Electricity Production from Food Waste Leachate (Fruit and Vegetable Waste) using Double Chamber Microbial Fuel Cell: Comparison between Non-aerated and Aerated Configuration

Willie Prasidha*, Akmal Irfan Majid
Department of Mechanical and Industrial Engineering, Faculty of Engineering, Universitas Gadjah Mada.
*E-mail address: willie.p@ugm.ac.id

Abstract

Two double chamber microbial fuel cells with different configurations were developed to produce electricity food waste leachate and studied for 30 days. Anode and Cathode were made by uncoated carbon felt and graphite rods. Food waste and water were incubated into the reactor. After more than 30 days, leachate with the neutral condition (pH 6.9) was collected from the leachate reactor. 500 ml leachate was used in the anode chamber and 500 ml catholyte was used in the cathode chamber. The first configuration, non-aerated MFC, the maximum OCV, maximum power density, average power density, and maximum current density were 373 mV, 25.7 mW/m^2, 3.7 mW/m^2, and 21.4 mA/m^2 respectively. For the second configuration, aerated MFC, maximum OCV, maximum power density, average power density, and current density were 404 mV, 25.7 mW/m^2, 6.1 mW/m^2, and 21.4 mA/m^2 respectively. Aerated MFC had higher maximum OCV and average power density than non-aerated MFC. From the study, supplying continuous dissolved air (oxygen) in the cathode chamber can produce more voltage and average power density in double chamber microbial fuel cell.

Keywords: Aerated microbial fuel cell, Food waste leachate, Double chamber

1. Introduction

Food wastes are the largest component in municipal waste of urban area (Levis et al., 2011) and it has the potential to produce energy. Most food waste generated from communities, restaurants and food factories ends up in the landfill without any sustainable treatment. In fact, food waste can be used as a useful source of energy [27]. One form of food waste is liquid waste and it called leachate. Leachate has a complex structure and high pollutant [26]. Food leachate is formed from the hydrolysis / acidogenic stage of the anaerobic process of microorganisms that are rich in volatile fatty acids [52]. Leachate obtained from food waste contains many organic elements [21] such as NH_4^+-N, heavy metals, organic and inorganic chlorine, salt, etc. Heavy pollutants from the leachate can contaminate water sources [43] and can adversely affect the health of the ecosystem.

One alternative to treat food waste leachate is using microbial fuel cell (MFC). MFC is a bioelectrochemical system that can convert chemical energy to electrical energy contained in an organic substrate directly [27]. MFC is one of the electrochemical technology to treat leachate and can produce clean energy [43] and it is effective as a source of energy and decreases organic matter in leachate [7]. There are two sides of the MFC, the anaerobic anode side and the aerobic cathode side separated by an electrolyte membrane. In general MFC, microbes are oxidation media from the substrate on the anode side. Microbes oxidize the substrate which produces proton and electron. Electron is produced from microorganisms on the anode side which is passed on to the cathode through an external circuit. From this circuit, electrical energy can be produced whose waste product is water. Due to the waste product produced by MFC is harmless, MFC is very environmentally friendly as a power generation system and an alternative choice for leachate treatment.

From the previous studies, food waste leachate can be used as a substrate to produce electricity using MFC. One of the food waste product is acidic food waste leachate. Using aerated double chamber MFC, it could produce more electricity than using non-aerated double chamber MFC from acidogenic food waste leachate [43]. It also reported by Greenman et al (2009), aerated MFC could produce more electricity than non-aerated MFC using landfill leachate substrate. Not only producing electricity, but MFC also could normalize the pH number of the substrate from acidic to alkaline conditions (pH 4-9) [28].

The objective of this study was to evaluate the performance between non-aerated and aerated double chamber microbial fuel cell from food waste leachate. Open circuit voltage and close circuit voltage was taken to analyze power density and current density of both configurations.

2. Materials and Methods

2.1. Food waste leachate

The food waste, which contains fruit waste and vegetable waste, was collected and incubated in an anaerobic reactor (Fig. 1). The reactor had one inlet on the top to put food waste and water in and also one outlet on the bottom to collect the leachate. There was a filter on the bottom of the reactor before the outlet to produce pure leachate. To produce its leachate, food waste in the reactor was submerged in the water for more than 30 days. After 30 days, the leachate was collected from the outlet of the reactor.

