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Utilization of Cassava Peel Waste for Renewable Electrical Energy Production Using Joule Thief Series with Microbial Fuel Cell Technology (Addition of Yeast and Acetate)

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Abstract

The Cassava peel waste can be used as a substrate in the Microbial Fuel Cell (MFC) system to produce electrical energy. MFC was made of acrylic with a size of 9×9×11 cm with a dual chamber type that can accommodate a substrate volume of ±350 ml. The MFC system consists of 10 cells arranged in series with voltage and current measurements every 2 hours for 72 hours using a multimeter. The maximum power MFC produces by adding 16 ml of acetate using a joule thief amplifier circuit is 8.42 W. In contrast, the addition of 24 gr yeast produces a maximum power of 7.82 W; without any addition, it produces 7.74 W of power. The amplifier also produces pretty good power. The maximum power produced by MFC without an amplifier circuit with the addition of 24 gr yeast is 2.51 mW, while 16 acetate is 2.18 mW. Without any addition, it produces 1.91 mW of power.

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Abstrak

Limbah kulit singkong dapat digunakan sebagai substrat dalam sistem Microbial Fuel Cell (MFC) untuk produksi energi listrik. MFC dibuat dari akrilik dengan ukuran 9×9×11 cm dengan tipe dual chamber yang dapat menampung volume substrat ±350 ml. Sistem MFC terdiri dari 10 sel yang diatur secara seri dengan pengukuran tegangan dan arus setiap 2 jam selama 72 jam menggunakan multimeter. Daya maksimum yang dihasilkan oleh MFC dengan penambahan 16 ml asetat menggunakan rangkaian amplifier joule thief adalah 8,42 W, sedangkan dengan penambahan 24 gr ragi menghasilkan daya maksimum sebesar 7,82 W dan tanpa penambahan apa pun menghasilkan daya sebesar 7,74 W. Amplifier juga menghasilkan daya yang cukup baik. Daya maksimum yang dihasilkan oleh MFC tanpa rangkaian amplifier dengan penambahan 24 gr ragi adalah 2,51 mW, sedangkan penambahan 16 ml asetat adalah 2,18 mW dan tanpa penambahan apa pun menghasilkan daya sebesar 1,91 mW.

1. Introduction

A microbial Fuel Cell (MFC) is a device for converting chemical energy into electrical energy through the catalytic activity of microorganisms (Chae et al., 2008). MFC is the same as a fuel cell, which consists of an anode, a cathode, and an electrolyte. However, the MFC as an anode component is used for microbial culture in microbial metabolic activity (e.g., microbial consortia that oxidize organic substrates such as glucose). The principle of MFC is in the form of microbial activity in the liquid medium. Microbial activity can produce organic components containing hydrogen elements such as ethanol, methanol, and methane gas that can produce electrons and electric current (Zahara, 2011). Several factors, including substrates, electrodes, and proton-conducting membranes, can influence the MFC system. Research on Microbial Fuel Cells (MFC) is exploratory, aimed at developing fundamental theories about MFC technology.

In the research of Utami et al. (2018), banana peel waste was utilized using Microbial Fuel Cell technology with permanganate as catholyte. In the research conducted by Utami et al. (2018), banana peel waste was utilized in

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Microbial Fuel Cell technology, with permanganate serving as the catholyte. This research was conducted using two chambers (anode and cathode). $KMNO_4$ as catholyte and connected to a series of electrochemical cells (voltaic cells), then measured the voltage, current, and power density value for 17 days. The results of measuring the maximum voltage value, maximum current, and maximum power density generated from the reactor are 1.455 V, 0.032 mA, and 31.9 mW/m^2 (Utami et al., 2019). Limbong et al. (2019) also conducted a study to analyze the effect of the decay time of stale bread substrate on the production of electrical energy in the Microbial Fuel Cell. This study used a dual-chamber reactor, where bacteria from the substrate in the anode compartment produce electrons through a salt bridge. Stale bread was used as a substrate at the anode, distilled water at the cathode, and a salt bridge (NaCl 1 M) as a proton transfer medium. The variation of substrate incubation time is 1 day, 3 days, and 5 days. The results showed that the longest rotting of stale bread could produce the highest electrical energy production with a voltage of 0.03669 V, a current of 0.33 mA, a power of 0.050 mW/m^2 and energy of 12.56989 kJ (Limbong et al., 2019).

Currently, many studies examine the performance of MFCs in producing good electrical potential, such as in terms of the configuration of the MFC reactor, types of electrolysis, electrode materials, and the utilization of microorganism cultures. Zahara (2011) has researched MFC by utilizing the culture of Saccharomyces cerevisiae, a yeast-type microorganism usually found in yeast. Saccharomyces cerevisiae cells can grow in a medium containing high concentrations of sugar water. Sugar compounds produced by cellulosic microorganisms for growth can be utilized by Saccharomyces cerevisiae. This species can ferment various carbohydrates and produce invertase enzymes that separate sucrose into glucose and fructose and convert glucose into alcohol and carbon dioxide (Agustining, 2012).

