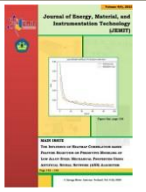
JOURNAL OF ENERGY, MATERIAL, AND INSTRUMENTATION TECHNOLOGY

Journal Webpage https://jemit.fmipa.unila.ac.id/



The Microbial Fuel Cell Characteristics of the PVA/Chitosan Membrane with Variations of Phosphate Acid and Sodium Alginate Derived from Vegetable Waste

Iqbal Adi Nugraha, Amir Supriyanto*, Gurum Ahmad Pauzi, and Junaidi

Department of Physics, University of Lampung, Bandar Lampung, Indonesia, 35141

Article Information

Article history:
Received April 26, 2022
Received in revised form May 25, 2022
Accepted November 2, 2023

Keywords: *electrical energy, PVA/Chitosan, microbial fuel cell*

Abstract

Microbial Fuel Cell (MFC) is one of the alternative energy sources as a producer of vegetable waste. The membrane that is commonly used in the MFC system is the Nafion membrane, but it is expensive and must be imported. PVA membrane and chitosan are an alternative substitute for Nafion membrane. The purpose of this study was to determine the electrical performance of variations of PVA/Chitosan membrane with the addition of sodium alginate or phosphoric acid. The study used a dual chamber MFC system made of acrylic with a volume of ±250 ml for each compartment. The anode compartment contains vegetable waste with carbon electrodes, and the cathode compartment contains seawater electrolytes with Cu(Ag) electrodes. The MFC system consists of 10 cells in series. From the study results, it was concluded that the vegetable waste substrate with the addition of EM4 bacteria could be used as an alternative energy source. The use of variations on the PVA/Chitosan membrane without addition produces the highest maximum voltage level of 2.25 volts compared to the addition of sodium alginate or phosphoric acid of 2.25 volts, 1.941 volts, and 2.1 volts.

Informasi Artikel

Proses artikel:
Diterima 26 April 2022
Diterima dan direvisi dari 25 Mei 2022
Accepted 2 November 2023

Kata kunci: *energi listrik, PVA/kitosan, microbial fuel cell*

Abstrak

Microbial Fuel Cell (MFC) merupakan salah satu sumber energi alternatif sebagai penghasil energi listrik dan dapat berasal dari limbah sayur. Membran yang umum digunakan pada sistem MFC yaitu membran nafion, tetapi harganya mahal dan harus import. Membran PVA dan kitosan merupakan alternatif sebagai pengganti membran nafion. Tujuan penelitian adalah untuk menentukan kinerja elektrisitas variasi membran PVA/kitosan dengan penambahan sodium alginat atau asam fosfat. Penelitian dilakukan dengan menggunakan sistem MFC dual chamber yang terbuat dari akrilik dengan volume masing-masing kompartmen ±250 ml. Kompartmen anoda berisi limbah sayur dengan elektroda karbon dan kompartmen katoda berisi elektrolit air laut dengan elektroda Cu(Ag). Sistem MFC terdiri atas 10 sel yang dirangkai seri. Dari hasil penelitian diperoleh kesimpulan bahwa substrat limbah sayur dengan penambahan bakteri EM4 dapat dijadikan salah satu sumber energi alternatif dan penggunaan variasi pada membran PVA/kitosan tanpa penambahan menghasilkan tingkat maksimum tegangan tertinggi yaitu sebesar 2,25 volt dibandingkan dengan penambahan sodium alginat atau asam fosfat sebesar 1,941 volt dan 2,1 volt.

1. Introduction

The materials after the end of a process are called garbage. A material can be considered garbage by seeing the level of construction. Organic waste includes the type of garbage according to its nature or organic waste, namely logging waste, wood industrial waste, waste of the law, or market waste such as vegetables. Waste is a cultural problem due to its impact on various sides of life (Sudrajat, 2007). Vegetable waste is one type of organic waste; this type is very easy to find in Indonesia or vegetable-producing countries (Imaduddin et al., 2014).

This vegetable or organic waste is usually processed by composting. However, this composting process can have an environmental impact, such as an asympidency in the environment that occurs at the final disposal site. In addition to using the composting process, the result of vegetable waste metabolism with the help of microorganisms

* Corresponding author.
E-mail address: amir.supriyanto@fmipa.unila.ac.id

can be utilized for microbial fuel cells (MFC), so they can generate electrical energy from various organic wastes (Akbar et al., 2017). The basic principle of MFC is equal to typical fuel cells unless the source of electrons, the electrons on the MFC, comes from the oxidation of organic compounds by microbial (Ismawati et al., 2015).

