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EFFECT OF DIFFERENT MEMBRANE USE IN MICRO-BACTERICAL VOLTAIC CELL FOR ELECTRICAL ENERGY GENERATION FROM WASTEWATER

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ABSTRACT

The sustainable, green and renewable energy are characteristics of energy source that are highly demanded nowadays. The world energy annual reported that the escalating electricity consumption will surpass energy output. For example, oil, biofuel, hydropower, nuclear and natural gas were projected depleted by 2050. Therefore, another alternative energy source from wastewater and design two columns of reactor was created, using the voltaic cell working principle that is capable to generate voltage. The voltage is one joule of energy per one coulomb unit charge passed. The wastewater contributed to the air pollution and released a bad smell to the surrounding environment. The method employed in this study was the anaerobic digestion (AD) from the fermentation process. Our aim in this study is to vary the type of membrane bridge in micro-bacterial cell, were parafilm, polyvinylidene fluoride-co-polyvinyllimdazole (PVDF-g-PVim) and agar-agar membranes, while the sample used was 100 mL of wastewater as a source for biocatalyst that was fixed with temperature of 35 oC fermentation. As a result, the value of voltage was increased from 0.50 V to 1.25 V measured using voltage meter, corresponding to parafilm membrane, agar-agar membrane and PVDF-g-PVim membrane, respectively. By *optimizing the membrane bridge type, the voltage of the micro-bacterial cell was enhanced almost three times compared to a conventional membrane. Our findings suggested that the high voltage can be obtained by using a cheap and eco-friendly membrane, and yet the voltage production from micro-bacterial cell can be improved, thus providing another alternative energy source in the future.*

Keywords: *Micro-bacterial cell, Wastewater, Membrane, Voltage, Energy*

INTRODUCTION

In contemporary times, a considerable amount of liquid and solid waste was disposed without undergoing intelligent and efficient recycling processes (Noor et al., 2020). This practice was contributed to the environmental pollution, particularly in the air, and it turns leaving an unpleasant odor in its wake. There is a vital need for a new and eco-friendly alternative energy source that is not only affordable, but renewable and sustainable energy as well. Ineffectual management and treatment of the entire sewage system, a coupled problem with a lack of expertise and technology, are key factors in exacerbating this issue. Consequently, both the annual escalation of the sewage waste management system in the reservoir center and maintenance expenses are on the rise. In addition, oil, biofuel, hydropower, nuclear, and natural gas (Forsberg, 2019) were stand out as the energy sources with the highest demand and highly usage. The annual increase in population corresponds with a rise in electricity demand (Sheffield, 1998). The World Energy Annual (WEA) studies forecasts showed that the escalating electricity consumption will surpass energy output (EIA, 2016). Furthermore, several other energy sources are listed projects which are depleted by 2050 (Holechek et al., 2022). As a result, rendering them was less sustainable (Owusu et al., 2016).

The micro-bacterial voltaic cell (MBVC) technology stands out as an alternative source of renewable energy, which functions through electro-bacteria cells or micro-bacterial voltaic mechanisms. Besides, it is using electrochemical principal working (Zeev et al.,2000). This innovative system generates power by utilizing two separate columns—one for organic waste and another one for clean water, where each of them operated under distinct conditions. In the organic waste column, the material undergoes anaerobic digestion within a reactor, which contains facultative anaerobic bacteria, where it produced hydrogen ions and electrons. These ions traverse a proton through membrane bridge to the aerobic reactor, and then they combine with oxygen molecules. The aerobic process (Mondal et al., 2017) requires oxygen, that occurs in the organic waste column, while the anaerobic process does not require oxygen. Anaerobic digestion involves hydrolysis, and acidogenesis processes (Qian et al., 2022).

