Available *online* at : http://jnte.ft.unand.ac.id/

Jurnal Nasional Teknik Elektro

| ISSN (Print) 2302-2949 | ISSN (Online) 2407-7267 |

The Study of Plant Microbial Fuel Cell for Alternative Energy Source

Melda Latif, Paskalina Aprila Tiy, Mumuh Muharam, Aulia, Amirul Luthfi

Departemen of Electrical Engineering, Universitas Andalas, Kampus Unand Limau Manih, Padang, 25163, Indonesia

ARTICLE INFORMATION

Received: November 23, 2022
Revised: June 23, 2023
Accepted: June 24, 2023
Available online: June 29, 2023

KEYWORDS

P-MFC, anode, cathode, humus soil

CORRESPONDENCE

Phone: +6281374102277
E-mail: melda_latif@eng.unand.ac.id

A B S T R A C T

The new and renewable energy technology MFC (Microbial Fuel Cell) is quite promising to produce electrical energy. However, MFC requires expensive nutrients such as glucose and maltose for the microbes to be active to produce electrons. Another weakness of MFC is its very short lifespan for electricity production, which is approximately around 10 days. To overcome this, P-MFC (Plant-Microbial Fuel Cell) technology was developed where nutrients for microbes are provided through humus for plants. To determine microbial activity, the research method was carried out with P-MFC using humus plus EM4 and variations in the number of Water Spinach, namely 20 and 25 stems. The values of voltage, current and electrical power of the P-MFC are measured for a period of an hour per day with the P-MFC circuit being loaded and without load. The results showed that 25 stems of Water Spinach have more microbial activities than 20 stems of Water Spinach. The 25 stems P-MFC produced 762.4 mV no-load average voltage and 125.8 mV, 085 mA for load condition, and the 20 stems produced 527.2 mV no-load average voltage and 58.94 mV, 0.28 mA for load condition. The result shows that the more stems of Water spinach more the activities of microbes.

INTRODUCTION

Renewable energy is the trend nowadays. The research about it is developed. The character of renewable energy is safe, renewable, and environmentally friendly. There are some sources of renewable energy that are used by humans as electrical energy for life necessities in the world. The annual growth of solar PV still dominates and is followed by wind, bioenergy, and hydropower [1]. Solar PV and wind turbines can be said they are established. The manufacture of Solar PV and wind turbine are always ready to sell in the market. The manufacture of electrical devices from bioenergy is still less in the world, but the research to develop bioenergy into electrical energy still continues.
MFC is one of the examples of bioenergy that has been extensively researched because MFC provides a solution for electricity production. There are several aspects of MFC that represent its weaknesses. Firstly, the use of substrates as food for microorganisms can be very expensive, such as glucose [2-3] and maltose [4]. Secondly, MFC has a very limited lifespan, approximately around 10 days [5]. Recently, to address these weaknesses, researchers have developed Plant-Microbial Fuel Cell (P-MFC).

The P-MFC is a fascinating technology that harnesses the natural processes of plants and microorganisms to produce electricity. It is a sustainable and eco-friendly way of generating power, where living plants and tiny microbes work together to provide energy without the need for traditional fuels. In P-MFC, there are three main aspects: the plant, the microbes, and the production of electrons. These three components work together to generate electricity through the natural interactions between plants and microorganisms. Research on P-MFC has explored various types of plants as potential candidates for electricity generation. Aquatic plants such as Spartina Anglica and Marine Plants [6-7], as well as terrestrial plants like Cordyline Fruticosa [8], Rice Oryza Sativa [9-11], and Physcomitrella patens [12], have been studied. These studies aim to understand the efficiency and effectiveness of different plant species in enhancing electricity production through the interaction with microorganisms in P-MFC.