MFC technology utilizes the microorganisms in nature by changing organic material into electrical energy. The nature of bacteria that can oxidize organic substances in MFC produces electron ions and protons, which will result in electrical potential differences so that the power of energy is generated. Generally, MFC uses two spaces separated by separators as a place of proton exchange and two electrodes as a place of electron exchange (Purnama et al., 2020).

The use of variations of membrane, waste, and bacteria against MFC has been studied. Based on research by Ibrahim et al. (2017) on the performance of MFC in the processing of liquid waste of the loading with the misinterpretation of the mixture of the PVA/Chitosan polymer. The membrane variation in the study used PVA/Chitosan composition 2: 3, 1: 1, 3: 2, and non-separators by testing the characteristics in membrane variations, as well as the MFC membrane analysis was also conducted in the study. Protons flow into cathodes through the membrane, and the electrons will stick in the anode and then flow through an external circuit or electrode (Ali & Widodo, 2019).

In this study, the membrane performance analysis was required in PVA/Chitosan with the addition of sodium alginate and phosphate acid and the membrane immersion method with the help of stearic acid polymer as hydrophobic material on the membrane. This soaking method was conducted by Liu et al. (2020) with the analysis of the use of stearic acid as a sponge-producing material for oil and water separators.

2. Research Methods

The tools and materials used in this research are acrylic 3mm mold with size 8 cm × 8 cm × 11 cm, connecting cable, pipe, 2.5mm Cu fiber, Ag as carbon Cu coat, martial separator, sea water-electrolyte, vegetable waste, embracive bacteria, multimeter, camera, and timer. The materials used to create the membrane include PVA, chitosan, sodium alginate, phosphate acid, stearic acid, 70% alcohol, Aquades, HNO3, and NaOH. This research was conducted in several stages, namely the process of design of the MFC tool, electroplating Ag on Cu, manufacture of membranes, membranes insertion, and system of data retrieval tests.

2.1. The design of MFC

The MFC tools are designed with a dual chamber method consisting of cathode compartments and anodes. The design of MFC uses acrylic as a material for manufacturing the chamber that is formed into a rectangle with a size of 8 cm × 8 cm × 11 cm and a thickness of 2 mm. MFC uses electrode (Cu(Ag)-C) in the manufacture of Cu(Ag) electrodes using the electroplating method. Then, the two-chamber is separated using the Chitosan separator as a place of proton exchange. The MFC system can be seen in **Figure 1**.

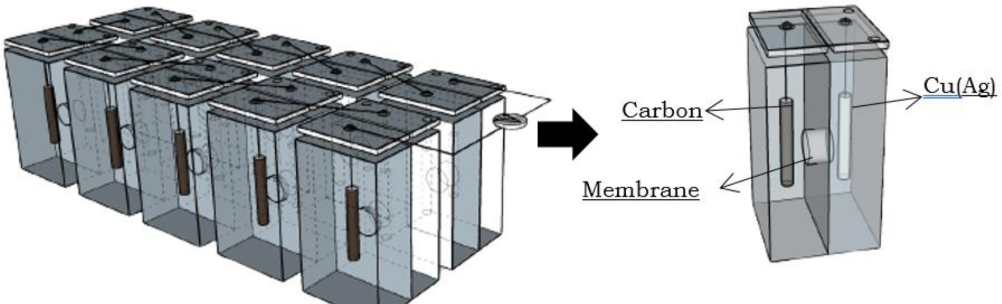


Figure 1. Design of MFC

In **Figure 1**, it can be seen that the MFC system uses ten samples and is connected in series to be measured by voltage using a multimeter. Electrica Cu(AG) size is 7 cm × 4 cm, and carbon has a long 7 cm and diameter of 0.8 cm.

2.2. Electroplating Cu(Ag)

The electroplating agent of the Ag on Cu is done by using a silver pulled ($AgNO_3$) 0.02 m to 300 ml as an electrolyte solution. Then, use the Cu metal of 4 cm × 7 cm as the anode and carbon stem as the cathode. Before electroplating, the Cu surface is cleaned using HNO_3 1% to remove the fat content that sticks to the Cu. It is cleansed using 96% ethanol to eliminate HNO_3 on Cu. The electroplating process can be done using a voltage of 2 volts for 5 minutes (Hardiyanti & Santoso, 2018).

2.3. Process of Membrane PVA/Chitosan

The Membrane Process requires a Chitosan solution with 2% concentration and 5% PVA solution as the primary material with a 2-3 comparison. In the early stages, both solutions are mixed and stirred using a Magnetic Stirrer for 12 hours and silent for 48 hours. The mixture will be cut square with a large size and wide by 4 cm. The piece was soaked into NaOH 2 m for 10 minutes and rinsed using Aquades, then drained (Ibrahim et al, 2017).

