RiCE: Research in Chemical Engineering

Volume 3 No. 2, 2024

Journal homepage: https://ejournal.ump.ac.id/index.php/rice

Wastewater Treatment of Tofu Industry Using Microbial Fuel Cell Method

Anwar Ma'ruf*, Tia Anggraeni

Chemical Engineering Department, Engineering and Science Faculty,
Universitas Muhammadiyah Purwokerto, Purwokerto, Indonesia
*Corresponding author:anwarump@yahoo.com

Article Info

Submited:
9 December 2024

Revised:
30 December 2024

Accepted:
31 December 2024

ABSTRACT

Microbial Fuel Cell (MFC) is a system for generating electrical energy by utilizing the interaction of bacteria with substrate. MFC generates electricity by oxidizing organic matter with the help of microbes. In this study, the substrate is tofu wastewater and cow rumen bacteria. The MFC used is a dual chamber equipped with a TiO_2 clay ceramic membrane. This study aimed to determine the production of electrical energy from tofu liquid waste substrate using MFC technology with the addition of nutrients in the form of urea and bacteria from the cow's rumen. The variation of the ratio of tofu liquid waste used is 20%. 40%, 60%, 80% and 100%. While the variations in the concentration of urea used were 1 - 5 grams. The results show that the greater the variation in the ratio of tofu liquid waste, the greater the energy potential. The highest average electric power is 381 volts from the 100% tofu liquid waste ratio. In addition, the greater the urea concentration the more it produces a large energy potential. The highest average electric power is 421 volts from 5 grams of urea concentration. The TiO_2 clay ceramic membrane in the MFC system was able to reduce the TSS and TDS values of tofu liquid waste. The highest percentage decrease for TSS is 37% and for TDS is 25% at the variation of the ratio of tofu liquid waste 100%.

Keywords: Microbial Fuel Cell, tofu wastewater, ceramic membrane

1. INTRODUCTION

Currently, there is an increase in the need for electrical energy due to the increasing population and industrialization. The electrical energy used in Indonesia is generated from fossil fuels, which are non-renewable natural resources and can cause an electrical energy crisis. Therefore, efforts are needed to produce renewable energy instead. One way is to use microorganisms based on electrochemical cells to produce electrical energy. The Microbial Fuel Cell method is used to produce electrical energy. Microbial Fuel Cell is a fuel cell that uses organic materials that are used as an energy source for microorganisms to carry out metabolic activities. MFC uses microorganisms as biocatalysts to convert chemical energy from organic materials into electrical energy[1].

Microbial Fuel Cell (MFC) has the advantage that the electrical energy produced can come from the utilization of organic waste. One of the organic wastes that can be utilized is liquid tofu waste. Liquid tofu waste is liquid waste that comes from the remaining processing of the tofu industry. Liquid tofu waste is one of the wastes that causes many environmental problems because of its high organic content, which causes an unpleasant odor. The high organic content in tofu liquid waste causes this waste to pollute the environment if not handled properly. Therefore, to reduce the impact caused, efforts are made to utilize tofu liquid waste as a substrate in the Microbial Fuel Cell (MFC) system. The application of MFC not only helps in the wastewater treatment process, but also produces electrical energy[2].

Microbial Fuel Cell (MFC) consists of anode and cathode chambers. Where the anode chamber contains the substrate while the cathode chamber contains the electrolyte. The proton exchange membrane (PEM) separates the anode and cathode chambers. Protons and electrons are produced from the anode chamber, the anode is where the substrate oxidation such as glucose, acetate and organic waste occurs. Later, electrons will move to the cathode chamber through an external circuit to produce an electric current. While the protons produced move through the proton exchange membrane (PEM) to the cathode chamber to meet the electrons[3].

