electrical power obtained by PMFC located indoors for 331 hours

3.2 Effect of pH and Dissolved Oxygen (DO) on PMFC

Overall, the pH value has little effect on the electrical power produced by the PMFC. pH measurements tend to produce values that are not significantly different or stable, with the highest increase or decrease in pH being 7.8 and the lowest pH being 6.8. Therefore, the range of pH values produced in the study is an average of 7 or nearly neutral. Neutral pH causes the process of proton and electron exchange at the electrode to be less optimal, so the change or decrease in the voltage, current, and electric power value is insignificant (Tang et al., 2014).

Dissolved oxygen (DO) is one of the components needed for plant growth processes that function for aerobic respiration around the roots. Dissolved oxygen is used as an Oxygen Reduction Reaction (ORR) to bind protons and electrons at the cathode. The transfer of electrons from the anode to the cathode can cause a voltage and electric current (Rosyadi et al., 2017). The highest average dissolved oxygen levels were recorded on the initial day of data collection. This occurrence maximizes the proton and electron transfer processes, thereby leading to increased voltage, current, and electrical power generation by the Proton Exchange Membrane Fuel Cell (PMFC). A decrease in oxygen levels can occur because the oxygen dissolved in the water is used for the proton and electron transfer process by the EAB that occurs around the electrode (Puspitaningrum et al., 2012). The effect of pH and dissolved oxygen level on PMFC is shown in the graph in **Figure 6** and **Figure 7**.

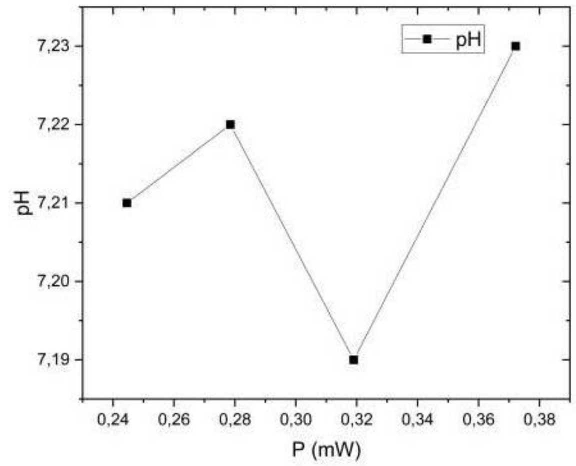

Figure 6. Effect of pH on PMFC Located Outdoors

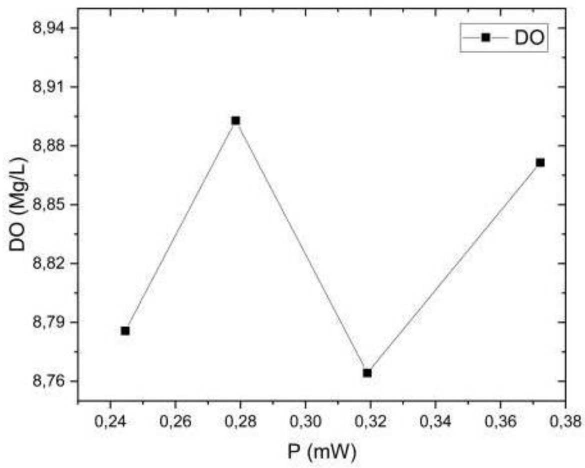

Figure 7. Effect of Dissolved Oxygen (DO) on PMFC Located Outdoors

3.3 Effect of Corrosion Rate on Electrodes

Research on PMFC also measured the corrosion rate experienced by Cu and Zn electrodes. After being used in the research period, the Cu and Zn electrodes undergo a corrosion process characterized by a slightly thinned and blackened electrode shape. Corrosion is one of the main problems affecting the decrease in electrical power output Corrosion. It can cause a decrease in the quality and strength of a material (Kamalia et al., 2018). Based on the use of electrodes on the PMFC during the study, data in electrode mass changes can be measured during the study. Research has produced different values of change in electrode mass. The mass of the electrode changes due to the chemical reaction between the electrode and the electrolyte (Fauzi et al., 2021). After getting the final mass, the mass loss (M) can be calculated by equation 1. The values of initial, final mass and mass loss of Cu and Zn electrodes in this study can be seen in **Table 3**.

Table 3. Electrode Mass Measurement

Reactor	Before Used		After Used	
	Mass Cu (g)	Mass Zn (g)	Mass Cu (g)	Mass Zn (g)
1	55	55	40	45
2	55	55	40	45
3	55	55	40	45
4	55	55	40	45

The result of calculating the corrosion rate that occurs on Cu and Zn electrodes can be seen in **Table 4**.

