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Study of Microbial Fuel Cell Technology using Dangke, Whole Milk, and Whey Substrates

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Abstract

Research with the aim of utilizing and processing dangke, whole milk, and whey as substrates in Microbial Fuel Cell-based research has been successfully conducted. The substrates were placed in anode chamber and $KMnO_4$ electrolyte solution was used in cathode chamber. The two chambers were then connected by a salt bridge. The Saccharomyces Cerevisiae microorganism was used as a catalyst compound. The highest voltage measurement results for each substrate were obtained at 659 mV for dangke, 670 mV for whole milk, and 998 mV for whey. The current measurement on each substrate of dangke, whole milk, and whey, respectively, it was 0.29 mA, 0.23 mA, and 0.37 mA. In general, the measurement results show that the MFC made using whey substrate has the best quality with a power density of 9.23×10^{-3} W/m^2. Thus, whey can be considered a promising alternative source of electricity by converting organic compounds.

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1. INTRODUCTION

Sustainable alternative energy sources are still an interesting topic in the world. One of the innovations in renewable energy is the Microbial Fuel Cell or MFC. Microbial Fuel Cell is a promising alternative technology to be developed. MFC is a device that uses bacteria to generate electricity from organic and non-organic compounds. According to Barua and Deka [1], bacteria are capable of producing electrical energy. There have been many studies examining ways to improve the performance of MFCs in generating electrical energy. Min et.al [2] studied the effect of temperature and anode media on the production of electrical energy. From the results of this research, the maximum power was produced at operating temperature of 30ºC and with the addition of phosphate buffer at the anode.

In addition, optimization of the MFC was also carried out in terms of the configuration of the MFC reactor, the type of electrolyte, and the electrode material for the electrical power generated. The result is a membrane less MFC with potassium ferricyanide as the electrolyte and granular activated carbon as the electrode capable of producing maximum electrical power [3]. Various types of microbes have been used in MFCs, including Geobacter sulfurreducens [4], Escherichia coli [5], Lactococcus lactic [6], Saccharomyces cerevisiae [7], and Shewanella oneidensis [8]. As well as several existing studies utilizing various kinds of substrates such as tofu dregs and other substrates that can be used as substrates for bacterial metabolism.

One of the substrates that has the potential to be developed using MFC technology is whey. Whey is a waste from processing cheese that is not used further. Currently, there are many cheese industries that have begun to develop along with the increasing interest of the community in processing food ingredients by adding cheese. Among the people of Enrekang district, there is a traditional cheese processing known as dangke. Dangke is a processed cow or buffalo milk without preservatives. The abundance of milk , dangke and whey that is wasted in Enrekang district causes the processed products to end up as animal feed, even though if studied carefully, the content is almost the same as processed industrial cheese. This is very unfortunate considering that whey contains protein, fat, and lactose that have great potential if further developed. Based on the potential of MFC as an electricity supplier and the potential of whey which has not been further exploited, the authors are interested in developing cheese whey as a substrate for bacteria growth in an MFC reactor to produce electrical energy.

Research using cellulose and glucose substrates has been carried out using different types of microbes. In the study of MFC made from cellulose that has been carried out by Kurniawati and Sanjaya [9], cow feces was used as a substrate with the microorganism Pseudomonas sp. with the resulting voltage of 0.75 V. In this study using Nafion as a proton exchange membrane. Nafion has been shown to have high proton conductivity and good chemical stability, but nafion has the disadvantage that it has an expensive price of around \$700/m^2 [10]. One way to obtain an economical proton exchange membrane is to use a salt bridge solution. In a study conducted by Maswati et al. [11] which used a salt bridge made of gelatin mixed with 0.1 M KCl then put into a chamber made of PVC pipe. The resulting performance is proven to be good because KCl has a high value of electrical productivity. The substrate used is water hyacinth with the microorganism Pseudomonas sp. produces a current of 3.06 mA and a voltage of 0.84 V. Research on glucose has also been carried out by ND Utari et.al [12] using a fruit waste substrate with the microorganism Saccharomyces Cerevisiae or yeast producing a power density of 201.37 mW/m^2. Saccharomyces Cerevisiae bacteria are more often used in the manufacture of MFC tools because they are more adaptive to various types of substrates used so that their performance can be said to be stable for various substrates. In addition, these bacteria are easy to find and have a relatively cheap price. Another way that is used to improve the performance of MFC equipment is to use the right electrolyte solution with the right concentration [13]. Electrolyte solution greatly affects the resulting voltage because it is influenced by the standard reduction potential of the solution. One of the electrolyte solutions that is often used in MFC equipment is potassium permanganate ($KMnO_4$) because it has a strong oxidizing agent with a standard reduction potential of 1.7 V. Cathode containing $KMnO_4$ has been carried out in Utami's study [14] using 0.1 M $KMnO_4$ with banana peel waste substrate produces a power density of 31.9 mW/m^2.