2.4. Process of Membrane PVA/Chitosan Membling + Phosphoric Acid

The membranes PVA/Chitosan process with the addition of phosphate acid is made through the first stage, that is to create a 2% chitosan solution using acetic acid solvent and 5% PVA using Aquades as the primary material with PVA comparison: chitosan 3:2 as many as 100 ml (Ibrahim et al., 2017). It then added 2.5% H_3PO_4 solution of 2 ml into the PVA/Chitosan solution. After that, all the materials were stirred using a Magnetic Stirrer at 40℃ for 10 minutes to become homogeneous. The PVA solution that HDO_4 has been mixed in the Petri's cup is then dried in the oven at 120℃ for 15 minutes (Nurdiati & Astuti, 2015).

2.5. Process of Membrane PVA/Chitosan + Sodium Alginate

Membrane PVA/Chitosan with the addition of sodium alginate is made through the first stage, that is to create a 2% chitosan solution using acetic acid solvent and 5% PVA using Aquades as the primary material with PVA comparison: Chitosan 3: 2 is 100 ml (Ibrahim et al., 2017). Then, make the sodium alginate solution with a 3% concentration using Aquades as much as 20 ml. Each solution is mixed and stirred using a magnetic stirrer to homogeneous at 60℃ for 6 hours. After that, the solution is printed using a cup and dried for 24 hours at room temperature (Noor et al., 2018).

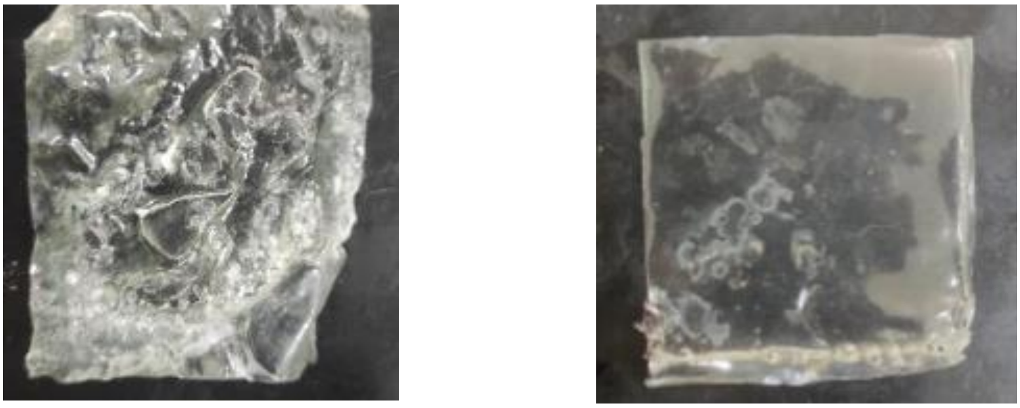
2.6. Coating of MFC membrane

The PVA/Chitosan membrane has a low water resistance rate, then the perpetration of treatment in order to increase the level of water resistance by immersion using the Stearic Acid solution. The solution was dissolving Stearic Acid with a 2% concentration using 100% mosary alcohol. The mixture of solutions was stirred using a magnetic stirrer to become homogeneous. Then, the membrane was soaked in the Stearic Acid solution for 12 hours. After that, the membrane is dried using an oven at 80℃ for 2 hours. The membrane is ready for use in the MFC system (Liu et al., 2020).

3. Results and Discussions

The MFC system research uses vegetable waste and variations of separators to produce renewable energy. In this study, the variation of the membrane used is PVA/Chitosan with a ratio of 3:2. Then, the PVA/Chitosan membrane is varied by adding sodium alginate and sphilosphic acid. This variation is based on the research composition of the allegine chitosan-sodium membrane in the Noor. (2018) research. The PVA/Chitosan membrane is also varied with the addition of phosphate acid added to PVA. This research uses PVA-acid acid composition in Susilawati et al. (2021). Comparison 3: 2 on PVA/Chitosan is the best result of 1: 1 and 2: 3 comparison in Ibrahim et al. (2017).