The MFC system usually uses a Proton Exchange Membrane (PEM) such as Nafion and ultrex. However, because the price of PEM is relatively expensive and the presence of water in the anode vessel, PEM becomes ineffective because water will conduct protons to the cathode. On the other hand, the removal of Proton Exchange Membrane (PEM) from the MFC system also has disadvantages. This is because without a membrane, oxygen will diffuse into the anode vessel so that it will affect the strength of the electricity produced. This is caused by increased oxygen transfer to the anode. Oxygen in the anode vessel will cause a decrease in the potential of the substrate due to the aerobic oxidation reaction of bacteria [4]. Many methods have been used to replace conventional Proton Exchange Membrane (PEM) with better materials. One way is to use ceramic membranes. Ceramics generally have stability, increase power, and provide a favorable environment for the metabolism of electroactive microorganisms. Ceramics in MFC technology are used as structural materials, media for ion exchange, and electrodes for Microbial Fuel Cells (MFC)[3].

The purpose of this study is to produce alternative electrical energy, by utilizing tofu liquid waste as a substrate for ceramic membrane applications in the MFC system. Therefore, this study is expected to provide information on the potential for electrical energy produced. In addition, it is expected to be an efficient and environmentally friendly alternative method for power generation.

2. MATERIALS AND METHODS

2.1 Materials

Tofu wastewater, HCl, NaOH, Aquadest, Ceramic membrane Clay-TiO_2, Urea, Cow Rumen, Glucose

2.2 Experimental procedure

2.2.1. Microbial Fuel Cell Reactor Preparation

The reactor is made of plastic (jar container) with a cover on the top. A hole is made at the end of the reactor lid with a soldering iron. A hole is made on both sides of the chamber measuring 3 cm x 3 cm as a place for the membrane. TiO2 clay ceramic membrane is used as a proton exchange membrane.

2.2.2. Cathode and Anode Compartments

The cathode is filled with distilled water with a volume of 5 liters of distilled water. While the anode contains a liquid tofu waste substrate with a waste to water ratio of 20%, 40%, 60%, 80% and 100%. The liquid tofu waste is incubated for 48 hours before use. After that, 100 ml of cow rumen fluid is added to the anode. Urea is also added to the anode with a urea concentration of 1%, 2%. 3%, 4% and 5%. Cow rumen bioactivator is made from a mixture of 100 grams of sugar, placed in a container containing 1 liter of water, then added 200 grams of bran and stirred until smooth. Next, 500 g of cow rumen is added, stirred and tightly closed for 2 days. The stirring process is repeated on the 3rd day and the mixture can be used as a bioactive agent on the 4th day. However, the rumen is filtered before use.

2.2.3. MFC Experiment

The electrodes are filled in the cathode and anode circuit, but before using the electrodes, the electrodes are first activated and cleaned. Soaking for 1 day using 1 M HCl on the graphite rod electrode and zinc electrode, after which rinsing is carried out using distilled water. Then soaking is carried out again for 1 day using 1 M NaOH and rinsing is carried out using distilled water. The electrodes that have been rinsed are soaked using distilled water until they will be used in the Microbial Fuel Cell experiment. The cathode section contains a zinc plate electrode (Zn) and the graphite rod will be used on the anode section. The electrodes are connected to a series of cables (for the electron transfer process) on a digital multimeter. After that, the results of the current strength shown on the multimeter screen are recorded.

2.3 Analysis of Response

2.3.1. Electricity Production Analysis

Electricity production was analyzed using a multimeter, with the negative pole in the anode space and the positive pole in the cathode space. The MFC process was carried out for 30 hours with data collection every 1 hour.

2.3.1. Analysis of TDS and TSS

TSS was analyzed by gravimetric method and TDS was analyzed by TDS meters.

3. RESULTS AND DISCUSSION

This study used TiO2 clay ceramic membranes on Microbial Full Cell for processing liquid tofu waste. Liquid tofu waste was used as a substrate located in the anode chamber and urea and cow rumen bacteria were added. While the cathode chamber was filled with 5 liters of distilled water as an electrolyte in the MFC. There is a mediator between the cathode and anode chambers, the mediator is the TiO2 clay ceramic membrane, its function is as a proton exchange

membrane. In this study, the types of electrodes used were copper and activated carbon. The operating time of this MFC system was carried out for 30 hours. Measurements of the electrical power that occurred during the operation of the Microbial Fuel Cell were carried out, and tests were carried out in the form of TSS and TDS tests before and after MFC treatment. This study aims to determine the effect of the ratio of liquid tofu waste and the effect of adding urea in generating electricity and the ability of MFC to reduce the TDS and TSS values of liquid tofu waste.