This MFC research continues to be developed both in the use of membranes (Ibrahim et al., 2020) as proton carriers (Sipayung et al., 2019), the use of electrodes (Akbar et al., 2018), and the use of waste and microbial culture to produce better electrical energy (Utari et al., 2018). 2014). Utari et al. (2014) studied fruit waste using MFC technology and adding yeast and acetate variations. The study results showed that fruit waste, considered garbage by the community, still contains simple organic material (glucose), which has the potential as a food source for bacteria. The addition of yeast helps increase the number of bacteria so that the number of protons and electrons is produced, and the addition of acetate can increase electricity production (Utari et al., 2014). Cassava and durian peel waste using used batteries can also be used to produce alternative electrical energy (Muhlisin, 2015), While Susanto et al. (2018) produce electrical characteristics of vegetable waste as a source of renewable electrical energy using two electrodes, namely copper (Cu) and zinc (Zn). Irsan's research (2016) also analyzed electrical characteristics using various types of cassava and cassava peels so that they can be used to charge cellphone batteries.

In previous studies, the production of electrical energy was tiny, so efforts were still required to increase the electrical voltage. One method to increase the voltage on the Microbial Fuel Cell is to use a Joule Thief circuit. The Joule Thief circuit is used to change the Direct Current (DC) voltage into a circuit into Alternative Current (AC) voltage, which uses the principle of a transformer as a voltage riser and a transistor as an oscillator to produce an oscillating voltage (AC voltage) (Manfaluthy, 2018). The use of joule thief has also been carried out by Budisusila et al. (2017) for energy-saving emergency lights. This study uses a 1.5 V battery voltage source and an LED as a load. Measurement of electrical characteristics in the circuit uses a multimeter to measure current and voltage and a lux meter to measure the light intensity of the LED. The number of LEDs used as a load in this study was 40 pieces arranged in series and parallel (Budisusila, 2017).

In this study, cassava peel waste was utilized with the addition of yeast using Cu(Ag) and Zn electrodes with and without joule thief. The dual-chamber MFC system was made using acrylic measuring 9×9×11 cm with a salt bridge to separate each cell. Voltage and current were measured using a multimeter with 20 LEDs and 3-watt LEDs as the load.

2. Methods

The tools was used in this study are an MFC system container made of acrylic with a thickness of 1.5 mm, PVC pipe with a diameter of 3 cm, a series of joule thief, measuring cup, scales, lux meter, blender, pliers, scissors, bolts, and so on. gallon. While the materials used include yeast tape, seawater, Cu(Ag) fibers, Zn rods, acetic acid, glass glue, $AgN0_3$ solution, $HN0_3$ solution, 96% alcohol, connecting cables, and crocodile clips. This research method was carried out in several stages, including electroplating Ag on Cu, making salt bridges, preparing cassava peel waste substrates, designing and manufacturing MFC systems, system testing and data collection.

2.1. Process of Electroplating Ag on Cu

The process of electroplating Ag (silver) on Cu (copper) using an electrolyte solution in the form of a silver-plated solution (AgNO3) as much as 300 ml. In electroplating, the electrodes are Cu fibers as the cathode and carbon rods as the anode. The surface of the Cu fibers is cleaned first with 1% HNO3 solution before starting electroplating to reduce the fat content attached to the Cu. After cleaning with a 1% HNO_3 solution, the Cu fibers were cleaned again with 96% alcohol to remove the HNO_3 content attached to the Cu. The electroplating process with a voltage of 2 volts for 5 minutes is shown in **Figure 1**.

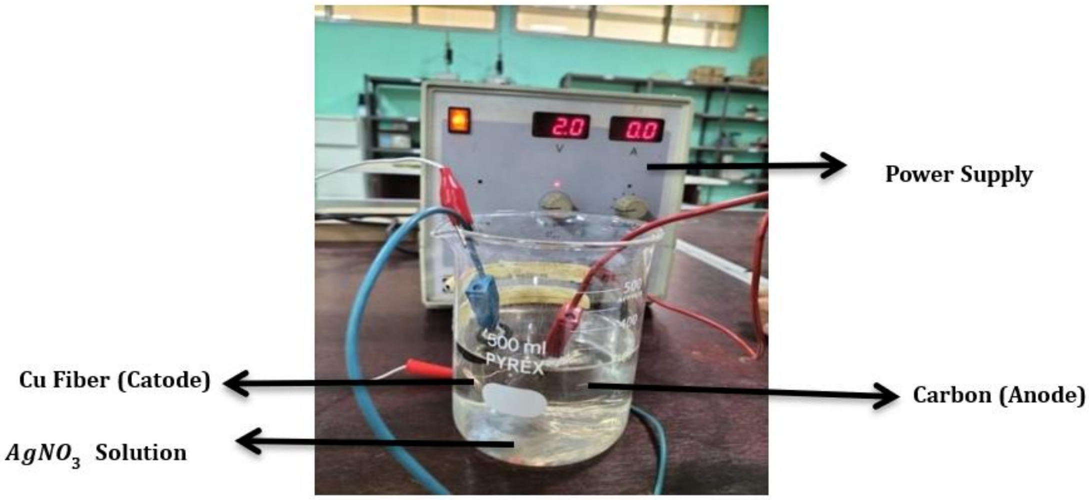


Figure 1. Electroplating process

2.2 Salt Bridge Process

The salt bridge in this study used agar mixed with seawater in a ratio of about 600 ml for every 7 grams of agar powder. The two ingredients are mixed by heating the stove with continuous stirring until homogeneous. Filtering seawater before being mixed with agar powder aims to remove particulates contained in seawater (Susanto, 2020). After the solution is homogeneous, it is printed on a 3 cm diameter pipe with a length of 2 cm, as shown in **Figure 2** and **Figure 3.**

