PERFORMANCE OF A CHAMBER-LESS MICROBIAL FUEL CELL WITH A PAPER-BASED MEMBRANE COATED BY VASELINE

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Abstract

Today, energy production problem is seriously in the world. Wastes is one of the renewable energy resources, it is converted to electrical energy by Microbial Fuel Cells (MFC). In this study, a chamber-less MFC was constructed by some acrylic parts, electrodes and a filter paper-based proton exchange membrane (PEM). Bacillus subtilis was incubated and fixed on activated carbon sheet. To replace chemically treated PEM, Vaseline was used to treat the paper-based PEM. To increase the output, multiwall carbon nanotube (MWCNT) liquid was used to glue the cathodic electrode and filter paper-based PEM. Current density and power density were measured. Maximum current density and power density were 55 μA/cm² and 3.86 μW/cm², respectively. Internal resistance of MFC was estimated between 5kΩ and 10kΩ based on the polarization curve. Vaseline-treated paper-based membrane and MWCNT gluing method had positive effectiveness on the performance of the chamber-less MFC.

Keywords: Microbial Fuel Cell, The chamber-less MFC, Vaseline, Multi Wall Carbon Nano Tube, Bacillus subtilis

I. Introduction

Nowadays, energy crisis has gone to a seriously situation due to depletion of fuel fossil, a population explosion the environmental disruption and so on. So, renewable energy resources are believed the effective solution for these problems. These resources have characteristics of recyclable and environmentally friendly. Therefore, these resources are going to be used as the main energy taken the place of fuel fossil in the future [VIII]. MFC is one of the renewable energies to generate electric power from chemical energy in the organic matters decomposed by microorganism. MFC has a potential for a generation of a huge electric power supporting human life [XVII].

Two main constructions of MFC are used for generating electric power. One type is double-chamber MFC, which has two chambers separated by a membrane and be
inserted an anodic and a cathodic electrode. Another type is single chamber MFC (it is also called air-cathode MFC) has one chamber attached with a membrane. This MFC has an anodic electrode in the anodic chamber and a cathodic electrode attached to the membrane on the cathodic side [IX] and [VII]. Microorganism forms biofilm on an anodic electrode to hand electron into anodic electrode. Microorganism degrades organic matters and produce protons, electrons, carbon dioxide. Electrons are absorbed by electron acceptors called mediators and is corrected to the anodic electrode. Protons are ions of hydrogen, it can migrate through membrane (from the anodic side to the cathodic side). Protons are corrected to the cathodic electrode. On the cathodic electrode, water is created by the reaction of electrons, protons and oxygen from air on the cathodic electrode [XVIII], [VI].

Chamber-less MFCs are focused on applying to sensors for discovery specific substance such as poisons [III], [IV]. The chamber-less MFC is composed of an anodic electrode, a membrane, and a cathodic electrode. Compared with other MFC constructions, the chamber-less MFC construction is very simple, thinly and light weight. Electrodes are stick to the membrane to increase voltage by narrowing distance between the electrodes [V], [X]. To generate electric power from chamber-less MFC, it is essential to inoculate organic matters or microbial in the anodic electrode. Solution contained organic matters or microbes is added to the electrode to generate electric power when needed [XIV]. An appropriate solution for the chamber-less MFC aimed at bio sensor application is that the used microbes must have viability under drying state [II], [XII].

Moreover, a lot of study uses PEM treated chemically for effectively exchange protons between the anodic electrode and the cathodic electrode. Treated membrane has high efficiency to generate electrical power. However, the chamber-less MFC usually aims at disposable construction and low-cost applications [XIII], [XI], [I]. Therefore, low-cost PEM materials are usually used.