This MFC research has a problem of membrane resistance to water because the type of material from PVA, chitosan, sodium alginate, and phosphate acid has hydrophilic properties or absorbs water. Hence, the membranes in this study still have leakage. Then, to overcome the leakage on the membrane, stearic acid. The use of this stearic acid has been realized by Liu et al. (2020) by using soaking methods on a sponge against the stearic acid solution as a polyurethane sponge, producing material to separate water with oil. From the research results, using the coating method on Stearic Acid produces membranes that are not easily destroyed in water. Stearic acid has a low water permeability and high hydrophobic properties (Wulansari and Atmaja., 2016). The higher value of water permeability causes the membrane performance in the fuel cells to decrease. Therefore, adding stearic acid to the membrane is very good because it has a low water permeability value (Victory et al., 2019). Then, the electrical voltage generated on MFC is better than not using the stearic acid. The results showing the membrane before the Stearic Acid coat and after the folding can be seen in **Figure 2**.



(a) (b)

Figure 2. PVA/Chitosan membrane prior before (a) and after (b) coated by Stearic Acid

A multimeter in open circuit voltage measures the MFC system. In this system, it meant an hour one during 72 hours, and this system uses series series as the path of the vines. Then, vegetable waste using a composition of water comparison: vegetable waste (1:2) and the comparison is added with AM4 bacteria as much as 10 ml. Then, it is saved for one day so bacteria can adjust and breed in the vegetable waste. The realization of the microbial tool fuel cell system can be seen in **Figure 3**.

Nugraha IA, Supriyanto A, Pauzi GA, and Junaidi, 2023, The Microbial Fuel Cell Characteristics of the PVA/Chitosan Membrane with Variations of Phosphate Acid and Sodium Alginate Derived from Vegetable Waste, *Journal of Energy Material and Instrumentation Technology, Vol. 4 No. 4, 2023*

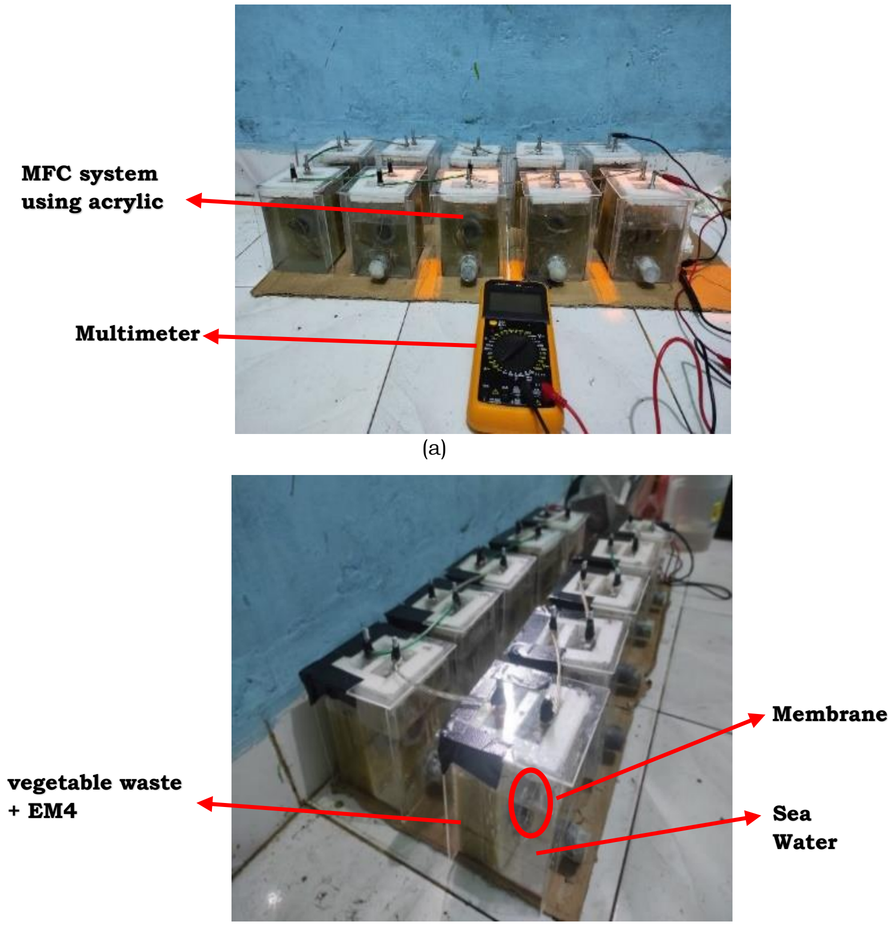


Figure 3. System Realization (a) Tools and (b) Materials on MFC

3.1 Measurement of Veterial Open Circuit Voltage (OCV)

The electrical voltage is measured using a multimeter in open circuit voltage (OCV), i.e., the voltage measured in electrical circuits without an external resistor. The results of the OCV voltage measurement are displayed in the form of graphs, as in **Figure 4**.