P-MFC can be designed in two main configurations: dual-chamber or single-chamber. For dual chambers, there are two separate chambers: the anode chamber and the cathode chamber. These chambers are connected through a selectively permeable membrane or a salt bridge. The membrane allows the transfer of ions between the two chambers while keeping the microorganisms physically separated. The plant and microbes reside in the anode chamber, where the organic matter from the plant is broken down by microorganisms to release electrons. The electrons then flow to the cathode chamber, where they react with oxygen to produce water, completing the electric circuit. For single chamber, both the anode and cathode are placed in the same chamber. There is no physical barrier between the anode and cathode; instead, they are separated by a distance or a

https://doi.org/10.25077/jnte.v12n2.1061.2023

separator that allows the flow of ions. The plant and microbes still function in the same way, with the microorganisms breaking down the organic matter from the plant, and the electrons move to the cathode to produce electricity. Researchers have explored both dual-chamber and single-chamber methods in P-MFC to study their efficiency, simplicity, and ease of operation. Each design has its advantages and disadvantages, and ongoing research aims to optimize these configurations for various applications and settings.

The shape of the chamber in P-MFC can vary based on the specific research and application. First, Tubular and Flat-Plate Chambers, many researchers, as mentioned in reference [6], have experimented with different chamber shapes, such as tubular and flat-plate configurations. These chambers can be made of various materials and are designed to accommodate the plant and microorganisms while providing efficient electron transfer. The chambers are connected using a membrane to allow ion exchange between the anode and cathode compartments. Second, Field Applications, P-MFC can be implemented in real-world environments, such as fields. As described in reference [11], researchers installed tubular P-MFCs in a Paddy Field, which is a flooded field used for rice cultivation. This application demonstrates the potential of P-MFC to generate electricity in natural settings, even in agricultural areas. The versatility of P-MFC in terms of chamber shape and the ability to deploy them in real-world scenarios highlights their potential as a sustainable and eco-friendly approach to electricity generation, especially in remote or agricultural areas. Continued research and experimentation will help refine and optimize P-MFC designs for practical applications in various settings.

Electrode materials play a crucial role in the efficiency and performance of P-MFC. Various types of electrode conductors have been studied for their effectiveness in facilitating the electrolysis process and electron transfer in P-MFCs. Here are some commonly used electrode materials. They are Teflon-coated copper wire [6], graphite [7, 10, 13], titanium wire [8], spiral copper and Zinc mesh [9], and Carbon [12]. The selection of the appropriate electrode material depends on factors like cost, conductivity, durability, and the specific application of the P-MFC. Researchers continue to explore different electrode materials to improve the performance and practicality of P-MFC for sustainable electricity generation.

In this paper, the research objective is to develop a P-MFC that generates electrical energy with a long lifespan and utilizes affordable materials. The P-MFC has a dual chamber that used a salt bridge as a substitute for membrane and water spinach for its plant. For growing media plants and microbes, humus soil is chosen. A carbon conductor is used for electrodes in this P-MFC.

METHOD

The important parts of a Plant-Microbial Fuel Cell are plant, humus soil, anode, catalyst, cathode, salt bridge, chamber, load and measuring instrument. The plant is used in this research is water spinach. Water spinach is favorite vegetable in Indonesia. It lives in watery land or moist soil.

The first step of experiment, water spinach nursery is done. The figure 1 is shown nursery of water spinach for two weeks.

Figure 1. Nursery of plants

After two weeks water spinach sprouts are ready to be planted at anode chamber in P-MFC. The number of water spinach is 20 and 25 at each of the two P-MFCs.

Figure 2 shows the design of dual chamber P-MFC had done. The salt bridge is connected between the anode chamber and the cathode chamber. In the anode chamber, was displaced anode rod, humus soil, and water spinach. In the cathode chamber was displaced cathode rod and potassium permanganate solution. An amperemeter and voltmeter are used to measure the current and voltage generated by the P-MFC.