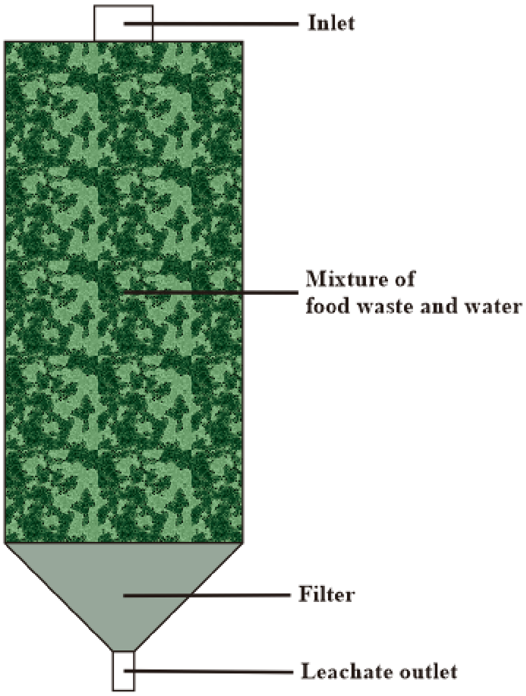

Fig. 1. Reactor for the production of food waste leachate.

2.2. Experimental setup

Two laboratory-scale double chamber MFCs were used in this study. The two chambers were designed with 500 ml working volume in each compartment and separated by a proton exchange membrane (Nafion 212). The anode was constructed of rectangular carbon felt (5 cm x 5 cm x 3 mm) and the cathode was constructed of four graphite rods (diameter = 10 mm, length = 5 cm). The electrodes were uncoated with any catalyst, so the price of the MFC configuration was cheaper than the MFC configuration with the coated electrode. The electrodes were submerged into the anode and cathode chamber.

The MFCs were operated in two configurations, non-aerated MFC and aerated MFC. For both configurations, the electrodes were connected by copper wire. A 100 Ω external resistance was used in the closed-circuit for closed circuit voltage (CCV) recording. For open-circuit voltage recording, the anode and cathode were not connected. The air pump was used to supply dissolved air which contained oxygen in the cathode chamber for aerated MFC configuration. The configuration of the aerated MFC is shown in Fig. 2.

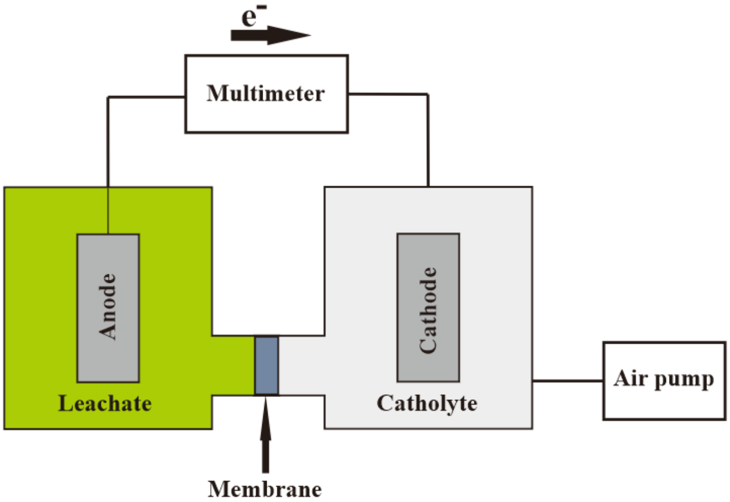

Fig. 2. Schematic of aerated double chamber microbial fuel cell.

For both configurations, the anode chamber was fed with 500 ml food waste leachate, which contained the pH was 7.1, and maintained to be an anaerobic condition. 2 g/L sodium acetate solution was used as 500 ml catholyte in the cathode chamber for both configurations and maintained to be an aerobic condition. The MFCs were operated for 30 days, OCV and CCV were recorded every 24 hours.

2.3. Analysis

For all configurations, The open-circuit voltage (OCV) and closed-circuit voltage (CCV) (100 Ω) were recorded using a digital multimeter. The current (I) was calculated as V = I x R, which is the voltage obtained from CCV (100 Ω). The power (P) (mW) was calculated as P = V x I and also power density (mW/m^2) and current density (mA/m^2) were calculated by dividing the obtained power and current by the surface area of the anode.