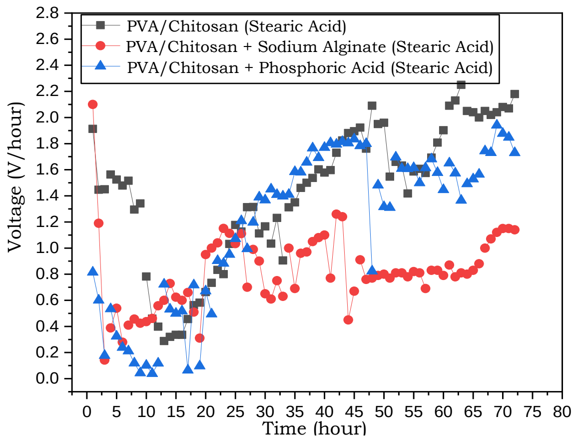


Figure 4. Relationship between VOVs on time with PVA/Chitosan variations using the addition of sodium alginate and phosphoric acid

In Picture 4 can be seen that the difference in PVA/Chitosan membrane variations (PK), PVA-Citosan-Sodium Alginate (PKS), and PVA/Chitosan-acid phosphoric (PKA) shows the maximum VOVV value of PK by 2.25 volts, then voltage (VOVV) on PKS of 2.1 volts, and the maximum value of V1C V1C of 1.941 volts. The voltage at the first hour generated by MFC on PK variations, PKS, and PKA in a row of 1.58 volts, 2.1 volts, and 0.81 volts. In comparison, the voltage value generated at 72 hours is 2.18 volts on the PK, 1.73 on the CCP, and 1.14 volts on the PKA. The variation shows the fluctuating value at all hours, but in the early hours of the decrease, the state of the electrode is not the first to be decomposed, so it produces high voltage values. At the next hour, the electrode begins to be domesticated with other ions so that the electrons in the electrode begin to be hampered, and the voltage value decreases (Pauzi et al., 2020).

After reaching the decline, the voltage rose in fluctuating due to the increased activity of microorganisms. In anode electrodes, organic materials in anaerobic conditions will be oxidized. The process that plays a role in generating electrons in MFC is that the more microorganisms contained in the anodic compartment, the higher the number of electrons generated and will affect the process of running oxidation. The electrons will flow through the anode electrode circuit (Cu(Ag)), and then the proton will pass through the separator to stabilize the existing charge in both compartments (Mufandi et al., 2018). The decrease in the measurable electrical value occurs when the microorganisms adapt to breaking the more complex substrates to be simple. An increased value of electricity is suspected because microorganisms are currently in the simple substrate spat in the waste (Kurniati et al., 2019).

The voltage in the membrane variation by adding sodium alginate consecutively produces the highest voltage at 11 hours to 17. However, the final result was that a membrane with the addition of sodium alginate experiences a better increase than a PVA/Chitosan membrane with the addition or addition of phosphoric acid. It is suspected that because of the oxygen that diffuses to the anode, the bacteria on the MFC series, an anaerobe or bacteria, can work well without requiring oxygen (Genisa & Auliandari, 2018). The effect of dissolved oxygen diffusion into anode is expected to vary as the role of such bacteria or microbes in systems that can cause bacteria breathing or eager oxygen. Thus, the duty of oxygen into anode space will affect the result of electrical MFC (Min et al., 2005). In MFC research, using this vegetable waste gets greater than MFC liquid waste Ibrahim et al. (2017), with the highest average voltage of the PVA/Chitosan treatment of 1.424 volts. It proves that using vegetable waste substrates has a better content for the needs of microorganisms. If the growth of microorganisms stalled, it will reduce this activity of microorganisms and cause the process of oxidation of the material to get less. It will produce the flow of electrons, and the protot generated less (Mufandi et al., 2018).

3.2 Measurement of Open Circuit Voltage (OCV)

The data retrieval results on electric power measurements (i) with MFC systems using vegetable waste with variations of PVA/Chitosan membranes, sodium alginate, and phosphoric acid for 72 hours in the graph. In the system, the graph shows the relationship between the power of the current time **and Figure 5.**