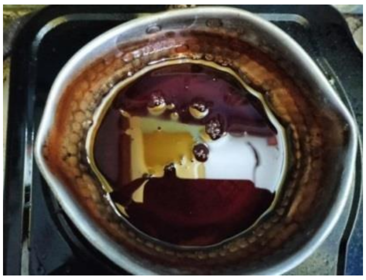
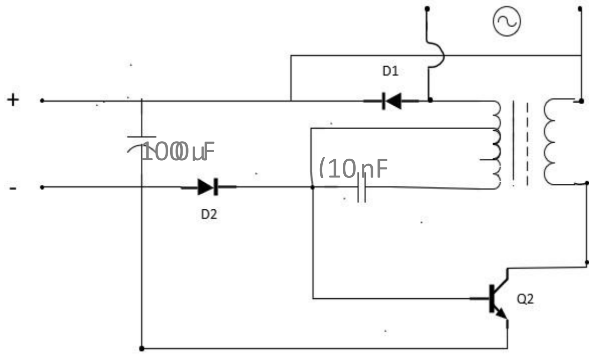


Figure 2. The process of making a salt bridge

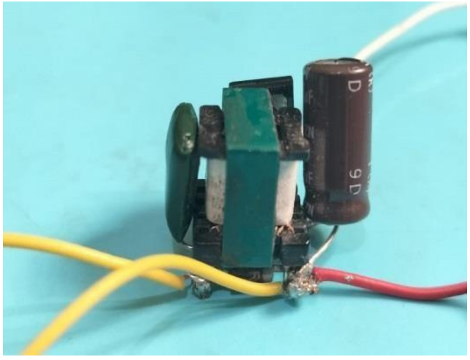
Figure 3. Salt bridge in solid form

2.3 Making a *Joule Thief circuit*

The joule thief circuit in this tool converts the DC voltage from the battery into AC voltage and then increases the voltage. This circuit consists of 2 capacitors worth 1000 F and 100 nF, 1 NPN D882 transistor, 2 R4000F diodes, and one step-up transformer, as shown in **Figure 4**.



(a)



(b)

Figure 4. Joule thief circuit: (a) circuit schematic, (b) module

2.4 MFC System Design and Manufacturing

The first stage begins with designing the MFC system using a dual chamber type with a salt bridge separator. This dual chamber type consists of 2 compartments (cells), namely the anode and cathode compartments. These two compartments will be made up of 8 pieces arranged in series. Copper (Cu) is used as fibers, and zinc (Zn) is used as plates. The container for each compartment uses acrylic material with a size of 9×9×11 cm, which can accommodate about ±350 ml. The anode compartment is made in a closed state or under aerobic conditions because oxygen in the room can inhibit the electric current generated. Under aerobic conditions, bacteria use oxygen or nitrate as the final electron acceptor to produce water. In the anode, no oxygen is formed, and bacteria must change from their function as natural electron acceptors to insoluble acceptors (Sitorus, 2010). Then, the cathode compartment is made in an open (aerobic) condition. The two compartments are also equipped with a filling and emptying system. Then, to separate these two compartments, a salt bridge is used, which will be placed between the compartments (cells), which can be seen in **Figures 5** and **Figure 6**.

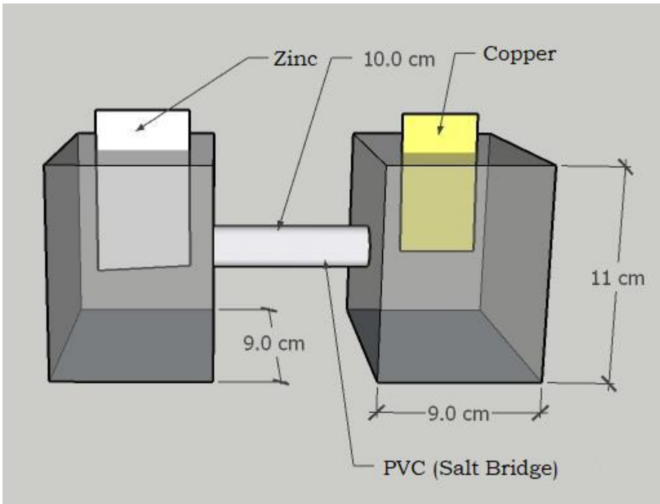


Figure 5. MFC system design

2.5 System Testing and Data Retrieval

Data was collected from three treatments: pure cassava peel waste and cassava peel with yeast and acetate. In the first treatment, eight cells were arranged in series, connected to a load (V_b), and measured using a multimeter and lux meter every 2 hours. The second treatment was also carried out using the same method on cassava peel waste with the addition of 24 g of yeast. In the third treatment of cassava peel waste with the addition of acetate, the exact measurements were also carried out using a multimeter. After that, data was collected on the three treatments by adding a joule thief circuit to the MFC system. Observational data is taken in voltage (V) and current (I). In addition, observational data in the form of internal resistance (R_{in}) and power (P) are obtained from the results of calculations using **Equation (1)** and **Equation (2)**.

$$R_{in} = \frac{V}{I} \qquad (1)$$

$$P = V \times I \qquad (2)$$

where R_{in} = internal resistance (Ω), V = voltage (volts), I = current (amperes), and P = power (watts).