This simple approach requires minimal resources to generate electricity by utilizing an electrolyte in the form of anaerobic digestion (AD) liquor that derived from the fermentation (Schäpper et al., 2009) process. Initially, implementation of low-power devices, communes less than 3 volts. This innovation holds a significant potential for commercialization because of abundant raw material, it is easily operated without complicated handlings, and it reduces costs associated with current commercial energy practices. As a part of our innovation project, this technology is envisioned to reduce the cost and to enhance accessibility for affordable equipment for households. Thus, it helps the community. Moreover, it is applicable to all communities and it helps them adopt renewable, cost-effective and environmentally friendly energy sources in their homes.

Herein, our research work created a source of energy with a low cost, abundant and renewable energy from wastewater to generate electrical energy source by using MBVC, with the objectives of further improving the voltage production. Therefore, to achieve this objective, our aim of this study is to focus on the membrane bridge which has various types. A far as per our concern, the effect of different membrane use in MBVC has not been reported elsewhere. By optimizing the membrane bridge, the performance of MBVC, particularly the voltage production can be successfully enhanced and improved.

LITERATURE REVIEW

Bioenergy from renewable agricultural products and waste materials is an attractive possible solution to the energy problem, and a variety of technologies are being developed. One of the systems is bio-electrochemical systems (BESs), which utilize the interaction between microbes and solid electron acceptors or donors to accomplish the removal of contaminants from organic waste, while simultaneously generating electricity generation. In this typical system BESs, micro-bacterial voltaic cell (MBVC) is a method in which microorganisms transform the chemical energy of organic compounds into electrical energy under anaerobic conditions (Sima, 2021). This technology can be used for organic waste materials such as solid waste produced by humans, as a source for biocatalysts and as a substrate. MBVC are inexpensive to construct because the method depends on materials produced in abundance and conventionally regarded as waste. MBVC is not just an alternative source of power generation but also considered reliable, cheap, and efficient process that utilizes renewable methods and does not generate any toxic by-product. Therefore, MBVC has been shown to be a potent technology for recovery and in situ conversion of chemical energy into electricity (Aniket et al., 2023). The main components of MBVC are the two columns, which are the negative anode anaerobic column (NAAC) and positive cathode aerobic column (PCAC), separated by a proton exchange membrane (PEM), a microfilter that allows only very small positively charged ions such as hydrogen ions (H+) to fit through. The NAAC is the electrode on which microorganisms colonize, and it is submerged in the organic substrate. The oxidation process takes place in the NAAC, where the microorganisms extract electrons from the organic material and transfer them to the electrode surface. Equation (1) shows the chemical reaction that occurs in NAAC (Jessica, 2013).

Anode: CH3COO- + 4H2O $\rightarrow$ 2HCO3- + 9H+ + 8e-(1)

The PCAC can be surrounded by a variety of oxidizing agents, including air and water. H+ generated at the AAC was passed through the membrane to the PCAC and combined with electrons and oxygen on the PCAC surface to form water, thus completing the electrical circuit Equation (2) (Felipe et al., 2018).

Cathode: 2O2 + 8H+ + 8e· $\rightarrow$ 4H2O (2)

One of the factors that could affect the MBVC performance was the type of membrane used. The membrane acts as a boundary between the NAAC and PCAC. It acts to avoid the unwanted mixing of species between both columns. PEM should also facilitate the transportation of only H+ ions from NAAC to PCAC, and repel all other anions and negatively charged particles, and prevent the crossover of O2 from both columns (Kamyab et al., 2019). PEM is partially permeable and made of ionomers that only conduct proton and restrict electrons. PEM also does not permit the flow of any gaseous products, such as carbon dioxide (CO2) in the NAAC and oxygen (O2) in the PCAC. PVDF-g-PVIm is a thin membrane composed of a hydrophobic polymer (PVDF) and a hydrophilic monomer (1-Vinylimdazole). This is also known as an ion exchange membrane. It is generated using the radiation-induced grafting procedure and then immersed in mild acid to create a proton conducting channel. A hydrogen ion can transmit and exchange over a membrane with an ionic conductivity of 10-4 to 10-3 Scm-1 (Lepit et al., 2012). The imidazole group, a basic group, can act as a proton donor and proton acceptor, supplementing water as a proton acceptor in novel proton-conducting polymers. Its basicity is higher than water, and the introduction of the imidazole group in a side-chain polymer significantly improved the proton transport of the PEM (Pue et al., 2009). Hydrophobic membranes offer strength, whereas hydrophilic membranes allow for water and ion transport between the two columns. The porous features of membranes with nanopore structure are to improve proton conductivity, demonstrating a strategy to increase proton exchange membrane performance (Chen et al., 2024). In this study, the PEM used were parafilm, polyvinylidene fluoride-co-polyvinylimidazole (PVDF-g-PVim) and agar-agar membranes. Both were desirable as PEM as its phase domain separation was hydrophilic and hydrophobic.