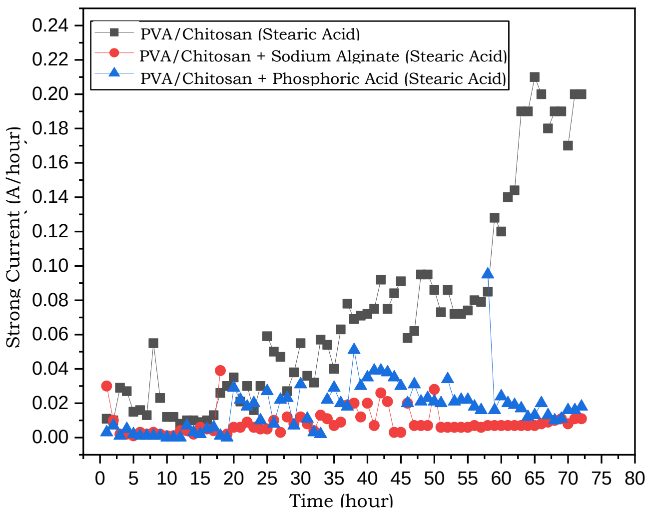
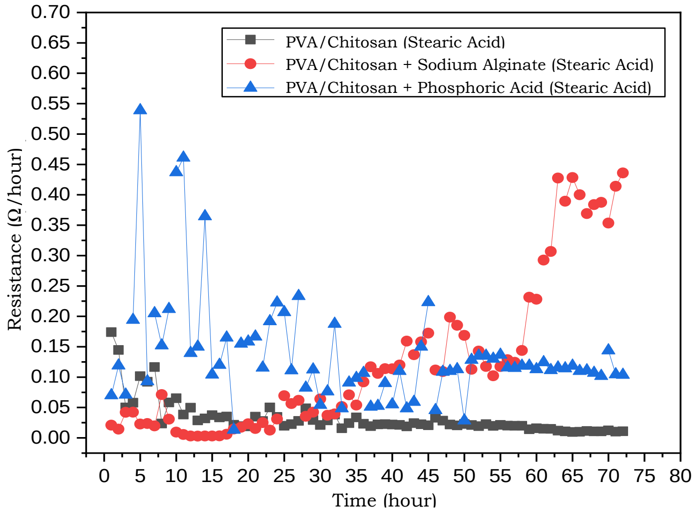


Figure 5. The image is between the power of the power of the power on the MFC system and the time

In **Figure 5**, it can be seen that the current value (i) at the first hour with the PVA/Chitosan membrane variation of 0.011 A, then on the PVA/Chitosan-Sodium Alginate of 0.03 A, and the powerful current value (i) in the PVA/Cositan-phosphoric acid of 0.003 A. The result shows that the first hour of PVA variations/chitosan-sodium alginate has the highest current compared to other variations at the first hour. It can also be seen on the graph in Figure 5 that shows the fluctuating value because the more ions produced in a solution it will, the higher the value of its conductivity. The existence of activity and growth in bacteria will affect the production of ions in the MFC system. According to Ali and Widodo. (2019), the value of electric fluctuation is caused by the interaction and competition of bacteria living in the substrate. Then, the substantial decline in electric current occurs due to reduced activity of bacterial metabolism. This decrease also occurs due to increasing obstacles due to the emergence of the growing biofilm, which becomes an internal barrier for the anode (Ibrahim et al., 2017).

Electric current is a flow of electrons translated at certain times; these electrons are brought by the donor ion, where more and more microorganisms in the solution will be more and more of the ions that are produced, and the more microorganisms in the solution will be increasingly small ion or electrons generated. In this case, the more electrons microorganisms produce, the better because the resulting ion is more significant, so the ability to deliver the electrons will be higher (Kholida & Pujayanto, 2015).

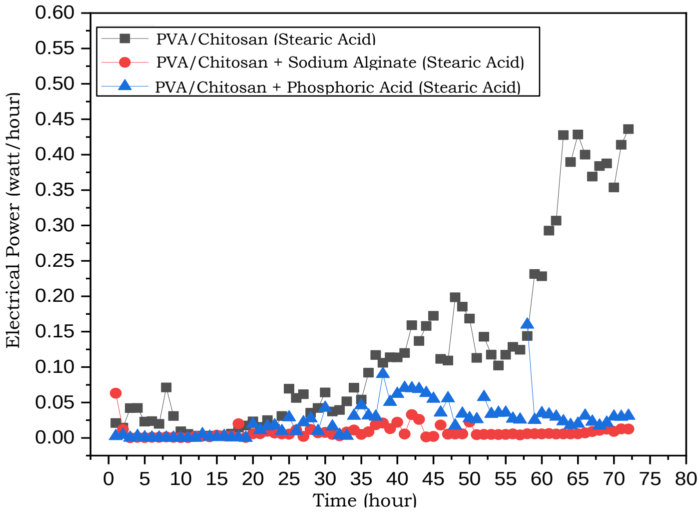
3.3 Measurement Size and Barriers



Picture 6. The relationship of the calculating drag (r) on the MFC results from the voltage measurement and the electric current to time.