**II. Materials**

**II.i. MFC Construction**

A chamber-less microbial fuel cell used in this study is shown in Fig. 1(Right). The size of the cell was 4 cm$^2$ (2cm×2cm). The cell with the electrode active area of 1 cm$^2$ (the electrode size was 1cm × 3cm). It consisted of the anodic
and cathodic electrodes made of carbon sheet contained activated carbon powder made of coconut shell. The anodic electrode was doped Bacillus subtilis (the inoculum was purchased from KOJI-ZA CO., LTD.) and broth (pure water 200ml (WAKOUZYUYAKU CO., LTD.), HANAKOUZYOU 0.5ml (SUMITOMOKAGAKUENGEI CO., LTD.), Glucose 1g). Broth was boiled for sterilization and promotion of bacteria growth, fuel for electricity generation is glucose planted in an anodic electrode during incubating and drying. MFC is kept under drying condition, MFC needs bacteria can live same condition for electricity generation. So, Bacillus subtilis was dried after making biofilm in drying oven at 40 degree. The cathodic electrode was dipped WMCNT liquid (carbon 6wt%, KJ TOKUSYUSI CO., LTD) to attach on the membrane, Part of the cathode electrode was dried under natural temperature. The anodic electrode and a cathodic electrode treatment are shown in Fig. 1(Left).

In this study, we prepared the chamber-less MFC and measured its performance. The MFC was made of activated carbon sheet for the electrodes, filter paper dipped Vaseline for the membrane and some acrylic parts for the MFC case. Bacillus subtilis was incubated and fixed on an anodic electrode. To increase the performance, CNT liquid was used as a gluing material on the cathodic electrode [XVI]. The MFC with the membrane dipped in Vaseline was confirmed to generate output voltage [XV]. Moreover, CNT gluing efficiently increased the performance of the MFC.

II.ii. Membrane

A filter paper (pore size of 6μm, thickness of 0.23mm, AZUMI FILTER PAPER CO., LTD.) was used as the membrane. The process is shown in Fig. 2. The one-side of filter paper was dipped with 0.023g of Vaseline (TAIYOUSEIYAKU CO., LTD.) to prevent water soaking. Two processed filter paper was piled as facing inside on Vaseline dipped. This Membrane construction is shown in Fig. 2. The membrane is made up 3 layers (top: the filter paper, middle: the filter paper-soaked Vaseline, bottom: the filter paper). Top and bottom layers are hydrophilic paper. Middle layer is hydrophobic paper effected by Vaseline. This membrane can separate an anodic side and a cathodic side and keep solution on hydrophilic layer.

![Fig. 2: Membrane construction and fabrication method](image-url)
III. Experimental Method

III.i. MFC Operation

The operation system of the MFC is shown in Fig. 3. Experimental apparatus (PC, data acquisition NI USB-6210 (National Instruments CO., LTD.), drying oven EOP-450V (ETTAS CO., LTD.) was prepared. The MFC was connected to an external resistor and a data acquisition system. MFC’s voltage across external resistor was recorded in a PC every 30 seconds. After starting measurement, a 50µl of water was dropped into the anodic electrode. Measurement was continued for 60 minutes. Recorded data was converted to graph, MFC performance was evaluated. To evaluate paper-based PEM with Vaseline treatment, Nafion PEM was used for comparison purpose. The cathodes with or without using MWCNT as the gluing material were also evaluated.

III.ii. Power Density Measurement

The MFC was connected to 5 external resistors (1kΩ, 5kΩ, 10kΩ, 20kΩ, 50kΩ). The MFC performance was calculated at the peak voltage. First, current density was calculated from voltage and external resistor. Second, electric power density was calculated from current density and external resistance.

IV. Result and Discussion

IV.i. The Comparison of Membrane

The discharging voltage across an external resistor (10kΩ) generated by the MFCs is shown in Fig. 4. Solid line is the voltage generated by the MFC with Nafion PEM for the membrane with MWCNT gluing at the cathodic electrode. The voltage generated by the MFC based on paper-based Vaseline-treated PEM with and without MWCNT gluing are shown in dashed line and dotted line, respectively. Each line’s peak voltage was 194mV, 160mV, 80mV, respectively. After 60 minutes, each line’s voltage was respectively degreased 145mV, 124mV, 70mV from the peak voltage. The MFC using Nafion PEM and MWCNT gluing generated the highest voltage (solid line). However, the MFC using the paper-based Vaseline-treated membrane with MWCNT gluing had generated comparable voltage (dashed line). The dotted line shows much lower voltage output because of not using MWCNT gluing. Based on this result, the paper-based Vaseline-

Fig. 3: Measurement set up

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treated membrane can be used as a low-cost alternative for the Nafion PEM with comparable performance. Moreover, MWCNT gluing at the cathodic side is very important for improving the performance of the MFCs. This is attributed to the improvement of the connection between the membrane and the cathodic electrode by MWCNT liquid. In MFC, the output was increased due to two MWCNT characteristics. One is shorter the distance of between an anodic electrode and a cathodic electrode. Another is electric resistivity of entire MFC was decreased.