Table 4. Corrosion Rate Elektrodes

Reactor	M (g)		d (g/cm^3)		A (cm^2)		t	CR (mm/years)	
	Cu	zn	Cu	zn	Cu	zn		Cu	zn
1	15	10	8.96	7.14	600	600	672	0.3637	0.3034
2	15	10	8.96	7.14	600	600	672	0.3637	0.3034
3	15	10	8.96	7.14	600	600	672	0.3637	0.3034
4	15	10	8.96	7.14	600	600	672	0.3637	0.3034

4. Conclusions

Based on the study's results, it is known that PMFC made from water hyacinth is influenced by the distance of the electrodes and the conditions of exposure to sunlight. The highest electrical power was obtained at about 0.6789 mW at a distance of 3 cm, and the PMFC was placed outdoors (exposed to sunlight). The corrosion rate on the electrodes for 28 days of use is 0.3637 mm/year for the Cu electrode and 0.3034 mm/year for the Zn electrode.

5. Bibliography

Hendrawan, M. A. (2020). Pengaruh Jenis Elektroda, Jarak Anoda-Katoda, dan Waktu Pertumbuhan Tanaman Eceng Gondok (Eichhornia Crassipes) Pada Teknologi Plant Microbial Fuel Cell (P-MFC). Skripsi. Universitas Pertamina. Jakarta.

Kadhafi, M. (2020). Studi Potensi Energi Listrik Dari Plant Microbial Fuel Cell (P-Mfc) Dengan Variasi Jenis Elektroda. Skripsi. Universitas Alauddin Makassar. Makassar.

Kamalia, L., Pauzi G. A., & Suciyati S. W., (2018). Analisis Laju Korosi Elektrode Bahan Cu-Zn dengan Metode *Sacrificial Anode* Pada Sistem Energi Listrik Alternatif Berbasis Air Laut. *Jurnal Teori dan Aplikasi Fisika*. Vol. 06. No. 02. Hal 249-255.

Mahadevan, A., Gunawardena, D. A., & Fernando, S. (2014). Biochemical and Electrochemical Perspectives of the Anode of a Microbial Fuel Cell. *Technology and Application of Microbial Fuel Cells*. InTech. https://doi.org/10.5772/58755

Maheshwari, K., Sharma., S.,Sharma, A.K., & Verma, S. (2018). Fuel Cell and Its Applications: A Review. *International Journal of Engineering Research & Technology (IJERT)*. Vol. 7. No. 6. Hal 6–9.

Novelendah, L., Senoaji, M. H., Sinurat, F., Musthofa, A. M. H., & Istirokhatun, T. (2018). Potensi Listrik Dan Degradasi Fosfat Berteknologi Plant Microbial Fuel Cell Dengan Media Tanaman Eceng Gondok. *Prosiding SEMNASTEK*. Vol. 17. Hal 16.

Prasad, J., & Tripathi, R. K. (2018). Plant Microbial Fuel Cell Energy Harvesting Boost Converter with/without the supercapacitor. *Majlesi Journal of Mechatronic Systems*. Vol. 7. No. 4. Hal 7-13.

Puspitaningrum, M., Izzati, M., & Haryanti, S., (2012). Produksi dan Konsumsi Oksigen Terlarut Oleh Beberapa Tumbuhan Air. *Buletin Anatomi dan Fisisologi*. No 1. pg 47-55.

Putranto, A. W., Sugiarto, Y., Kusumarini, N., & Wiranti, T. (2018). Pengaruh Pemberian Pupuk Urea Dan Jarak Elektroda Terhadap Tegangan Listrik Plant Microbial Fuel Cell Tanaman Padi (Oryza Sativa). *Jurnal Teknologi Pertanian*. Vol. 19. No. 1. Hal 43–50.

Rosyadi. F.A., Laily, E.N., Sitoresmi, S., & Yushardi. (2017). Pemanfaatan Alga Hijau Sebagai Biokatoda Pada PMFC (*Photosynthetis Microbial Fuel Cell*). *Jurnal Teknik Kimia*. Vo. 12. No. 1. Hal. 4–8.

Tang, J., Liu, T., Yuan, Y., & Zhuang, L. (2014). Effective Control of Bioelectricity Generation from a Microbial Fuel Cell by Logical Combinations of pH and Temperature. *The Scientific World Journal*. Hal. 1–7. https://doi.org/10.1155/2014/186016