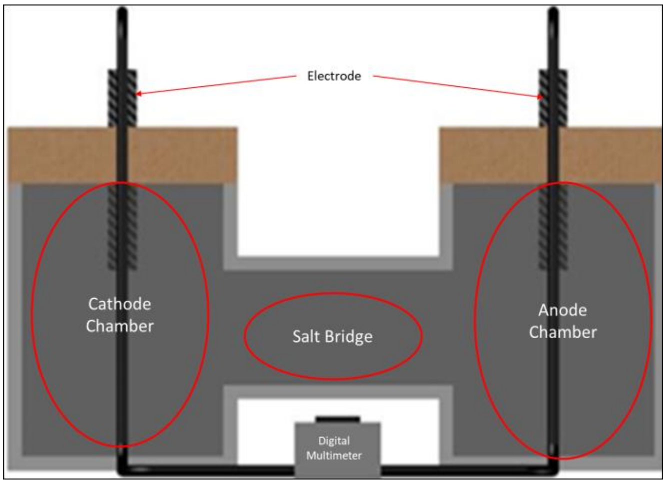
Based on this, the researchers tried to utilize and process whey, dangke, and whole milk into substrate materials on the MFC device. In this study, the use and comparison of whey, dangke and milk were used as substrates alternately and placed in the anode chamber and for the cathode chamber $KMnO_4$ electrolyte solution was used because of the good standard reduction potential. The two chambers are then connected by a membrane made of salt bridges from mixing agar and KCl. The microorganisms used were the same for both substrates, namely Saccharomyces Cerevisiae or yeast because they had good performance to convert organic compounds into energy. Then the research continued with the measurement of the electric current and voltage produced. Measurements are made without installing external resistance on the tool. In the development of MFC, of course, increasing the resulting power density is a target that must be achieved and its usefulness continues to be developed. To know the quality of the substrate and the design of the MFC, it is necessary to test the power density.

2. EXPERIMENT

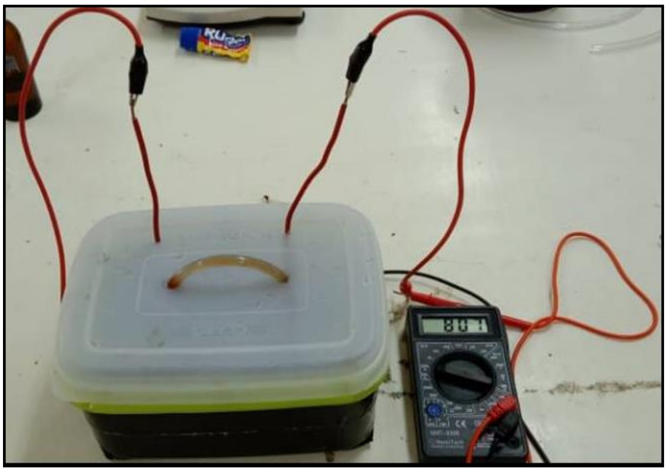
The working procedure in this study consisted of three steps. The research began with the design and manufacture of the MFC reactor (Figure 1), preparation of dangke, whole milk, and whey substrates, as well as testing the voltage and power density of the MFC reactor.

2.1 MFC Reactor Design and Manufacturing

The reactor used in this study is based on a double chamber. In the reactor there are two chambers that are be separated by a salt bridge. The first one is anode and the other one is cathode with each chamber having a volume of 700 ml. Both chambers are in the form of blocks with dimensions of 7 cm x 10 cm x 10 cm made of acrylic with a thickness of 3 mm whose top is made to be open and closed because the reaction process requires anaerobic conditions. In each room, a hole about 4 cm x 4 cm was made to attach a salt bridge. At the top of each chamber, a 1 cm diameter hole was made for the electrode installation.