METHODOLOGY

A dual-compartment MBVC comprises anodic and cathodic chambers separated by a PEM. Figure 1 shows a dual-chamber MBVC. The metal electrodes used in this study were copper (Cu) at the anode and aluminium (Al) at the cathode chambers, respectively, while the PEM used was parafilm, where it allows the ion hydrogen flows to aerobic column. The sample used was 100 mL of wastewater as a source for biocatalyst. Before the experiment started, the sample was put in an incubator at temperature 35oC (±1) for one week in order to boost the microorganisms.

The study was done in 15 days (360 hours), and voltage (V) and Current(I) were recorded using multimeter and calculated using the equation (3). This procedure was repeated for two times by using PVDF-g-PVim membrane, agar-agar membranes and parafilm membrane, respectively, as shown in (1). The size of membrane used was 6.02 cm (width) x 13.5 cm (length) x 0.1 cm (thickness)

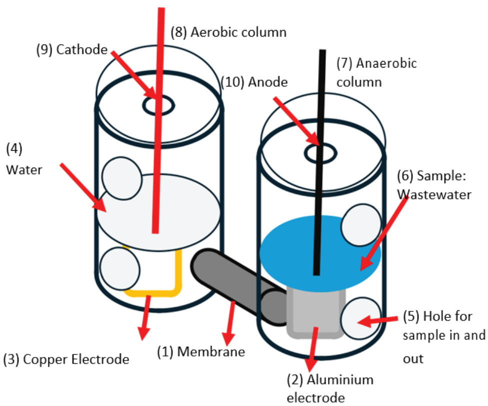

Figure 1. The Dual-compartment MBVC

Source: Author, 2025

In Figure 1, it shows a hole in both columns to allow the exchange with a new sample as shown in no 5, while the samples of wastewater inserted in no 7 anaerobic column and no 4 was clean water to allow production of water molecules when the hydrogen ions are released from the microorganisms. It reacted with the oxygen ions and electron. All the parameters were fixed including the volume of water and the samples. The experimental work was performed in the room temperature. On the other hand, the measurement of power we had taken through the connection of no 9 and no 10 was at the terminal of multi-meter.

The power of MBVC was measured by using the equation (3) to confirm the effect of different membrane type on the performances (power and voltage) of MBVC's:

$$P = I \times V \tag{3}$$

Where P is the power of MBVC's in watt (w), I is the current in unit of ampere (A), and V is the voltage in volts unit.

RESULTS AND DISCUSSION

Figure 2 and 3 show the voltage recorded and power generated on the wastewater sample by using different types of membranes. The data were recorded in 360 hours, which was 15 days. It can be seen that the voltage for all types of PEM was in the range of 0.51 to 1.25V. Parafilm membranes showed the lowest voltages, which was in the 0.51 to 0.58 V. Followed by an agar-agar membrane with value 0.59 to 0.66 V. The highest voltage was observed in the PVDF-g-PVim membrane, which ranged from 1.02 to 1.25V. The difference in values could be due to the materials embedded in the membrane (Felipe et al., 2018). The increased voltage in the PVDF-g-PVim was a result of the ionic channel that passes through its hydrophilic characteristics and nanopores of the membrane. Therefore, the PVDF-g-PVim showed the promising membrane in producing a better voltage and power. The selection of type of membrane is important to stimulate the proton exchange membrane (PEM) in MBVC.