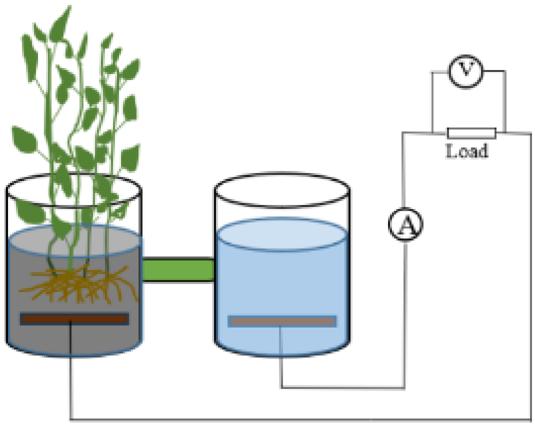

Figure 2. Dual Chamber P-MFC

To find more microbes, the humus soil is used. Humus soil is soil that has organic content as habitat for soil-fertilizing microorganisms, so that the soil is rich in nutrients needed by plants. The color of this soil is black, comes from burning organic wastes.

Microbes that live in humus soil as a group of plants (flora) include bacteria, fungi, algae and actinomycetes. Called flora because it has characteristic as plants that can carry out photosynthesis. The most abundant in the soil is bacteria.
In 1 gram of soil can be found about 109 bacteria. Some names of bacteria in the soil include Pseudomonas, Agrobacterium, Flavobacterium, Bacillus, Clostridium and Rhizobium. Bacteria can grow rapidly until the food material around them runs out. Bacteria can also live in an environment lacking in oxygen or are facultative aerobes [16].

https://doi.org/10.25077/jnte.v12n2.1061.2023

To increase the number of microbes, a solution of EM4 (Effective Microorganism-4) is added to the anode chamber [17]. The content of EM4 is fermented bacteria where if the solution is mixed into humus soil, it will add soil nutrients so that it will increase the number of microbes.

To maintain microbes in the soil, the experiment did under sunlight. Sunlight helps the plant in the photosynthesis process. Photosynthesis is a chemical process from sunlight to plants that will produce food (glucose) for plants and microbes around plant roots.

The chemical reactions in the anode chamber and cathode chamber can be seen in equations 1 and 2 [18]. From equation (1), microbes carry out activities from food and water originating from plant roots and humus soil nutrients to produce carbon dioxide, hydrogen ions and electric charges.

$$2C_6H_{12}O_{12} + 12H_2O \rightarrow 12CO_2 + 48H^+ + 48e^- \quad (1)$$

$$12O_2 + 48H^+ + 48e^- \rightarrow 24H_2O \quad (2)$$

The electric charge flows from the anode to the cathode through the load resistor, while the hydrogen ions (positive charge) pass through the salt bridge to the cathode chamber. The flow of electron ions from the anode to the cathode and positive ions through the salt bridge is known as electrolysis.

A salt bridge is a bridge filled with material through which positive charges can pass. The salt bridge is a substitute for the membrane. The materials used for the salt bridge are jelly, distilled water, NaCl, and HCl. All of these ingredients are mixed by cooking and put into the bridge mold until it hardens. After hardening a bridge is installed between the anode and cathode vessels.

The electrode used at the anode and cathode are carbon rods with a diameter of 10 mm and a weight of 12.98 grams. The advantages of using carbon include being easy to obtain, insoluble, and cheap. The form of carbon used can be seen in Figure 3.

Figure 3. Carbon for electrode

The chemical processes that occur in the cathode chamber can be seen in equation (3). In this chamber, potassium permanganate is mixed with salt and water. KMnO4 is an oxidizing agent and NaCl is a reducing agent from a redox reaction. A redox reaction can be defined as a chemical reaction in which electrons are transferred between two reactants involved.

$$2KMnO_4 + 6NaCl + 4H_2O \rightarrow 2MnO_2 + 6NaOH + 2KOH + 3Cl_2 \quad (3)$$

The material specifications of the P-MFC used can be saw in Table 1. In this table, experiment 1 is a P-MFC experiment for 20 stems, and experiment 2 is for 25 stems of water spinach.