(a)



(b)

Figure 1. (a) Reactor Design **(b)** MFC Reactor

2.2 Dangke, Whole Milk, and Whey Substrate Preparation

Substrate preparation begins with activating the graphite electrode by immersing the graphite electrode into a solution of HCl and NaOH for 12 hours each. While waiting for the activation process, a salt bridge was made by dissolving 3 grams of KCl into the gelatin. Next, the cathode chamber as filled with 47.6 grams of $KMnO_4$ which was previously dissolved in 500 ml of Aquabides. As for the anode chamber, it was filled with a solution made from a mixture of 5 grams of yeast and 150 ml of Phosphate Buffer. In addition, 500 grams of mashed dangke was added to the anode chamber. The two filled anode and cathode chambers were then connected using a salt bridge that had been made. After that, graphite electrodes that had been wrapped with copper wire were inserted into each of the cathode and anode chambers. The last step is to connect each end of the copper wire with a multimeter and record the results of measuring current and voltage for 5 hours with one hour intervals. The same working procedure was carried out for 500 ml of whole milk and 500 grams of whey.

2.3 The Power Density of MFC Technology

In this study, an analysis of the effect of substrate variations on the performance of the MFC was carried out which can be seen from the current and voltage measurements using a digital multimeter. MFC was measured based on the length of working time to determine the large changes in current and voltage without resistance. From the current and voltage strength data, the power density value can be calculated, namely power per unit area of the anode compartment.

3. RESULT AND DISCUSSION

3.1 MFC Reactor Design

The Microbial Fuel Cell (MFC) reactor in this study is dual chamber based as shown in Figure 1 (a), which has two compartments (anode and cathode) with electrodes in each compartment. The anode compartment is tightly closed to prevent the entry of oxygen because the anode chamber contains anaerobic bacteria to carry out metabolic processes. While the cathode chamber is closed normally so that dirt or other bacteria do not enter from the environment. The reactor is also equipped with a salt bridge as a separator between the anode and cathode chambers and serves to move protons from the anode to the cathode.

This system corresponds to the dual chamber microbial fuel cell reactor used by Rahimnejad et al [3] where carbon graphite electrodes were used and prior to the study preparation was carried out. The purpose of electrode preparation is to regenerate the electrode and remove metal contamination and organic matter. The difference is that in the Rahimmnejad et al. reactor, Nafion 117 membrane was used as a separator of the anode and cathode compartments. Meanwhile, in this study, a salt bridge was used as a separator that had previously been made using gelatin and KCl. In addition, different materials were used in the manufacture of the reactor, namely the use of glass replaced with acrylic which aims to make the reactor more durable.

The purpose of using a double chamber system is to make electron attachment to the electrode more effective when compared to a single chamber system. Where, bacterial metabolism that takes place in batches in one container causes collisions between electrons when bacteria begin to enter the exponential phase so that many electrons cannot stick to the electrode and result in less than maximum electrical energy produced. In the double chamber system, an electrolyte solution is also used as an electron acceptor which will help the performance of the electrodes to maximize the electrical energy produced.

3.2 Anode and Cathode Reaction Mechanism

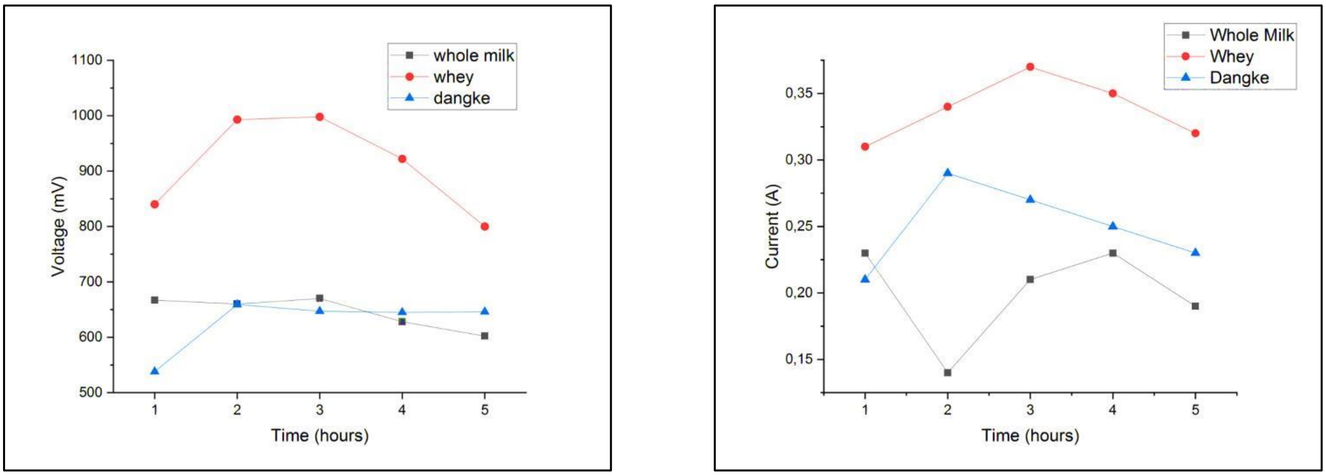
Inside the anode chamber, there is a bacterial culture and a substrate. For the metabolic process of bacteria, glucose is needed as a carbon source. The glucose will be converted into carbon dioxide, protons and electrons. In this study, dangke, whole milk, and whey were used interchangeably as carbon sources. The three carbon sources in question were obtained from Danca Hamlet Farm and Dairy Processing, Bontongan Village, Enrekang Regency.