3. Results and discussion

The electricity from food waste leachate was produced during the experimental period. The configurations were operated continuously for 30 days at open and closed circuit conditions. During the operation, the condition of the leachate was neutral. The OCV and CVC were recorded at a time interval of 24 hours. The maximum OCV (under no-load condition) was obtained on the first day (24 hours after starting) of operation and was observed to be 373 mV for non-aerated MFC. For aerated MFC, the maximum OCV was 404 mV, which was obtained on the seventh day of operation. It indicated that the maximum microbial growth happened on the first day for non-aerated MFC and seventh day for aerated MFC. After the OCV reached maximum voltage on the first day, the performance declined to -157 mV on the twenty-fifth day for non-aerated MFC. The decline of performance indicates the decrease in nutrient concentration in the feed. The negative phase started to develop from the twentieth day, which is indicative of the bacteria begin to die due to the exhaustion of nutrients. Different from non-aerated MFC, the aerated MFC had a slight decrease of OCV during the operation. The minimum OCV of aerated MFC was 146 mV. The graph of OCV during the experiment is shown in Fig. 3.

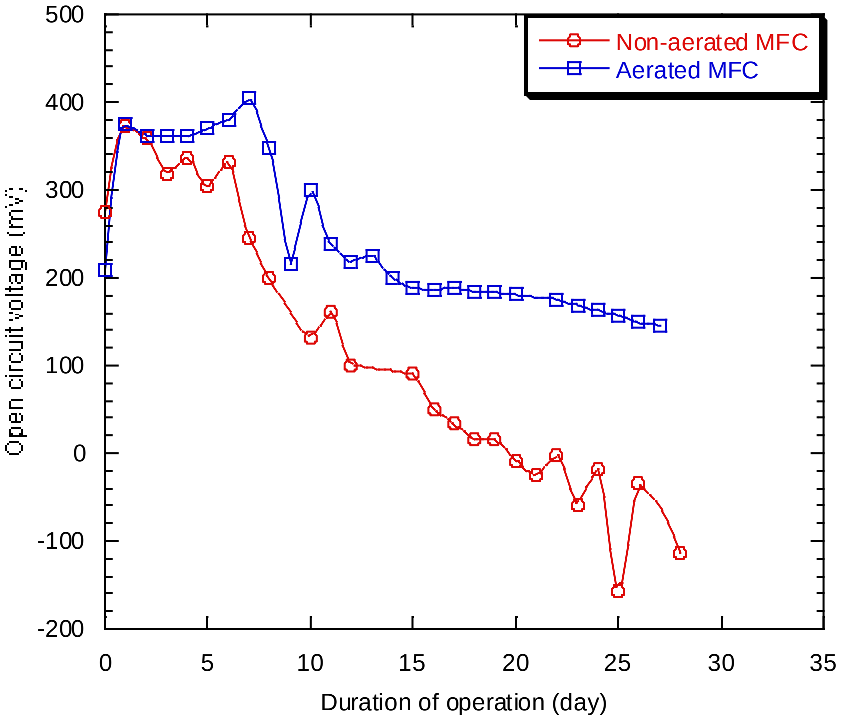

Fig. 3. Open circuit voltage of MFCs during operation.

Both configurations had a different characteristic of the current density curve. As shown in Fig. 4, between non-aerated MFC and aerated MFC, had the same maximum current density (21.4 mA/m^2) but they were obtained on a different day of operation. The maximum current density of non-aerated MFC was obtained on day one of operation. While for the aerated MFC, the maximum current density was obtained on day seven of operation. Aerated MFC had a more stable current density than non-aerated MFC which is shown in the area under the curve in Fig 3. The area under the current density's curve of aerated MFC is larger than non-aerated MFC. The minimum current density of non-aerated MFC and aerated MFC were -5.3 mA and 7.1 mA respectively. In the non-aerated MFC, negative current density was achieved from day 23 of operation. It indicates that the bacteria start to die in the anode chamber. While the negative phase of current density was not obtained in the aerated MFC.