3.1. Characteristics of Liquid Tofu Waste

Waste quality is a specification of waste that is measured by the amount of pollutants in the waste. The pollution content of the waste includes various parameters. The lower the number of parameters and concentrations, the lower the risk of environmental pollution[5]. There are two factors that must be considered in tofu and tempeh industrial waste, namely physical and chemical properties. Physical properties include temperature, color, total solids and odor. While chemical properties include organic materials, inorganic materials and gases. Organic substances contained in tofu liquid waste include 40% - 60%, carbohydrates 25% - 50%, fat 10%, and other suspended solids which in nature can undergo physical, chemical and biological changes that will produce toxic substances or create a growing medium for pathogenic microorganisms. The large amount of water used at each stage of the tofu making process will certainly increase the amount of liquid waste produced. If waste is disposed of directly without going through a processing process, it will cause environmental pollution because organic materials will settle in water bodies, rot and pathogenic microorganisms will develop which cause disease.

To control environmental pollution from tofu liquid waste, the government issued Regulation No. 05 of 2014 Attachment XVIII concerning Wastewater Quality Standards for Soybean and Nut Processing Businesses and/or Activities. Wastewater Quality Standards are listed in Table 1.

3.2 Effect of Tofu Wastewater Ratio on Electrical Power

The electric current was measured using a multimeter where the negative pole was connected to the anode while the positive pole was connected to the cathode. The substrate is the factor that most affects the performance of MFC in generating electricity. In this study, a substrate derived from tofu liquid waste was used.

Figure 1 shows the effect of the tofu liquid waste ratio on electrical power, for a tofu liquid waste ratio of 20%, electrical power is generated of 192 volts, at a waste ratio of 40% it is 262 volts, at a waste ratio of 60% it is 299 volts, at a waste ratio of 80% it is 315 volts and for tofu liquid waste of 100% it is 362 volts. From these data, it was found that the highest electrical power was generated from a tofu liquid waste ratio of 100%. The greater the organic content, the greater the potential energy produced. This is because of the large number of organic compounds as microbial food so that microbial metabolism increases and produces greater electricity. The metabolic process produces protons and electrons. Protons diffuse through the salt bridge or membrane to the cathode space. Electrons are carried to the electrodes at the anode flowing through the electrical circuit to the cathode. The flow of electrons from the anode to the cathode produces a potential difference that produces electricity [6].It shows that a reactor with a substrate volume of 250 ml produces greater electrical power, namely 6121526.4 mJ compared to a reactor with a substrate volume of 100 ml which only produces power of 956707.2 mJ. This shows that the substrate ratio affects the amount of electricity production. In this study, using variations in the substrate ratio showed that the results of the substrate ratio can affect the amount of electricity production. The resulting electrical power is getting bigger along with the addition of the liquid tofu waste substrate ratio [6].

3.3 Effect of Urea Concentration on Electrical Power

Nutrients play a major role as a source of energy, a building block for cells, and as an electron acceptor in bioenergy reactions (reactions that produce energy). Nutrients function as additional organic materials consumed by microorganisms to help bacteria produce electricity. In this study, the nutrients used came from urea.

Figure 2 shows the effect of urea concentration on the electrical power produced, the average electrical power produced for a urea concentration of 1 gram is 346 volts, for 2 grams of urea the power produced is 360 volts, for 4 grams of urea the power produced is 390 volts and for a urea concentration of 5 grams is 414 volts. From these data, it was found that the highest electrical power was produced from a urea concentration of 5 grams. The greater the urea concentration, the more potential energy is produced Putranto (2018)[7].