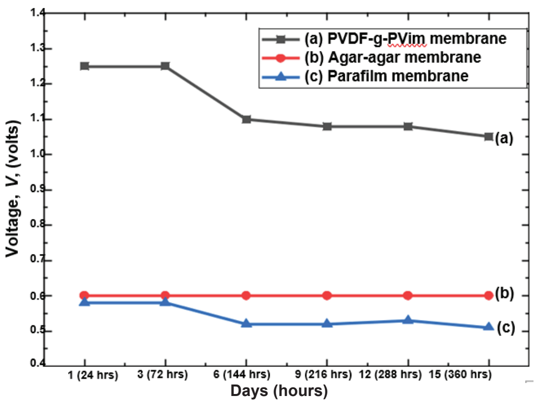

Figure 2. The Performance Comparison in Terms of Voltage at Different Types of Membrane: (a) PVDF-g-PVim, (b) Agar-agar and (c) Parafilm

Source: Author, 2025

Furthermore, Figure 3 shows the recorded power generated through MBVC at different types of membranes. The data were taken from 1 day to 15 days. The purpose of this measurement was to examine the generation of power by MVBC corresponding to one coulomb unit charge over the stipulated time (15days-360hrs) passed through different types of membrane, and the generation power was calculated by using equation (3) and it was found that the maximum value of recorded power was 0.225 watt and it declined before decreasing to around 0.198 watt and finally reached at 0.190. However, the value of the powers was still maintained, which was above 0.19 watt after 1 week, indicating that the stability of the PVDF-g-PVim membrane was much better than another two membranes. This was shown in Figure 3(b) and (c), whereby it recorded the average power values were 0.11 watt and 0.10 watt for agar-agar and parafilm membrane, respectively. Both membranes showed almost nearly recorded power values to each other in between 3 days. However, the power of parafilm membrane exhibited slowly decreased the trend after 3 days. This might be due to the stability is less as compared to the PVDF-g-PVim membrane that has much good of proton negotiation in membrane that was attributed by the factor of membrane surface, which will be discussed further in the FESEM section.

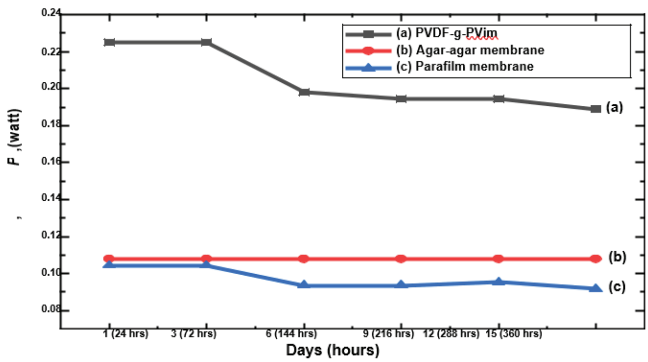

Figure 3. The Performance Comparison in Terms of Generated Power at Different Types of Membrane: (a) PVDF-g-PVim, (b) Agar-agar and (c) Parafilm

(note: the value of current in ampere has been set constant)
Source: Author, 2025

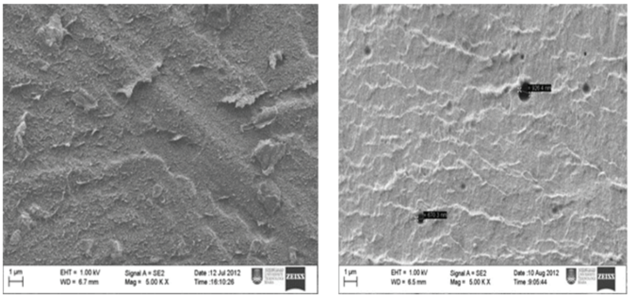

Figure 4. (a) Surface Properties Grafting Membrane, (b) Nanopore of Cross-sectional FESEM Images of PVDF-g-PVim Membranes.
Source: Author, 2025