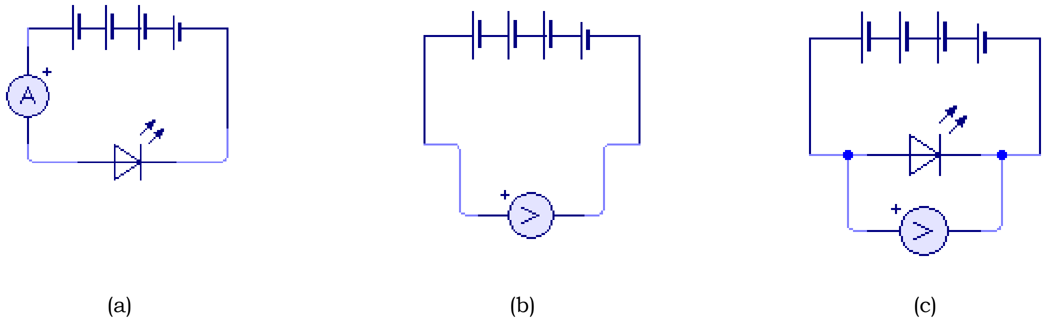


Figure 6. MFC system measurement : (a) equivalent circuit for measuring current strength, (b) equivalent voltage measuring circuit, (c) voltage measurement equivalent circuit with load

3. Results and Discussions

3.1. Realization of MFC System

An MFC system with a dual chamber type arranged in a series of as many as eight units has been realized. The container used for the MFC system is made of acrylic and is 9×9×11 cm in size. In each cell, there are Cu(Ag) and Zn electrodes, which are placed in different compartments; the cathode section contains Cu(Ag) electrodes with 350 ml of seawater electrolyte, while the anode contains Zn electrodes with 350 ml of cassava peel waste. This research utilizes fermented cassava peel waste, which is then measured using a multimeter with a load of 20 and 3-watt LEDs, as shown in **Figure 7** and **Figure 8**.

Figure 7. Measuring instrument used

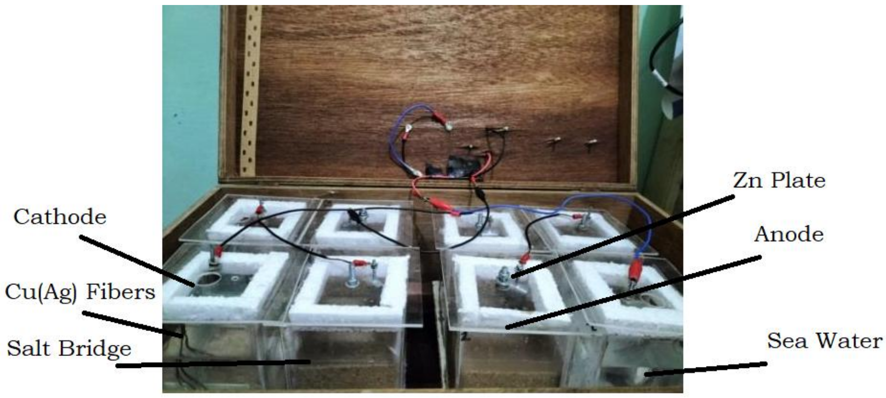
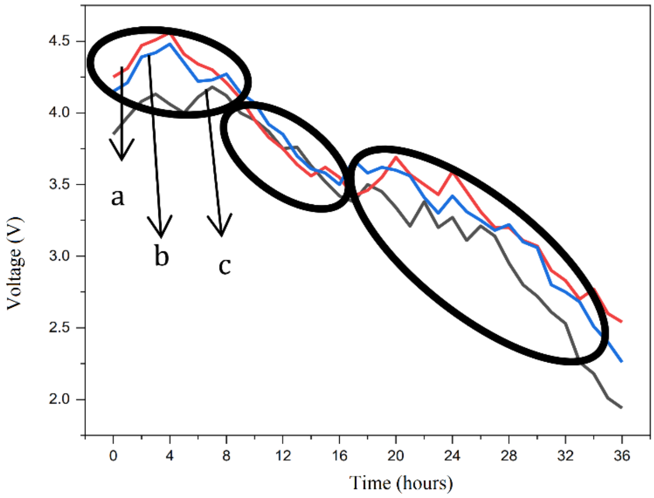


Figure 8. MFC system when measuring

3.2. Electrical Characteristics Research Results

MFC Voltage with Cassava Peel Waste Substrate

The data collected consisting of voltage measurements from the MFC system using a cassava peel waste substrate with added yeast and acetate without a joule thief circuit presented in graphical form. **Figure 9** shows data analysis and graphs using the relationship between the voltage (*V*) **value and time**.



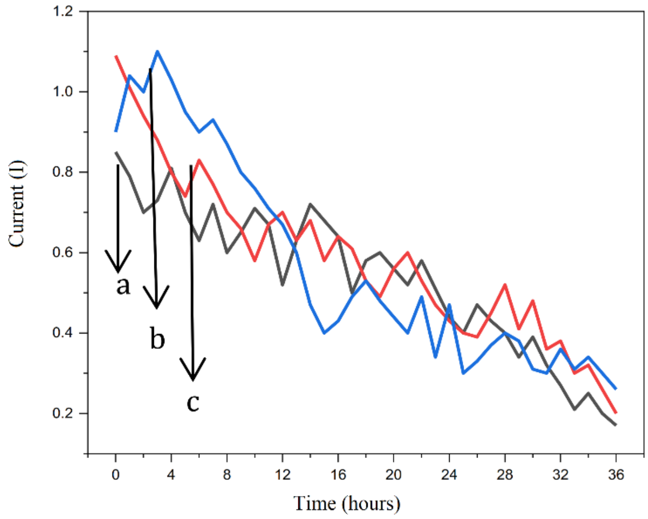
Information:
a = Pure cassava peel waste;
b = Cassava peel waste + yeast 24gr;
c = Cassava peel waste + 16 ml acetate.