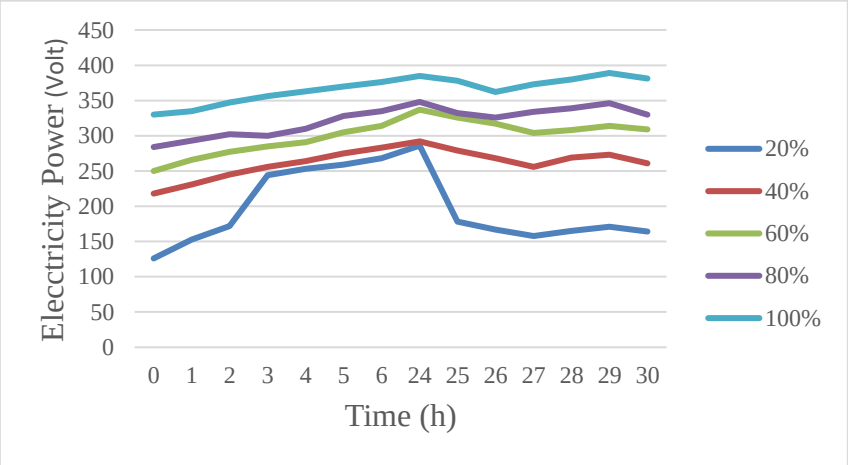

Figure 1. Power of Electricity at various concentration of tofu wastewater

Table 1. Maximum concentration of wastewater

Parameters	Maximum Concentration, mg/L
COD	300
BOD	150
TSS	200
TDS	2000

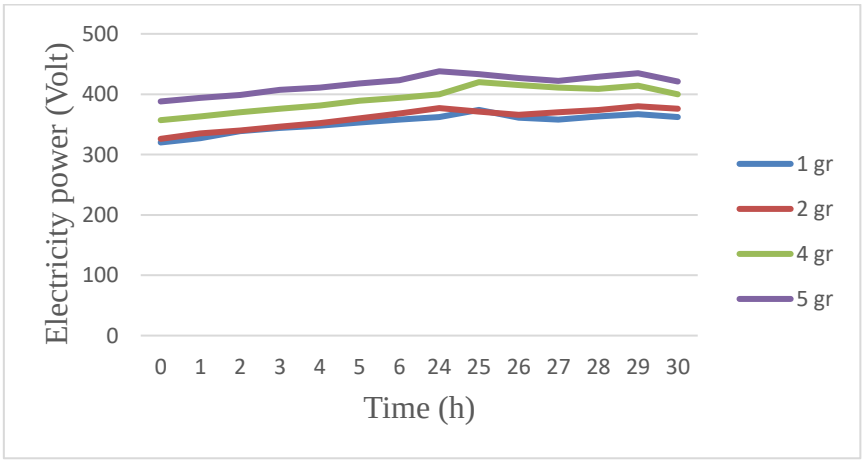

Figure 2. Power of Electricity at various addition of urea

Table 2. TTS and TDS parameters

Parameters	Tofu waste concentration				
	20%	40%	60%	80%	100%
TSS initial (mg/L)	400	400	500	700	800
TSS initial (mg/L)	300	300	400	500	500
TDS initial (mg/L)	784	807	818	826	844
TDS initial (mg/L)	705	686	670	653	633

This is because the addition of urea not only adds nutrients to the substrate, but also as additional food for bacteria to grow and live in the substrate if the bacteria increase, of course it will increase the electrical energy produced because the bacteria will increasingly degrade the liquid tofu waste substrate[8]. There was an increase in electrical power in the addition of urea from 10 grams of 451 volts while the addition of 8 grams of urea was only able to produce 400 volts. In this study, urea was added with 1 gram, 2 grams, 3 grams, 4 grams, and 5 grams. The resulting electrical power is greater along with the addition of the amount of urea[9].

3.4. Effect of Microbial Fuel Cell in Reducing TDS and TSS Values

Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) are parameters that indicate the presence of organic load in wastewater. The higher the TDS and TSS levels, the greater the presence of organic pollutants in the waste. After the MFC system was implemented, there was a decrease in TSS and TDS values. At a tofu liquid waste ratio of 20%, there was a decrease in TSS of 15%, for a ratio of 40% there was a decrease in TSS of 15%, for a ratio of 60% there was a decrease in TSS of 20%, for a ratio of 80% there was a decrease in TSS of 28% and for a ratio of 100% there was a decrease of 37%. The highest decrease in TSS concentration reached 37%, namely at a tofu liquid waste ratio of 100% (**Table 2**). This is because the greater the amount of substrate contained in tofu liquid waste, the greater the organic load that must be decomposed by microbes. So that at a waste ratio of 100% the decrease in TSS is higher than at a ratio of 20%. While at the TDS concentration, the tofu liquid waste ratio also decreased. The highest decrease in TDS concentration occurred at a tofu liquid waste ratio of 100% with a decrease in TDS of 25%. There was a decrease in TSS and TDS, resulting in a decrease in TSS and TDS values of 43% and 20%. This occurs because organic compounds in liquid waste have been partially degraded during the running of the MFC. Organic compounds are degraded through the bacterial metabolism process. Bacteria use organic compounds as substrates and produce electrons as their metabolic waste [7].