Figure 4 shows the FESEM morphologies of the membrane surface for graft and PVDF-g-PVim membranes. The images were taken at the scale of magnification of 1 μm. Generally, the membrane surface shows a bit rougher, was not uniform indicating that grafting of imidazole functional group onto PVDF backbone materialized, while Figure 4(b) shows the cross-sectional image of PVDF-g-PVim, the ocean-like-surface were not smooth and rough due to grafting penetration of comonomer imidazole via radiation-induced graft polymerization technique (Kean te al., 2021). In addition, it could be seen clearly that the porous area was seen at magnificent 5.0 K via cross-sectional images of grating membranes. These indicates the surface of membranes was slightly rough, attributing to the attachement of modifying PVDF surface with functional group of -NH in imidazole ring. The ring acted as a donor and acceptor of proton that was suitable for the flowability of the hydrogen ions (Szilvia et al., 2021). The embedded imidazole as functional groups onto the PVDF backbone to accommodate proton transfer produced by anaerobic digestion of microbe's activity from wastewater. Furthermore, the porous features of membranes with nanopore size provided a proton conductivity pathway, demonstrating a strategy to increase proton exchange membrane performance between dual compartment of chamber.

Although using agar-agar solution as a membrane and parafilm is low cost, the voltage and power output have been observed to be low compared with PVDF-g-PVim membranes. One of the factors could be due to the thickness of the agar-agar membrane, which produced high internal resistance and lowered the conductivity of the hydrogen ions (Giovanni et al., 2019). While in the parafilm membrane, the factor could be due to the lack of structure that acts as a donor and acceptor of protons for the flowability of the hydrogen ions. Parafilm is made of polyolefin polymer, which is produced by the polymerization of the olefin monomer unit, hydrocarbon whose molecules contain a pair of carbon linked together by a double bond (Figure 5). Although the C-H bonds have high hydrophobic properties, the membrane can still allow the passing through of smaller ions, such as hydrogen ions, in small quantities, which explains the lower voltage results (Imran et al., 2021).

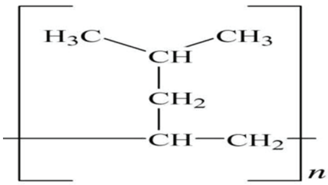

Figure 5. (a) Structure of Polyolefin

Source: Author, 2025

CONCLUSION

The highest evaluation of voltage and power measurement showed potentials from PVDF-g-PVim as a PEM in a dual compartment chamber of MBVC compared to parafilm and agar-agar membrane, whereby recorded maximum power and voltage are 0.23 watt and 1.25 volts, respectively. This could be due to the materials embedded in the PVDF-g-PVim membrane containing hydrophilic properties of imidazole functional group in a side chain grafting polymer membrane for proton transfer pathways from the anode to cathode, which is a crucial part of energy conversion in the MBVC device. Eventually, our work may contribute a new idea towards improving a better value of voltage and develop another alternative energy source with using a cheap, abundant and effective of membrane bridge. Hence, our findings suggested that by using a suitable membrane, the production of the voltage value of MBVC can be improved and enhanced, and it thus provides plenty of capacity of improvement in the future studies, such as varying the pH values and changing the volume of water.

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AUTHOR CONTRIBUTIONS

All the authors contributed to the final write-up of manuscripts. Below is breakdown:

1. Rafidah Selaman: Conducted experimental work, analysed results and wrote analysis, data collecting and designed the prototype.
2. Mohd Faizal Achoi: plotted the result, methodology, draw and labelled the picture, discussion, writing, and editing.
3. Mohd Ruzaleh Nurdik: wrote the introduction, instrumental assistance, editing and cited the references.
4. Ajis Lepit: Collected the sample, performed the experimental work, provided the concept of analysis, suggested parameters, and SEM analysis.

CONFLICT OF INTEREST

The authors declare there was no conflict of interest.

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