Fig. 4: The comparison of the discharging voltage of the MFCs with Nafion PEM and MWCNT gluing (solid line), paper-based Vaseline-treated PEM with MWCNT gluing (dashed line) and without MWCNT gluing (dotted line)

IV.ii. Discharging Voltage and Polarization Curve

The discharging voltage by five external resistors (1kΩ, 5kΩ, 10kΩ, 20kΩ, 50kΩ) of the MFC is shown in Fig. 5.

Fig. 5: The discharging voltage by five external resistors of the MFC based on paper-based Vaseline-treated membrane with MWCNT gluing

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A. 5 scales of external resistor in the Fig. 5 is identified by color (1 kΩ: Red, 5 kΩ: Blue, 10 kΩ: Black, 20 kΩ: Yellow, 50 kΩ: Green). Each peak voltage was 55 mV, 139 mV, 160 mV, 173 mV, 201 mV, respectively. The discharging voltage by 1 kΩ resistor was fallen to near 8 mV in around 20 minutes. From the peak voltage value and external resistance value, the current density and power density were calculated. MFC’s performance was evaluated by the polarization curve of voltage across external resistors and the power density as a function of the current density. Polarization curve is shown in Fig. 6.

**Fig. 6:** Polarization curve of the MFC based on paper-based Vaseline-treated membrane with MWCNT gluing

Dashed line expresses the relation between the maximum discharging voltage and the current density. Solid line expresses the relation between the current density and the power density. The maximum power density was 3.86 μW/cm² obtained at 5 kΩ external resistor. From both lines, the MFC’s internal resistance was estimated. The point that both lines crossed was the most effective performance of the MFC, so the MFC’s internal resistance was between 5 kΩ to 10 kΩ.

V. Conclusion

The chamber-less MFC was aimed to ecological electric generation and bio sensor, constructed by activated carbon sheet loaded *Bacillus subtilis* as the anodic electrode and filter paper treated Vaseline as the low-cost membrane. The cathode side was used CNT to glue the membrane and the cathodic electrode to improve the connection. To confirm the effectiveness of Vaseline and MWCNT gluing, the MFCs used Vaseline-treated membrane or Nafion PEM, and the MFCs with or without CNT-gluing were investigated. The MFC used Vaseline-treated membrane was generated comparable output compared with the one using Nafion PEM. The MFC with the use of MWCNT gluing outperformed the one without the use of MWCNT gluing.
Reference

I. Abhinav Choudhury, Lepakshi Barbora, Divyanshu Arya, Banwari Lal, Sanjukta Subudhi, S. Venkata Mohan, Shaikh Z. Ahammad and Anil Verma. 2017. Effect of electrode surface properties on enhanced electron transfer activity in microbial fuel cells. 17: 186-192

II. Daniel Sohmen, Shinobu Chiba, Naomi Shimokawa-Chiba, C. Axel Innis, Otto Berninghausen, Roland Beckmann, Koreaki Ito and Daniel N. Wilson. 2015. Structure of the Bacillus subtilis 70S ribosome reveals the basis for species-specific stalling. NATURE COMMUNICATIONS 6 6941: 1-10

III. Dengbin Yu, Lu Bai, Junfeng Zhai, Yizhe Wang, Shaojun Dong. 2017. Toxicity detection in water containing heavy metal ions with a self-powered microbial fuel cell-based biosensor. Talanta 168: 210–216

IV. Ezgi Bayram and Erol Akyilmaz. 2016. Development of a new microbial biosensor based on conductive polymer/multwalled carbon nanotube and its application to paracetamol determination. Sensors and Actuators B 233: 409–418