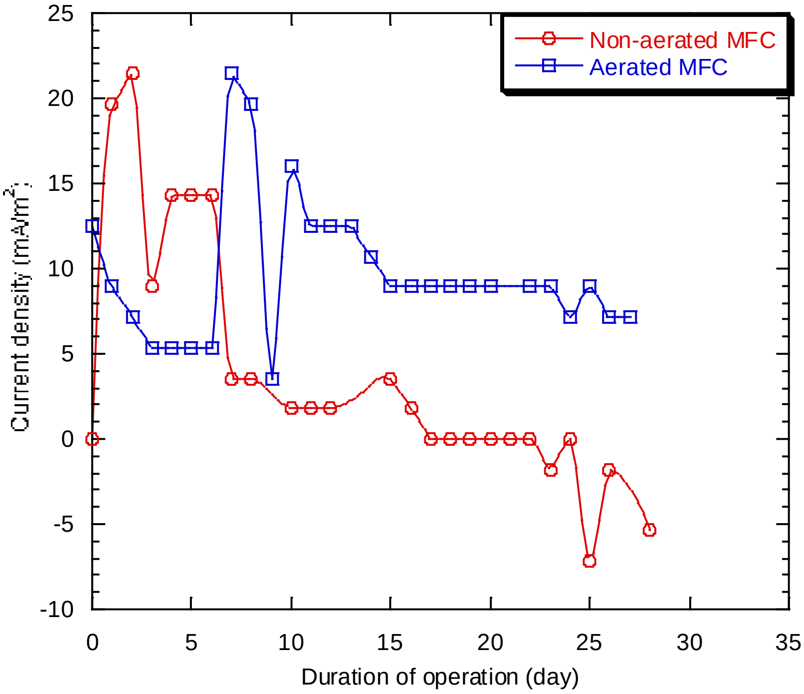

Fig. 4. The current density of MFCs during operation.

As shown in Fig. 5, Both of configurations had the same maximum power density, which was reached on day two of operation for non-aerated MFC and day seven for aerated MFC and was observed to be 25.7 mW/m^2. As shown in Fig 5, the aerated MFC had a more stable power density than non-aerated MFC. It was indicated by the area under the curve of power density for both configurations, which is shown in Fig 4. The aerated MFC had a larger area under the power density's curve than non-aerated MFC. It also indicated by the average power density, aerated MFC had higher power density than non-aerated MFC. The average power density of non-aerated MFC and aerated MFC were 3.7 mW/m^2 and 6.1 mW/m^2 respectively. It happened because continuous dissolved oxygen supplied at the cathode chamber of aerated MFC. Oxygen is an electron acceptor and could improve the production of voltage and power density by promoting the electron and proton transfer rates. There were more electron acceptors in the cathode chamber of aerated MFC than in the cathode chamber of non-aerated MFC. Due to it, the production capacity of aerated MFC was greater than non-aerated MFC.

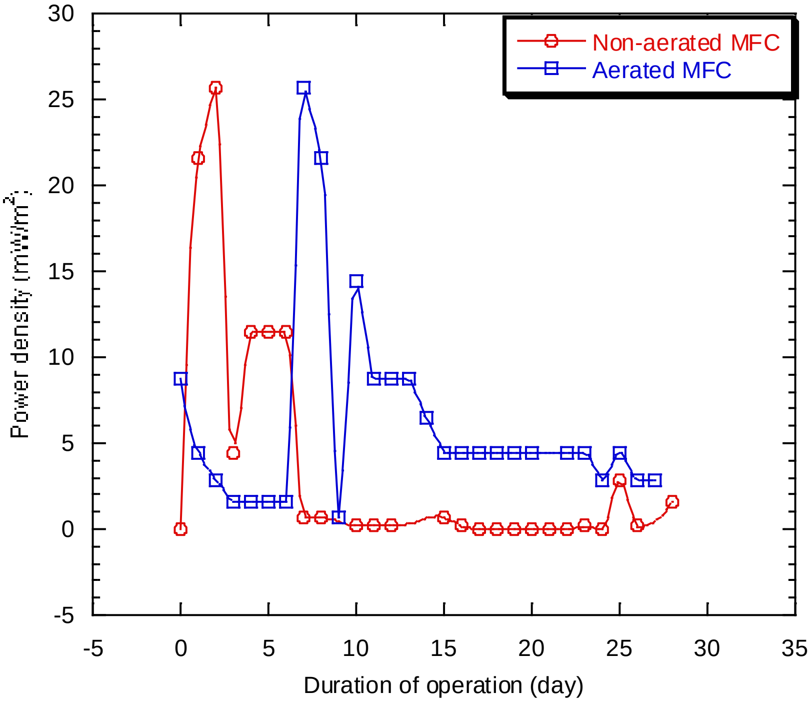

Fig. 5. The power density of MFCs during operation.