4. CONCLUSION

The results of the study indicate that variations in the ratio of tofu liquid waste affect the performance of the Microbial Fuel Cell in generating electricity. The greater the organic content, the greater the potential energy produced. The highest average electrical power is 381 volts from a tofu liquid waste ratio of 100%. The results of the study indicate that urea concentration affects the performance of the Microbial Fuel Cell in generating electricity. The greater the urea concentration, the greater the potential energy produced. The highest average electrical power is 421 volts from a urea concentration of 5 grams. The TiO2 clay ceramic membrane in the MFC system is able to reduce the TSS and TDS values of tofu liquid waste. The highest percentage reduction for TSS is 37% and for TDS is 25% at a variation of the tofu liquid waste ratio of 100%.

ACKNOWLEDGMENT

Thanks to the Research and Community Service Board of UMP

CONFLICT OF INTEREST

No potential conflict of interest was reported by the author(s).

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Anwar Ma'ruf: Conceptualization, Methodology, Investigation, Formal analysis, Writing original draft. Supervision.
Tia Anggraeni: Data curation, Data analysis.
All authors have read and agreed to the published version of the manuscript.

REFERENCES

[1] Aghababaie, M., Farhadian, M., Jeihanipour, A., & Biria, D. (2015). Effective factors on the performance of microbial fuel cells in wastewater treatment–a review. *Env Tech Rev*. 4(1): 71–89. https://doi.org/10.1080/09593330.2015.1077896

[2] Hermayanti, A., & Nugraha, I. (2014). Potensi perolehan energi listrik dari limbah cair industri tahu dengan metode salt bridge microbial fuel cell. *In J. Sains Dasar* , 3(2): 162-168.

[3] Winfield, J., Gajda, I., Greenman, J., & Ieropoulos, I. (2016). A review into the use of ceramics in microbial fuel cells. *Biores Tech*. 215: 296–303. https://doi.org/10.1016/j.biortech.2016.03.135

[4] Kim, T., Kang, S., Sung, J. H., Kang, Y. K., Kim, Y. H., & Jang, J. K. (2016). Characterization of polyester cloth as an alternative separator to nafion membrane in microbial fuel cells

for bioelectricity generation using swine wastewater. J Micro Biotech, 26(12): 2171–2178. https://doi.org/10.4014/jmb.1608.08040

[5] Sahu, O. (2019). Sustainable and clean treatment of industrial wastewater with microbial fuel cell. Results in Eng. 4:100053. https://doi.org/10.1016/j.rineng.2019.100053

[6] Das, S., & Mangwani, N. (2010). Recent developments in microbial fuel cells: A Review. *J Sci Ind Res* . 69(10):727-731

[7] Putranto, A. W., Sugiarto, Y., Kusumarini, N., Wiranti, T., & Normalasari, L. (2018). Pengaruh Pemberian Pupuk Urea Dan Jarak Elektroda Terhadap Tegangan Listrik Plant Microbial Fuel Cell Tanaman Padi (*Oryza sativa*). J Tekn Pert. 19(1):43-50. doi: 10.21776/ub.jtp.2018.019.01.5

[8] Lazcano, C, Brandón, M, G, Revilla, P,& Domínguez, J. (2013). Short-term effects of organic and inorganic fertilizers on soil microbial community structure and function. *Biol Fert Solis*. 49(6):722-72

[9] Moqsud, M, A, Yoshitake, J, Bushra, Q, S, Hyodo, M, Omine, K, Strik, D. 2015. Compost in plant microbial fuel cell for bioelectricity generation. Waste. Manag. 36:63-69