V. Jumma Shaikh, Niranjan P Patil, Vikas Shinde and Vishwas B Gaikwad. 2016. Simultaneous Decolorization of Methyl Red and Generation of Electricity in Microbial Fuel Cell by Bacillus circulans NPP1. Journal of Microbial & Biochemical Technology volume 8(5): 428-432

VI. Jung Rae Kim, Giuliano C. Premier, Freda R. Hawkes, Richard M. Dinsdale and Alan J. Guwy. 2009. Development of a tubular microbial fuel cell (MFC) employing a membrane electrode assembly cathode. Journal of Power Sources 187: 393–399

VII. Mirella Di Lorenzo, Alexander R. Thomson, Kenneth Schneider, Petra J. Cameron and Ioannis Ieropoulos. 2014. A small-scale air-cathode microbial fuel cell for on-line monitoring of water quality. Biosensors and Bioelectronics 62: 182–188

VIII. Mostafa Rahimnejad, Arash Adhami, Soheil Darvari, Alireza Zirepour, Sang-Eun Oh. 2015. Microbial fuel cell as new technology for bioelectricity generation: A review. Alexandria Engineering Journal 54: 745–756

IX. Naveen Shankar, Arun Panchapakesan, Suhas Bhandari, H N Ravishankar. 2014. Simultaneous cellulose hydrolysis and bio-electricity generation in a mediatorless Microbial Fuel Cell using a Bacillus flexus strain isolated from wastewater. Research in Biotechnology, 5(1): 6-12

X. Nengwu Zhu, Xi Chen, Ting Zhang, Pingxiao Wu, Ping Li and Jinhua Wu, 2011. Improved performance of membrane free single-chamber air-cathode microbial fuel cells with nitric acid and ethylenediamine surface modified activated carbon fiber felt anodes. Bioresource Technology 102: 422–426

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XI. Niloofar Hashemi, Joshua M. Lackore, Farrokh Sharifi, Payton J. Goodrich, Megan L. Winchell and Nastaran Hashemi. 2016. A paper-based microbial fuel cell operating under continuous flow condition. TECHNOLOGY volume 4, Number 2: 98-103

XII. Pascale B, Beauregard, Yunrong Chai, Hera Vlamakis, Richard Losick, and Roberto Kolter, 2012. Bacillus subtilis biofilm induction by plant polysaccharides. PNAS: E1621–E1630

XIII. Rene A. Rozendal, Hubertus V. M. Hamelers, and Cees J. N. Buisman, 2006. Effects of Membrane Cation Transport on pH and Microbial Fuel Cell Performance. Environ. Sci. Technol 40: 5206-5211

XIV. Wei Yang, Jun Li, Qian Fu, Liang Zhang, Xun Zhu and Qiang Liao. 2017. A simple method for preparing a binder-free paper-based air cathode for microbial fuel cells. Bioresource Technology 241: 325–331

XV. Xinyang Li, Guicheng Liu, Fujun Ma, Shaobin Sun, Siyu Zhou, Ryanda Enggar Anugrah Ardhic, JoongKee Lee and Hong Yao. 2018. Enhanced power generation in a single-chamber dynamic membrane microbial fuel cell using a nonstructural air-breathing activated carbon fiber felt cathode. Energy Conversion and Management 172: 98–104

XVI. Xiayuan Wu, Xiaomin Xiong, Gianluca Brunetti, Xiaoyu Yong, Jun Zhou, Lijuan Zhang, Ping Wei and Honghua Jia. 2017. Effect of MWCNT-modified graphite felts on hexavalent chromium removal in biocathode microbial fuel cells. The Royal Society of Chemistry Advanced 7: 53932-53940

XVII. Yoganathan K and Ganesh P. 2015. Electrogenicity assessment of Bacillus subtilis and Bacillus megaterium using Microbial Fuel Cell technology. International Journal of Applied Research 1(13): 435-438

XVIII. Zainab Z. Ismail and Ali Jwied Jaeel. 2013. Sustainable Power Generation in Continuous Flow Microbial Fuel Cell Treating Actual Wastewater: Influence of Biocatalyst Type on Electricity Production. The Scientific World Journal Volume 2013: 1-7