4. Conclusion

Electricity generation from food waste leachate (fruit waste and vegetable waste) were obtained using two configurations of double chamber microbial fuel cell. The first configuration, non-aerated MFC, the maximum OCV, maximum power density, average power density, and current density were 373 mV, 25.7 mW/m^2, 3.7 mW/m^2, and 21.4 mA/m^2 respectively. For the second configuration, aerated MFC, maximum OCV, maximum power density, average power density, and current density were 404 mV, 25.7 mW/m^2, 6.1 mW/m^2, and 21.4 mA/m^2 respectively. This study proved that supplying dissolved air (oxygen) in the cathode chamber increases the output of the double chamber microbial fuel cell.

Acknowledgments

The authors like to acknowledge the Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada for the facilities and support to carry out this work.

References

[1] Ahn, Y., Zhang, F., Logan, B.E., 2014. Air humidity and water pressure effects on the performance of air-cathode microbial fuel cell cathodes. Journal of Power Sources 247, 655-659.
[2] Archer, S.A., Wilckens, R.S., 2018. Systematic analysis of biomass derived fuels for fuel cells. International Journal of Hydrogen Energy 43, 23178-23192.
[3] Arshad, A., Ali, H.M., Habib, A., Bashir, M.A., Jabbal, M., Yan, Y., 2019. Energy and exergy analysis of fuel cells: A review. Thermal Science and Engineering Progress 9, 308-321.
[4] Castresana, P.A., Martinez, S.M., Freeman, E., Eslava, S., Lorenzo, M.D., 2019. Electricity generation from moss with light-driven microbial fuel cells. Electrochimica Acta 298, 934-942.
[5] Cheng, S., Logan, B.E., 2007. Ammonia treatment of carbon cloth anodes to enhance power generation of microbial fuel cells. Electrochemistry Communications 9, 492-496.
[6] Cheng, S., Liu, H., Logan, B.E., 2006. Increased performance of single-chamber microbial fuel cells using an improved cathode structure. Electrochemistry Communications 8, 489-494.
[7] Choi, J., Ahn, Y., 2015. Enhanced bioelectricity harvesting in microbial fuel cells treating food waste leachate produced from biohydrogen fermentation. Bioresource Technology 183, 53-60.
[8] Damiano, L., Jambeck, L., 2009. Leachate Treatment and Electricity Production in Microbial Fuel Cells. Proceedings of the International Waste Management and Landfill Symposium, Sardinia 2009, S. Margherita di Pula (Cagliari, Italy), October, 2009.
[9] Das, D., 2018. Microbial Fuel Fuel Cell A Bioelectrochemical System that Converts Waste to Watts. Springer, New Delhi.
[10] Fischer, F., 2018. Photoelectrode, Photovoltaic and photosynthetic microbial fuel cells. Renewable and Sustainable Energy Reviews 90, 16-27.
[11] Flores, G.H., Varaldo, H.M.P., Castanon, T.R., Feria, O.S., Seijas, N.R., 2017. Harvesting energy from leachates in microbial fuel cells using an anion exchange membrane. International Journal of Hydrogen Energy 42, 30374-30382.
[12] Galvez, A., Greenman, J., Ieropoulos, I., 2009. Landfill leachate treatment with microbial fuel cells: scale-up through plurality. Bioresource Technology 100, 5085-5091.
[13] Ganesh, K., Jambeck, J.R., 2013. Treatment of landfill leachate using microbial fuel cells: Alternative anodes and semi-continuous operation. Bioresource Technology 139, 383-387.
[14] Greenman, J., Galvez, A., Giusti, L., Ieropoulos, I., 2009. Electricity from landfill leachate using microbial fuel cells: Comparison with a biological aerated filter. Enzym and Microbial Technology 44, 112-119.
[15] Hassan, M., Wei, M., Qiu, H., Su, Y., Jaafry, S.W.H., Zhan, L., Xie, B., 2018. Power generation and pollutants removal from landfill leachate in microbial fuel cell: Variation and influence of anodic microbiomes. Bioresource Technology 247, 434-442.
[16] He, W., Yang, W., Tian, Y., Zhu, X., Liu, J., Feng, Y., 2016. Pressurized air cathodes for enhanced stability and power generation by microbial fuel cells. Journal of Power Sources 332, 447-453.
[17] Hu, J., Zhang, Q., Lee, D.J., Ngo, H.H., 2018. Feasible use of microbial fuel cells for pollution treatment. Renewable Energy 129, 824-829.
[18] Huang, D., Li, M.J., Song, B.Y., Liu, Z.B., 2019. Structure and dynamics of microbial fuel cell catalyst layer. Electrochimica Acta 300, 404-416.
[19] Huang, L., Li, X., Cai, T., Huan, M., 2018. Electrochemical performance and community structure un three microbial fuel cells treating landfill leachate. Process Safety and Environmental Protection 113, 378-387.
[20] Iigatani, R., Ito, T., Watanabe, F., Nagamine, M., Suzuki, Y., Inoue, K., Electricity generation from sweet potato-shochu waste using microbial fuel cells. Journal of Bioscience and Bioengineering.
[21] Kang, K., Shin, H., Park, H., 2002. Characterization of humic substances present in landfill leachates with different landfill ages and its implications. Water Research 36, 4023-4032.