Figure 9. Graph of voltage against time

The graph in **Figure 9** shows the voltage results in the form of a graph that looks to experience changes in voltage in a row for 36 hours. The voltage obtained both on pure cassava peels, cassava peels that were given yeast 24 g, and cassava peels that were given acetate of 16 ml at the time of measurement at 0 hours experienced relatively high results, around 3.85 V, 4.25 V, and 4,15 V. This happened because the bacteria had adapted to the substrate media in the form of waste that had previously been fermented for about seven days before being inserted into each cell. It is called the lag phase (adjustment), an adjustment period to the new environment. At the 0 to 6-hour measurements, the voltage of additional 24 g yeast cassava peel waste was increased by 9.41%. It is due to the ability of active microorganisms to rapidly divide and synthesize cell material so that the number of these bacteria allows more and more numbers to increase, which results in faster metabolic processes and greater electrical output; this phase is referred to as the exponential phase (splitting) (Ardi, 2020). The voltage of cassava peel waste with the addition of acetate also increased by 7.18%. Then, at 7 to 16 hours, the voltage of cassava peel waste with the addition of 24 gr yeast decreased and increased by an average of 2.04%. The same thing happened to voltage of cassava peel waste with the addition of acetate, which decreased and increased by an average of 2.15%. All results are in the stationary phase, which the phase that bacterial growth does not increase anymore and ratio number of bacterial cells to number dead bacteria is 1.00 (Febriansyah, 2011). That results was consistent with the research of Safitri et al. (2020), which the voltage has fluctuation value during the observation process. Then, from the 17th hour until the last measurement (36th hour), the voltage of cassava peel waste with the addition of yeast decreased and increased by an average of 11.28%. In comparison, the voltage of cassava peel waste with the addition of acetate was 8.50%. According to Logan (2008), a decrease in the voltage value can be caused when microorganisms adapt to break down more complex substrates into simpler ones.

Strong MFC Current with Cassava Peel Waste Substrate

In addition to measuring the voltage, the current generated in the MFC system has a substantial value. The results of observations, in the form of the relationship between the value of the current strength (I) and the time taken up to 36 hours, are shown in graphs and data tables, which can be seen in **Figure 10.**



Information:
a = Pure cassava peel waste;
b = Cassava peel waste + yeast 24gr;
c = Cassava peel waste + 16 ml acetate.

Figure 10. Resistance value against time

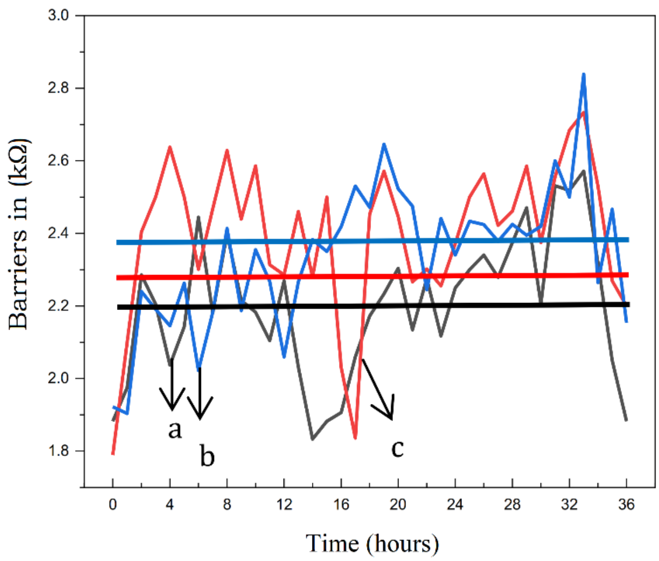
Figure 10 shows the maximum current strength value was 1.09 mA produced by cassava peel with 24 g yeast. Pure cassava peel and cassava peel with 16 ml of acetate produces a current strength of 0.85 mA and 0.9 mA. It shows that cassava peel waste with the addition of yeast produces a current strength of 28.24% higher than pure cassava peel waste. In contrast, the cassava peel waste with the addition of acetate produces a 5.88% higher current than pure cassava peel waste. It is because adding yeast helps increase the number of bacteria present in the waste (Utari et al., 2014). In the second hour measurement, the current of cassava peel waste with the addition of yeast increased by 34.29%.

In comparison, the cassava peel waste with the addition of acetate was increased by 42.86%. Then, at the 3rd-hour measurement, the cassava peel waste with the addition of acetate had higher current than the cassava peel waste with yeast 50.68% and 20.55%. In the 4th hour, the current of cassava peel waste with the addition of yeast was decreased by 1.23%, while the current of cassava peel waste with the addition of acetate was increased by 20.16%. Then, at the 10th hour, the current of cassava peel waste with yeast decreased by 18.31%, while the current of cassava peel waste with acetate was increased by 7.04%. The current decreasing and increasing occurred continuously in the cassava peel waste with the addition of yeast and acetate from the 11th to the 18th hour. Due to the bacteria's condition, it began to enter the death phase. In this phase, the rate of cell death continues to increase while the rate of cell division is zero (Sumarsih, 2007). As result, the number of living bacterial cells was decreasing. The glucose level at the anode decreases over time, leading to a reduction in the rate of cell metabolism and consequently, a smaller resulting current. The low current is related to the high resistance within the MFC system circuit (Kim, 2006). In addition, the small current strength value is caused by the resistance contained in the MFC system circuit being too large (Kim, 2006).