Table 1. Specification of dual chamber P-MFC

Parameter	Specification
Chamber size	Heigh = 8 cm Width= 6,7 cm Volume = 359,12 cm^3
Electrode diameter/weight	10 mm^2/12,98 gr
Cable area	2 mm^2
Salt bridge size	Length = 5 cm
Water spinach age	65 days
Water spinach weight	20 stems= 45,25 gr 25 stems = 48,23 gr
Humus soil weight	1,8 kg
H2O volume/chamber	100 ml
Jelly/ aquades/HCl	5 gr/ 200 ml/ a half tea spoon
EM4 volume in anode chamber	Experiment 1: 70 ml Experiment 2: 90 ml
Carbon Conductor size	8 mm x 30 mm

Figure 4 shows a Plant Microbial Fuel Cell (P-MFC) with water spinach planted in the anode chamber (Component 2). Bacterial metabolism oxidizes organic matter from the water spinach, releasing protons and electrons. The electrons move towards the cathode chamber (Component 1) via the jumper wires (Components 4 and 5), while protons migrate through the salt bridge (Component 3). In the cathode chamber, oxygen reacts with protons to form water, completing the electric circuit. Essentially, this P-MFC harnesses the symbiotic relationship between water spinach and bacteria, generating electricity from bacterial metabolism.

Figure 4. The prototype of P-MFC.

RESULTS AND DISCUSSION

Plant MFC research was carried out with two variations, namely using 20, and 25 stems of water spinach. The measurement results from the P-MFC are the voltage and current measured using a multimeter.

No-load (Voc), load voltage, and load current measurements were carried out for 24 hours for about 10 days. Figures 5, 6, and 7 represent the data of average measurements taken over a period of 10 days. Figure 5 is the PMFC no-load voltage curve with 20 and 25 water spinach stems. The no-load stress on the P-MFC with 25 water spinach stems increased in a straight line, whereas with 20 water spinach stems it decreased in a wavy manner.

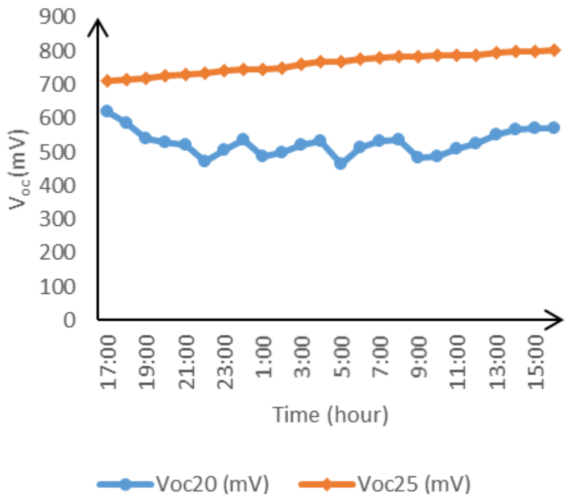

Figure 5. The P-MFC No-Load Voltage

With a large number of water spinach planted, the number of bacteria that live will be more. The average no-load voltage of P-MFC with 25 water spinach stems is 762.4 mV and with 20 water spinach stems is 527.2 mV.

For load conditions, the load voltage can be seen in Figure 6. The load used is a 300-ohm resistor.

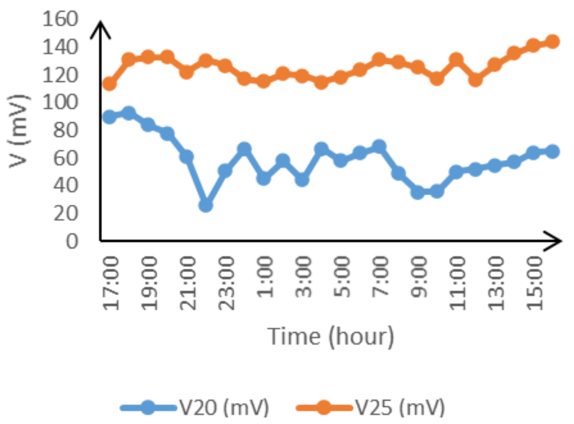

Figure 6. The P-MFC Load Voltage.