The result of the calculation of the blocks is seen in **Figure 6**, the value of the blocks in the first hour of the 0.143 k accuracy membrane, next to the variations of the PVA/Chitosan-sodium alginate membrane, which shows the accounting in the first hour of 0.07 k accuracy, and in the PVA/phosphate acid variation of 0.272 k (0.272 k). The charts show a fluctuating value and a slight rise due to a cortical in the electrodes growing so large that the rate of resistance (r) will be greater. That corresponds with the V, and I obtained it based on Ohm's law, which is the value of the obstacle versus the current value. As the value of the hindrances increases, the resulting currents become smaller, and so do the opposite. The factors that increase the value of the internal barriers, which form the biofilm on the surface of the anode, resulting in a thickage of substrata, electrodes, electrolytes, and membranes (Syamsul et al., 2019).

The calculation in the PVA/Chitosan variation has a high point of resistance at the first of the 2 hours of 0.145 k accuracy, the second of the 5th hour of 0.539 k accuracy, and the third of the 18th hour of 0.717 k accuracy. Then, the lowest obstacle calculation of the three variations can be seen from the average value on the 0.032 k membrane variation. At the same time, other variations have additional sodium alginate on the membrane.



Picture 7. The relationship of the value of calculating (P) in the MFC system as a function of time

The graph in Picture 7 shows that the power value (P) is highest in the variation of PVA/Chitosan, which lies at the 72nd-hour point of 0.436 watts. Then, the highest power in the PVA/Chitosan variation with the addition of sodium alginate would be in the first hour at 0.063 watts. In the membrane variations with the addition of phosphate, acid would lie at 58 hours of 0.159 watts. The variations in the PVA/Chitosan membrane have an average value of 0.127 watts and an average value on variations with a successive increase in the sodium alginate and phosphate acid of 0.008 watts and 0.026 watts. The power value (P) over time in the PVA/Chitosan variation is greater than the variations in sodium alginate and phosphate acid because the power (P) results from tension (V) and current (I). Therefore, the greater the voltage and the current would be, the higher the force (P) produced and the opposite. The chart shows that fluctuating and increasingly more excellent value is due to the production of electrons produced by microorganisms increasing and producing massive levels of voltage and currents (Fadhila et al., 2020).

4. Conclusions

The maximum voltage produced on the PVA/Chitosan membrane was 2.25 volts larger than the PVA/Chitosan membrane with the addition of phosphate acid and sodium alginate of 1.941 volts and 2.1 volts. Our research on comparative variations of PVA/Chitosan membranes without adding and with adding sodium alginate or phosphate acid produces different electrical values. Differences in the membrane quality affect the value of electrical characteristics produced. MFC studies using vegetable waste result from voltage electromagnetism and electrical currents that measure time. Vegetable waste could be used as a renewable energy alternative. The PVA/Chitosan membrane, without adding, has more excellent electrical properties than the addition of sodium alginate and phosphate acid.

5. Bibliography

Akbar, T. N., Kirom, M. R., & Iskandar, R. F. (2017). Analisis Pengaruh Material Logam Sebagai Elektroda Microbial Fuel Cell Terhadap Produksi Energi Listrik. Proceeding of Engineering, 4(2): 2123–38.

Ali, M., & Widodo, A. A. (2019). Biokonversi Bahan Organik Pada Limbah Cair Rumah Pemotongan Hewan Menjadi Energi Listrik Menggunakan Microbial Fuel Cell. *Jurnal Envirotek,* 11(2): 30–37.

Fadhila, N., Kirom, M. R., & Fitriyanti, N. (2020). "Fuel Cell Analysis Electrical Energy Production Using Fish Pool and Rice Waste Substrate By Using Sediment Microbial Fuel Cell." 7(2): 4315–22.

Genisa, M. U., and Auliandari, L. (2018). "Sebaran Spasial Bakteri Koliform Di Sungai Musi Bagian Hilir." *Majalah Ilmiah Biologi Biosfera: a Scientific Journal* 35(3): 131–38.

Hardiyanti, F., & Santoso, M. Y. (2018). "Analisis Pelapisan Tembaga Terhadap Laju Korosi Dan Struktur Mikro Grey Cast Iron." *Jurnal Teknologi Maritim* 1(1): 37–42.