In the 19th hour, the current of cassava peel waste with yeast was decreased by 18.33%, and the current of cassava peel waste with the addition of acetate was decreased by 20%. t 28 hours, the cassava peel waste with the addition of yeast increased by 30%, while the current of cassava peel waste with the addition of acetate produced the same current as the pure cassava peel waste. From the 29th hour until the end of the measurement (36th hour), the current of cassava peel waste decreased continuously with the addition of yeast. So, the average current value of increase and decrease in cassava peel waste with yeast is 16.17%, while in cassava peel waste with the addition of acetate was 25.60%. Then, the final current value obtained in pure cassava peel waste was 0.17 mA, while the current of cassava peel waste with acetate and yeast was 0.2 mA and 0.26 mA. The yeast activity in the anode made form biofilm on the electrode surface (Nevin, 2008). The formation of this biofilm could lead to increase in internal resistance at the anode (Zahara, 2011).

Barriers in MFC with Cassava Peel Waste Substrate

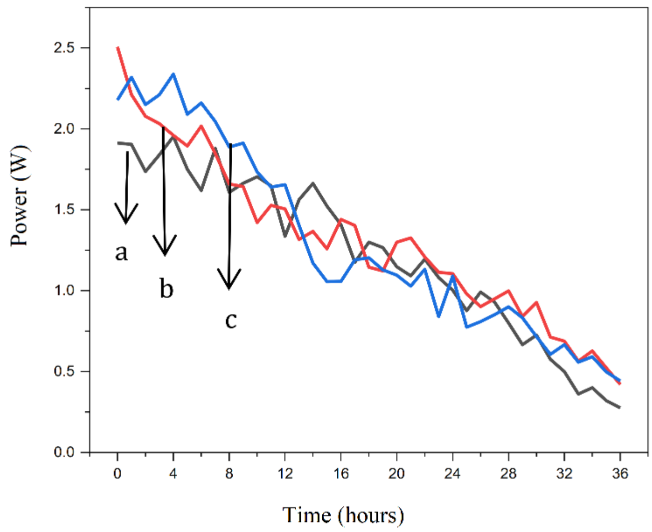
The measurement of internal resistance (R_{in}) was obtained from the calculations of **Equation (1)**. The data is displayed in a graph in **Figure 11.**



Information:
a = Pure cassava peel waste;
b = Cassava peel waste + yeast 24gr;
c = Cassava peel waste + 16 ml acetate.

Figure 11. Resistance value against time

Figure 11 shows that the internal resistance value (R_{in}) in pure cassava peel waste was 1.88 kΩ, cassava peel waste with the addition of yeast was 1.78 kΩ, and in cassava peel waste with the addition of acetate was 1.92 kΩ. It shows that the R_{in} value produced in pure cassava peel waste is 4.96% greater than that of cassava peel waste with yeast and 2.12% smaller than that of cassava peel waste with the addition of acetate. Then measurements were made on pure cassava peel waste at 1 to 36 hours to obtain a R_{in} value of 2.20 Ω in cassava peel waste with the addition of yeast of 2.39 kΩ and in cassava peel waste with the addition of acetate of 2.34 kΩ. In cassava peel waste with the addition of yeast and acetate, the average of resistance in cassava peel waste with the addition of yeast was 10.38%, while in cassava peel waste with the addition of acetate was 9.12 %. Cassava peel waste with the addition of yeast produces a more excellent internal resistance (R_{in}) than cassava peel waste with the addition of acetate. One of the major inhibiting factors can occur due to the biofilms. The biofilm that continues to grow over time can close the electrode and increase the internal resistance of the anode, causing a decrease in the value of the current generated by the MFC system (Kim et al., 2006). According to Ohm's Law, if the resulting current is small, the resistance obtained will be even better.



Information:
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b = Cassava peel waste + yeast 24gr;
c = Cassava peel waste + 16 ml acetate.

Figure 12. Graph of power to time

MFC Power with Cassava Peel Waste Substrate

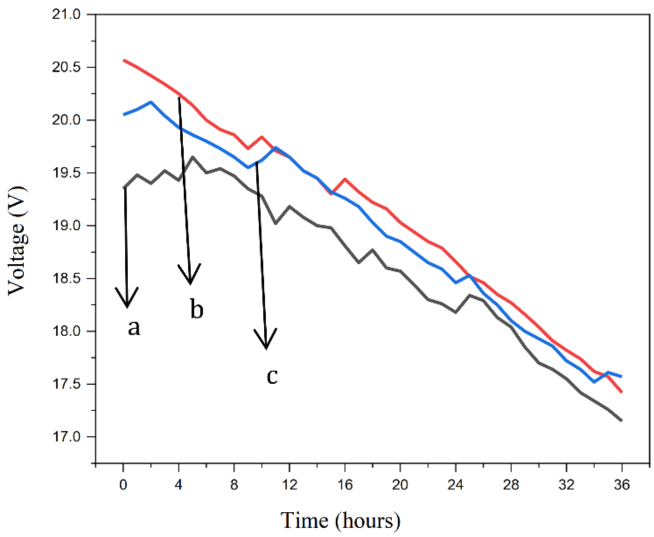
In addition to the R_{in} value, calculations were carried out to find the power (*P*) obtained by the MFC system in this study. The calculation of the *P* value was using **Equation (1)**, the results of which can be seen in **Figure 12**.