In Figure 6, the load voltage generated by the P-MFC with 25 water spinach stems has a greater value than 20 water spinach stems. The average load voltage with 25 stems of water spinach is 125.8 mV and with 20 stems is 58.94 mV.

The current flowing in the resistor with 20 stems and 25 stems of water spinach can be seen in Figure 7. The graph of the P-MFC load current with 25 stems of water spinach increases when the current is measured for 24 hours, while with 20 sems of water spinach, the graph of the current fluctuates with the final value remaining the same. The average current with 25 stems of water spinach is 0.58 mA and with 20 stems is 0.28 mA.

From Figures 5, 6, and 7, it can be seen that the number of bacteria with 25 stalks of water spinach is more than 20 stems of water spinach. This is proven by the magnitude of the voltage and current generated with 25 stems of water spinach which is greater than 20 stems. The graph fluctuates due to the lifetime and death time of bacteria in the P-MFC. However, the food for the microbes is consistently supplied by plants through photosynthesis, ensuring the stability of electrical energy production.

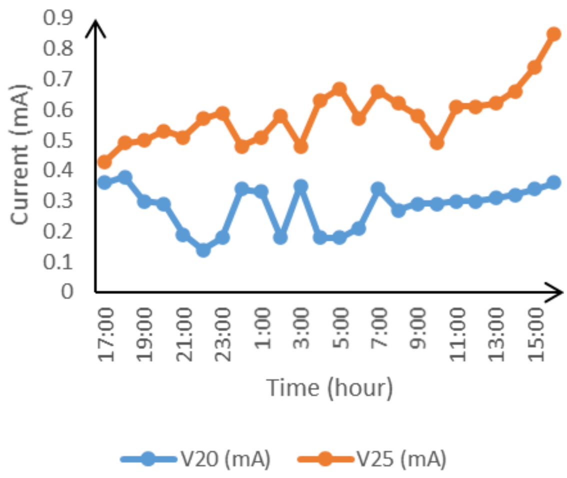

Figure 7. The P-MFC Load Current

From the results of this study, it is evident that the P-MFC has a better and more stable lifespan compared to MFC as reported in reference [3]. In the previous study [3], the electricity production in MFCs tended to decrease and even deplete from the first day until day 10. This result is consistent with the findings of reference [19], which indicated that the major drawback of these technologies was the rapid utilization of substrate by the microbes to generate power. Similarly, reference [20] states that P-MFC is a promising modification of MFC that leverages the unique plant-microbe rhizosphere region of a plant and converts solar energy into bioelectricity.

However, in this recent study, the P-MFC demonstrated superior performance by increasing the number of water spinach plants. Using 25 water spinach stems in the P-MFC resulted in higher voltage and current compared to using 20 water spinach stems. This indicates that the P-MFC exhibits better stability and longevity in electricity production, possibly due to a better supply of food for the microbes through photosynthesis from the increased number of water spinach plants.

The use of dual chambers with a salt bridge, water spinach as the plant, and humus soil as the growing media for plants and microbes indicates a comprehensive study on enhancing P-MFC performance. The choice of carbon as the electrode conductor further highlights the focus on maximizing electrical conductivity.

https://doi.org/10.25077/jnte.v12n2.1061.2023

CONCLUSIONS

The number of water spinach plants has a direct impact on the voltage and current generated by the P-MFC. Increasing the number of water spinach plants on the P-MFC leads to higher voltage and current production. Here are the specific measurements from the study P-MFC with 25 water spinach stems: No-load average voltage 762.4 mV, Load average voltage (using a 300-ohm load resistor) 125.8 mV, Average current 0.58 mA. P-MFC with 20 water spinach stems: No-load average voltage 527.2 mV, Load average voltage (using a 300-ohm load resistor) 58.94 mV, and average current 0.28 mA. The results show that having 25 water spinach stems on the P-MFC results in higher voltage and current output compared to having 20 water spinach stems.