[22] Kim, K.Y., Yang, W., Evans, P.J., Logan, B.E., 2016. Continuous treatment of high strength wastewaters using air-cathode microbial fuel cells. Bioresource Technology 221, 96-101.
[23] Kim, K.Y., Yang, W., Logan, B.E., 2015. Impact of electrode configurations on retention time and domestic wastewater treatment efficiency using microbial fuel cells. Water Research 80, 41-46.
[24] Lanas, V., Logan, B.E., 2013. Evaluation of multi-brush anode systems in microbial fuel cells. Bioresource Technology 148, 379-385.
[25] Larios, A.L.V., Feria, O.S., Varaldo, H.M.P., Huerta, R.G.G., Noyola, M.T.P., Leal, E.R., Seijas, N.R., 2014. Bioelectricity production from municipal leachate in a microbial fuel cell: Effect of two cathodic catalysts. International Journal of Hydrogen Energy 39, 16667-16675.
[26] Levis, J.W., Barlaz, M.A., 2011. What is the most environmentally benefical way to treat commercial food waste?. Environ. Sci. Technol 45, 7438-7444.
[27] Li, X.M., Cheng, K.Y., Selvam. A., Wong. J.W.C., 2013. Bioelectricity production from acidic food waste leachate using microbial fuel cells: Effect of microbial inocula. Process Biochemistry 48, 283-288.
[28] Li, X.M., Ka, Y.C., Wong, J.W.C., 2013. Bioelectricity production from food waste leachate using microbial fuel cells: Effect of NaCl and pH. Bioresource Technology 149, 452-458.
[29] Logan, B.E., 2008. Microbial Fuel Cell. John Wiley & Sons, New York.
[30] Logan, B.E., Murano. C., Scott. K., Gray. N.D., Head. I.M., 2005. Electricity generation from cysteine in a microbial fuel cell. Water Research 39, 942-952.
[31] Logan, B.E., Regan, J.M., 2006. Electricity-producing bacterial communities in microbial fuel cells. TRENDS In Microbiology 14, 12.
[32] Luo, Y., Zhang, F., Wei, B., Liu, G., Zhang, R., Logan, B.E., 2013. The use of cloth fabric diffusion layers for scalable microbial fuel cells. Biochemical Engineering Journal 73, 49-52.
[33] Mateo, S., Canizares, P., Rodrigo, M.A., Morales, F.J.F., 2019. Reproducibility and robustness of microbial fuel cells technology. Journal of Power Sources 412, 640-647.
[34] Min, B., Cheng, S., Logan, B.E., 2005. Electricity using membrane and salt bridge microbial fuel cells. Water Research 39, 1675-1686.
[35] Min, B., Kim, J.R., Oh, S.E., Regan, J.M., Logan, B.E., 2005. Electricity generation from swine wastewater using microbial fuel cells. Water Research 39, 4961-4968.
[36] Moharir, P.V., Tembhurkar, A.R., 2018. Effect of recirculation on bioelectricity generation using microbial fuel cell with food waste leachate as substrate. International Journal of Hydrogen Energy 43, 10061-10069.
[37] Myung, J., Saikaly, P.E., Logan, B.E., 2018. A two-staged system to generate electricity in microbial fuel cells using methane. Chemical Engineering Journal 352, 262-267.
[38] Nguyen, H.T.H., Kakarla, R., Min, B., 2017. Algae cathode microbial fuel cells for electricity generation and nutrient removal from landfill leachate wastewater. International Journal of Hydrogen Energy 42, 29433-29442.