Furthermore, the electrons generated from metabolism will reduce NAD^+ to NADH in bacterial cells. In the electron transfer chain that occurs at the bacterial plasma membrane, NADH will be oxidized to form NAD^+ and electrons. The electrons that are still in the cell are then transferred outside the cell to the electrode at the anode by mediators produced by the bacteria. The electrons then flow to the cathode through the external circuit, while the H+ protons diffuse through the salt bridge.

On the cathode, there is potassium permanganate (KMnO4) which is useful for capturing electrons from the anode. In solution, KMnO4 is ionized into K^+ and MnO^- ions. Furthermore, Mn^{7+} ions from MnO^- will be reduced to Mn^{2+} ions with the help of electrons from the anode. Then Mn^{2+} ions are re-oxidized by H^+ protons at the cathode with the help of oxygen. The interaction between protons and electrons is what causes the potential difference between the ends of the electrodes at the cathode and anode. The electrical energy produced by this MFC system is proportional to the metabolism of bacteria, while the efficiency of electron transfer from bacteria to electrodes is proportional to the number of bacterial cells that contact electrodes [15].

3.3 The Measurement of Electricity

The voltage and current measurement results for each substrate are shown in the Figure 2.



(a) **(b)**

Figure 2. Measurement results of a) Voltage and b) Currents for Dangke, Whole Milk, and Whey Substrate on MFC Technology

Figure 2 shows that the highest voltage and current values were obtained from the whey substrate, which were 998 mV and 0.37 mA, respectively. The voltage and current measurement results tended to increase at the beginning of the measurement until three hours of measurement and decreased after that. This is probably due to the decreased metabolism of bacteria in a relatively long time. The low current value is caused by bacteria that are still adapting to the environment so that the growth of bacteria is very slow, resulting in the production of electrons produced is still small. This affects the results of strong current output, considering that strong currents can occur when there is attachment to the electrode. In line with the results of voltage and current measurements, the results of the calculation of the high-power density of the whey substrate with a value of 9.23 x 10-3 W/m2 as shown in Figure 3 below.

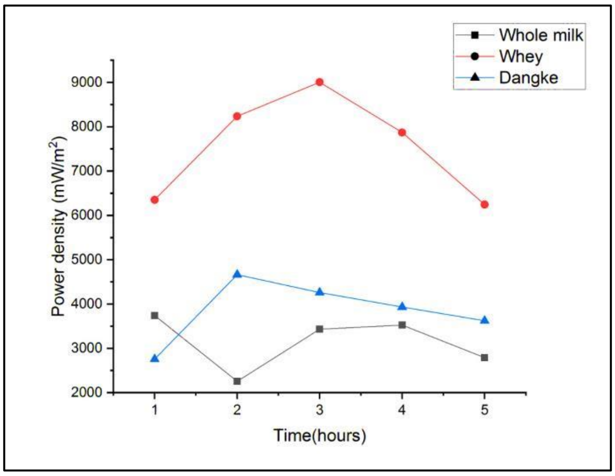


Figure 3. Power density calculation results of Dangke, Whole Milk, and Whey as Substrate in MFC Technology

In general, the results show that whey, which is the waste of the milk and dangke processing industry, has the potential to be utilized as an alternative source of electrical energy in the future through MFC technology. However, more effective efforts are needed to process this waste in order to obtain maximum results; in this case the voltage and current generated can be greater and stable in the long term.

4. CONCLUSION

The potential of natural materials in the form of dangke, whole milk, and whey as an alternative source of electrical energy has been successfully explored using double chamber-based MFC technology. The results of measurement show that the highest value of voltage and current were 998 mV and 0.37 mA respectively, which were obtained from the substrate using whey.

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