Another result of this study is that the lifespan of the P-MFC is quite long and stable, even though inexpensive materials are used in its construction.

ACKNOWLEDGMENT

This work was supported by Electrical Engineering Department, Universitas Andalas, Padang, Indonesia under contract No. 14/UN.16.09.D/PL/2022.

REFERENCES

[1] International Energy Agency, "Global Energy Review 2020, The impacts of the Covid-19 crisis on global energy demand and CO_2 emissions," July 2020.

[2] J. C. Biffinger, J. Pietron, R. Ray, B. Little and B.R. Rinfeisen, "A biofilm enhanced miniature microbial fuel cell using *Shewanella uneidensis* DSP10 and oxygen reduction cathodes," Biosensors and Bioelectronics, vol. 22: 1672-1678, 2007.

[3] E. Purwati, M. Latif, H. Purwanto, dan O. Andrean. "Inovasi Energi Terbarukan dari Perancangan Prototipe Microbial Fuel Cell Tipe Seri, Pararel dan Seri-Pararel dengan memanfaatkan Bakteri Escherichia Coli," Majalah Ilmiah Dinamika, 40(1): 132141, 15 Februari 2014.

[4] F. Z. Fitriani, L. Suyati, dan W. H. Rahmanto. "Pengaruh Konsentrasi Substrat Maltosa terhadap Potensial Listrik Baterai Lactobacillus bulgaricus (MFC)," Jurnal Kimia Sains dan Aplikasi, 20(2): 74-78, 2017.

[5] L. Jessica." An Experimental Study of Microbial Fuel Cells for Electricity Generating: Performance Characterization and Capacity," Journal of Sustainable Bioenergy Systems, 2013,3, 171-178. http://dx.doi.org/10.4236/jsbs.2013.33024

[6] R. A. Timmers, D. P. B. T. B. Strik, H. V. M. Hamelers and C. J. N. Buisman, "Long-term Performance of a plant microbial fuel cell with Spartina anglica," Appl Microbiol Biotechnol (2010) 86:973–981.

[7] M. Helder, D. P. B. T. B Strik, H. V. M Hamelers and C. J. N. Buisman, "The flat-plate plant-microbial fuel cell: the effect of a new design on internal resistances," Biotechnology for Biofuels 2012, 5:70, http://www.biotechnologyforbiofuels.com/content/5/1/70.

[8] T. Mulyono, Misto, Busroni and Siswanto. "Bioelectricity Generation From Single-Chamber Microbial Fuel Cells With Various Local Soil Media and Green Bean Sprouts as Nutrient," Int. Journal of Renewable Energy Development, vol. 9, no. 3, pp. 423-429, 2020

[9] E. O. de la Rosa, J. V. Castillo, M.C. Campos, G.R. B. Pool, G. B. Nuñez, A. C. Atoche and J. O. Aguilar, "Plant Microbial Fuel Cells–Based Energy Harvester System for Self-powered IoT Applications," Sensors, vol. 19, no. 1378, 2019, doi:10.3390/s19061378, [Online], Available: http:// www.mdpi.com/journal/sensors, [Accessed Aug. 8, 2022]

[10] Y. Goto, N. Yoshida1,Y. Umeyama, T. Yamada, R. Tero and A. Hiraishi," Enhancement of electricity production by graphene oxide in soil microbial fuel cells and plant microbial fuel cells," Frontiers in Bioengineering and Biotechnology, vol. 3, article-42, April 2015, doi: 10.3389/fbioe.2015.00042, [Online], Available: https://www.frontiersin.org/journals/bioengineering-and-biotechnology, [Accessed Aug.8, 2022]