Figure 12 shows the power value against time in cassava peel waste with the addition of yeast and acetate variations with the power value in cassava peel waste with the addition of yeast greater than 2.51 mW, while in cassava peel waste with the addition of acetate of 2.18 mW and cassava peel waste pure 1.91 mW. Then, at the 8th-hour measurement of cassava peel waste with the addition of acetate, there was an increase in the power value of 17.41% compared to cassava peel waste with the addition of acetate of 3.17%. At the 15th hour, the cassava peel waste with the addition of acetate decreased by 30.67%, while the cassava peel waste with the addition of yeast decreased by 17.37%. Furthermore, at the 21st-hour measurement, the cassava peel waste with the addition of acetate increased the power value by 21.43%, while the cassava peel waste with the addition of yeast decreased by 5.86%. At the 22nd hour of measurement, each substrate's power value decreased and increased until the end, namely the 36th hour. So, the average value of the decrease and increase in cassava peel waste with yeast was 11.46%, and cassava peel waste with the addition of acetate was 13.03%. Then, at the end of the measurement of cassava peel waste with the addition of acetate, it produces a power value of 0.44 mW, while the cassava peel waste with yeast is 0.42 mW, and pure cassava peel waste is 0.28 mW. It is due to the high activity of bacteria during this adaptation period and the high levels of nutrients in the cells in the early operating phase of the MFC (Hassan et al., 2018).

3.2. Results of Measurement of Substrate Electrical Characteristics using Joule Thief

MFC system Voltage Measurement

The data collection results in voltage generated by the MFC system from cassava peel waste using a Joule Thief Circuit, with variations in the addition of yeast and acetate displayed in **Figure 13 as** voltage value (*V*) versus time.



Information:
a = Pure cassava peel waste;
b = Cassava peel waste + yeast 24gr;
c = Cassava peel waste + 16 ml acetate.

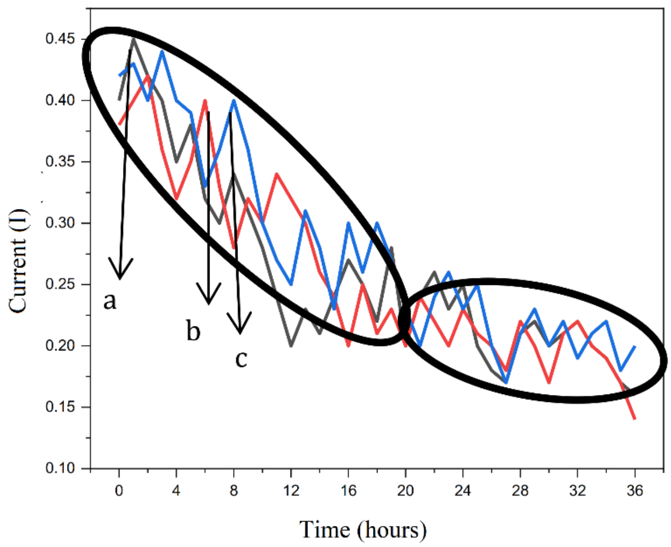
Figure 13. Graph voltage to time

Figure 13 shows the results of measuring the stress of cassava peel waste with variations of yeast and acetate for 36 hours. The measurement results showed fluctuations in almost all voltages at each addition of yeast and acetate variations, as well as pure cassava peel. At the 0-hour measurement, cassava peel waste with the addition of yeast produced the highest voltage by 20.57 V compared to pure cassava peel waste and cassava peel waste with the addition of acetate by 19.35 V and 20.05 V. Cassava peel with the addition of yeast produces voltage value of 6.30% greater and cassava peel waste with the addition of acetate produces 3.62%, also greater than pure cassava peel waste. Then, at the 6th-hour measurement, the cassava peel waste with the addition of yeast results voltage increase of 25%. At the same time, in the cassava peel waste with the addition of acetate, the voltage increased by 3.13%.

Furthermore, at the 18th measurement, the voltage of cassava peel waste with the addition of yeast decreased by 17.65%, while the cassava peel waste with the addition of acetate increased by 17.65%. Then, at the 12th-hour measurement, the voltage of cassava peel waste with yeast increased by 60%, while the cassava peel waste with the addition of acetate increased by 25%. Furthermore, at the 18th-hour measurement, the cassava peel waste with the addition of yeast decreased by 4.55%, while the cassava peel waste with the addition of acetate increased by 36.36%. Then, at the 22nd-hour measurement, the voltage of cassava peel waste with the addition of yeast decreased by 25.38%, while the cassava peel waste with acetate decreased by 7.69%. Furthermore, for each substrate, there was an insignificant decreasing and increasing in the measurement from the 23rd to the 36th hour. The average value of the decrease and increase in cassava peel waste with the addition of yeast at the 1st-hour to 36th-hour measurement was 2.58%, while the cassava peel waste with the addition of acetate was 1.79%. So, the voltage value in the last measurement was 36 hours on pure cassava peel waste of 17.15 V. In contrast, cassava peel waste with the addition of yeasts is 17.42 V, and cassava peel waste with acetate is 17.57 V. The joule thief circuit reacts quickly, so the voltage decreases faster.