Ibrahim, B., Suptijah, P., & Syahreza, F. (2017). "Kinerja Microbial Fuel Cells Pada Pengolahan Limbah Cair Pemindangan Dengan Membran Separator Campuran Polimer Kitosan/PVA." *Jurnal Teknologi Industri Pertanian* 27(3): 235–41.

Imaduddin, M., Hermawan, H., Hadiyanto, H., & Wawan, W. (2014). Pemanfaatan Sampah Sayur Pasar Dalam Produksi Listrik Melalui Microbial Fuel Cells. *Media Elektrika,* 7(2): 22–35.

Ismawati, N., Aminin, A., & Suyati, L. (2015). "Whey Tahu Sebagai Penghasil Biolektrisitas Pada Sistem Microbial Fuel Cell Dengan Lactobacillus Plantarum." *Jurnal Sains Dan Matematika* 23(2): 43–49.

Kholida, H. (2015). "Hubungan Kuat Arus Listrik Dengan Keasaman Buah Jeruk Dan Mangga." 6: 42–46.

Kurniati, E., Haji, A. T. S., & Permatasari, C. A. (2019). "Pengaruh Penambahan EM4 Dan Jarak Elektroda Terhadap Listrik Yang Dihasilkan MFC (Air Lindi)." *Jurnal Sumberdaya Alam dan Lingkungan* 6(3): 19–30.

Liu, H., Su, S., Xie, J., Ma, Y., & Tao, C. (2020). "Preparation of Superhydrophobic Magnetic Stearic Acid Polyurethane Sponge for Oil-Water Separation." *Journal of Materials Research* 35(21): 2925–35.

Min, B. S. C., & Bruce, E. L. (2005). "Electricity Generation Using Membrane and Salt Bridge Microbial Fuel Cells." *Water Research* 39(9): 1675–86.

Mufandi, I., Azizah, I. N., Efendi, A., & Mufrodi, Z. (2018). "Pengolahan Slurry Sampah Melalui Microbial Fuel Cells Di Pasar Giwangan Yogyakarta." *Jurnal Teknik Kimia* 5(1): 29–36.

Noor, H. F. (2018). Kinerja Membran Komposit Kitosan-Sodium Alginat pada Sistem Microbial Fuel Cell dalam Menghasilkan Biolistrik dari Limbah Pemindangan Ikan. *Institut Pertanian Bogor,* 6(11): 951–52.

Nurdiati, D., & Astuti. (2015). Sintesis Komposit PAni/Karbom dari Tempurung Kemiri (Aleurites Moluccana) Sebagai Elektroda Kapasitor. *Jurnal Fisika Unand,* 4(1): 51–57.

Pauzi, G. A., Nisa, M. A., Samosir, A. S., Sulitiyanti, S. R., & Simanjuntak, W. (2020) "Peningkatan Karakteristik Listrik Sel Elektrokimia Cu (Ag) -Zn Dengan Penggunaan Anoda Tumbal Mg Pada Accumulator Berbahan Air Laut." *Jurnal Teori dan Aplikasi Fisika* 8(1): 83–92.

Purnama, wisnu adi, Kirom, M. R., & Qurthobi, A. (2020). Analisis Pengaruh Temperatur dengan Substrat Lumpur Sawah terhadap Produksi Arus Listrik Microbial Fuel Cell. *Proceeding of Engineering,* 7(1): 1172–77.

Sudrajat, H. R. 2007. *Mengelola Sampah Kota.* Jakarta: Penebar Swadaya.

Susilawati, S., Prayogi, S., Arif, M. F., Ismail, N. M., Bilad, M. R., & Asy'ari, M. (2021). "Optical Properties and Conductivity of Pva–H3 Po4 (Polyvinyl Alcohol–Phosphoric Acid) Film Blend Irradiated by γ-Rays." *Polymers* 13(7), 1605.

Syamsul, N. H., Wahyudhin, I., & Kirom, M. R. (2019). Studi Pengaruh Suhu Subtrat Terhadap Produksi Daya Listrik Microbial Fuel Cell Dengan Substrat Lumpur Sawah Dan Nasi Basi. *Proceeding of Engineering,* 6(2): 5478–84.

Victory, S., Sakhila, S., Putri, R. E., Amelia, A., Hutagalung, S. D., & Asriza, R. O. (2019). "Karakteristik Fungsional Edible Film dari Komposit Pati/Kitosan/Asam Stearat." 17(2): 143–48.

Wulansari, A. D., & Atmaja, L. (2016). "Pengaruh Variasi Konsentrasi Metanol Terhadap Daya Serap Dan Permeabilitas Metanol Membran Komposit Kitosan/Montmorilont-Glutaraldehid." *Skripsi* 5(2): 6–11.