[11] E. Sudirjo, P. de Jager, C.J.N. Buisman and D.P.B.T.B. Strik, "Performance and Long Distance Data Acquisition via LoRa Technology of a Tubular Plant Microbial Fuel Cell Located in a Paddy Field in West Kalimantan, Indonesia," Sensors, vol. 19, no. 447, 2019, doi:10.3390/s19214647, [Online], Available: http:// www.mdpi.com/journal/sensors, [Accessed Aug. 8, 2022]

[12] P. Bombelli, R. J. Dennis, F. Felder, M. B. Cooper, D. M. R. Iyer, J. Royles, S. T. L. Harrison, A. G. Smith, C. J. Harrison, and C. J. Howe, "Electrical output of bryophyte microbial fuel cell systems is sufficient to power a radio or an environmental sensor," Royal Society Open Science, vol. 3: 160249, 2016, http://dx.doi.org/10.1098/rsos.160249 [Online], Available:: https://royalsocietypublishing.org/, [Accessed August 7, 2022]

[13] K. Wetser, K. Dieleman, C. Buisman and D. Strik, "Electricity from wetlands: Tubular plant microbial fuels with silicone gas-diffusion biocathodes," Applied Energy, vol. 189, pp. 642-649, 2017, [Online] Available: http://dx.doi.org/10.1016/j.apenergy.2016.10.122

[14] D. P. B. T. B. Strik1, H. V. M. Hamelers (Bert), J. F. H. Snel and C. J. N. Buisman," Green electricity production with living plants and bacteria in a fuel cell," International Journal Of Energy Research, 2008, [Online], Available: www.interscience.wiley.com, DOI: 10.1002/er.1397

[15] A.R. P.Hidayat, A. R. Widyanto, A. Asranudin, R. Ediati, D. O. Sulistiono, H. S. Putro, D. Sugiarso, D. Prasetyoko, A. S. Purnomo, H. Bahruji, B. T. I. Ali and Irmariza Shafitri Caralin, "Recent development of double chamber microbial fuel cell for hexavalent chromium waste removal," Journal of Environmental Chemical Engineering, vol. 10, 107505, 2022, [Online], https://www.elsevier.com/locate/jece, [Accessed Sept. 27, 2022]

[16] Yulipriyanto, "Mikroorganisme Tanah Sebagai Sumber Belajar Mikrobiologi Dan Sumbangannya Bagi Manusia, "Cakrawala Pendidikan No.1, Tahun IX, Februari 1990. [Accessed Oct. 10, 2022]

[17] M. Latif, A. D. Fajri dan M. Muharam, "Penerapam Sampah Buah Tropis untuk Microbial Fuel Cell," Jurnal Rekayasa Elektrika Vol. 16, No. 1, hal. 1-7, April 2020, DOI: 10.17529/jre.v16i1.15723, [Online], Available: https://jurnal.unsyiah.ac.id/JRE/article/view/15723

[18] R. Shaikh, A. Rizvi, M. Quraishi, S. Pandit, A. S. Mathuriya, P. K. Gupta, J. Singh and R. Prasad," Bioelectricity production using plant-microbial fuel cell: Present state of

art," South African Journal of Botany 140 (2021) 393_408. [Online]. Available: https://www.elsevier.com/locate/sajb [Accessed Oct. 06, 2022].
[19] S. Maddalwar, K.K. Nayak, M. Kumar, and L. Singh, "Plant microbial fuel cell: Opportunities, challenges, and prospects," Bioresource Technology, vol. 341, (2021) 125772
[20] R. Nitisoravut and R. Regmi," Plant microbial fuel cells: A promising biosystems engineering," Renewable and Sustainable Energy Reviews, 76, (2017), 81–89

https://doi.org/10.25077/jnte.v12n2.1061.2023