MFC system current measurement

The current produced by the joule thief module that was measured for 36 hours as shown in **Figure 14** as graph the current strength to time.



Information:
a = Pure cassava peel waste;
b = Cassava peel waste + yeast 24gr;
c = Cassava peel waste + 16 ml acetate.

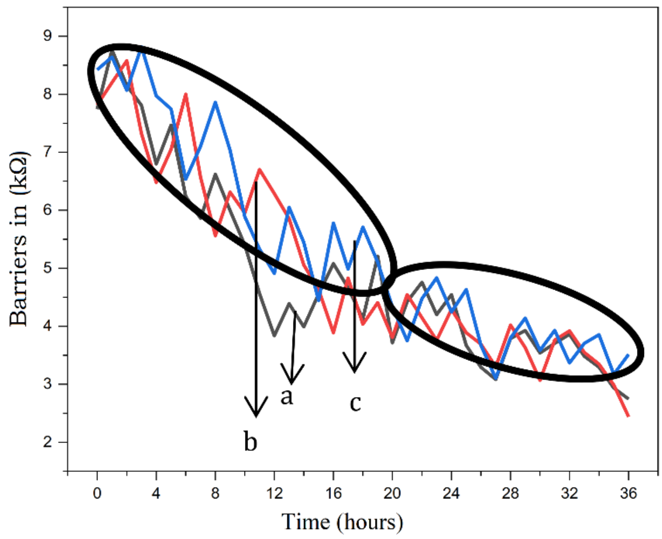
Figure 14. The relationship between the value of the current strength with time

Figure 14 is the result of measuring the current strength generated by the joule thief module. The current strength is obtained after the generator is connected to the joule thief module, and measurements are made using a multimeter for 36 hours. In the first measurement, which is 0 hours, cassava peel waste with acetate of 0.42 mA, while pure cassava peel waste produces a current of 0.4 mA, and cassava peel waste with the addition of yeast is 0.38 mA. It shows that cassava peel waste with the addition of acetate produces a current strength value of 5% greater than the value of pure cassava peel, and cassava peel waste with the addition of yeast produces a current strength of 5% greater than pure cassava peel waste. At the 1st-hour- to 18th-hour measurement of cassava peel waste with the addition of yeast, there was an insignificant decrease and increase, so the average current strength value was 15.37%.

In comparison, the current of cassava peel waste with the addition of acetate has average of 15.37%. Then, from the 19th hour until the 36th hour, the average current of cassava peel waste with the addition of yeast has 6.54%, while the cassava peel waste with the addition of acetate was 9.71%. So, the final measurement the current of cassava peel waste with yeast was 0.14 mA, and on cassava peel waste with the addition of acetate of 0.20 mA. The increase and decrease in the value of the current strength occurred continuously until the end of the measurement (36 hours). It was due to an electrical double layer, when the electrolyte was left for longer it would be flatter and decrease electric current (Pauzi & Wicaksana, 2020).

Power on the MFC system

Equation (2) substitutes the measured voltage and current to obtain the resulting power value. For 36 hours, pure cassava peel with addition of yeast and acetate is shown in **Figure 15**.



Information:
a = Pure cassava peel waste;
b = Cassava peel waste + yeast 24gr;
c = Cassava peel waste + 16 ml acetate.

Figure 15. Graph Power to time

Figure 15 shows the power generated by the joule thief module. The power was obtained after the generator was connected to the joule thief module. In the first measurement (hour 0), cassava peel waste with the addition of acetate produced a greater power of 8.42 W compared to pure cassava peel waste and cassava peel waste with the yeast of 7.74 W and 7.81 W. 1 to 19 hours, the power of cassava peel waste with the addition of yeast was increased and decreased by an average of 15.92%. In contrast, the cassava peel waste with the addition of acetate increased and decreased power by an average of 14.93%. Then, from the 20th hour to the 36th hour, the power of cassava peel waste with the addition of yeast was increased and decreased insignificantly or exceptionally good, with an average of 6.23%, while the cassava peel waste with the addition of acetate was increased and decreased by an average of 10.79%. It happens because the power value (P) is the product of the resulting voltage (V_b) and current (I); if V_b and I are more significant, the P value will be more excellent and vice versa; the smaller the I value, the smaller the value will be the resulting P value. It also occurs due to corrosion on the electrodes and the reduced concentration of substrate and seawater, which causes a reduction in the electrical energy produced (Rizky, 2019).

In this study, the joule thief increases the voltage, obtaining reasonably high light intensity because the current and light intensity values are directly proportional: the higher the electric current, the greater the light intensity obtained.

4. Conclusions

Based on the results and discussion of this study, it was concluded that the MFC system using cassava peel waste as a substrate produced good electrical characteristics in the form of voltage and current. The electrical characteristics of the MFC system produce a maximum voltage of 3.85 V and a current of 0.85 mA. The MFC system generates a relatively high maximum power by adding yeast and acetate. The maximum power produced by adding yeast is 2.51 mW and with the addition of acetate of 2.18 mW. The MFC system uses a joule thief amplifier circuit that affects the voltage and current generated. The maximum power produced with the addition of acetate is 8.42 W; with the addition of yeast, it produces a power of 7.82 W, and without any addition (pure), it produces a power of 7.74 W.

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