[39] Oh, S.E., Logan, B.E., 2005. Hydrogen and electricity production from a food processing wastewater using fermentation and microbial fuel cell technologies. Water Research 39, 4673-4682.
[40] Ozdemir, M., Atalay, V.E., Bermek, H., Ozilhan, S., Tarhan, N., Catal, T., 2019. Removal of a cannabis metabolite from human urine in microbial fuel cells generating electrocity. Bioresource Technology Reports 5, 121-126.
[41] Puig, S., Serra, M., Coma, M., Cabre, M., Balaguer, M.D., Colprim, J., 2011. Microbial fuel cell application in landfill leachate treatment. Journal of Hazardous Materials 185, 763-767.
[42] Priya, A.D., Setty, Y.P., 2019. Cashew apple juice as substrate for microbial fuel cell. Fuel 246, 75-78.
[43] Rikame, S.S., Mungray, A.A., Mungray, A.A., 2012. Electricity generation from acidogenic food waste leachate using dual chamber mediator less microbial fuel cell. International Biodeterioration & Biodegradation 75, 131-137.
[44] Rossi, Ruggero., Evans, P.J., Logan, B.E., Impact of flow recirculation and anode dimensions on performance of a large scale microbial fuel cell. Journal of Power Source 412, 294-300.
[45] Saito, T., Mehanna, M., Wang, X., Cusick, R.D., Feng, Y., Hickner, M.A., Logan, B.E., 2011. Effect of nitrogen addition on the performance of microbial fuel cell anodes. Bioresource Technology 102, 395-398.
[46] Slate, A.J., Whitehead, K.A., Brownson, D.A.C., Banks, C.E., 2019. Microbial fuel cells: An overview of current technology. Renewable and Sustainable Energy Reviews 101, 60-81.
[47] Sonawane, J.M., Adeloju, S.B., Ghosh, P.C., 2017. Landfill leachate: A promising substrate for microbial fuel cells. International Journal of Hydrogen Energy 42, 23794-23798.
[48] Stager, J.L., Zhang, X., Logan, B.E., 2017. Addition of acetate improves stability of power generation using microbial fuel cells treating domestic wastewater. Bioelectrochemistry 118, 154-160.
[49] Walter, X.A., Santoro, C., Greenman, J., Ieropoulos, I., 2019. Self-stratifying microbial fuel cell: The importance of the cathode electrode immersion height. International Journal of Hydrogen Energy 44, 4524-4532.
[50] Wang, X., Cheng, S., Zhang, X., Li, X., Logan, B.E., 2011. Impact of salinity on cathode catalyst performance in microbial fuel cells (MFCs). International Journal of Hydrogen Energy 36, 13900-13906.

[51] Wu, Shijia., He, Weihua., Yang, W., Ye, Y., Huang, X., Logan, B.E., 2017. Combined carbon mesh amd small graphite fiber brush anodes to enhance and stabilize power generation in microbial fuel cells treating domestic wastewater. Journal of Power Sources 356, 348-355.
[52] Xu, S.Y., Lam, H.P., Karthikeyan, O.P., Wong. J.W.C., 2011. Optimization of food waste hydrolysis in leach bed coupled with methanogenic reactor: effect of pH and bulking agent. Bioresour Technol 102, 3702-8.
[53] Ye, Y., Zhu, X., Logan, B.E., 2016. Effect of buffer charge on performance of air-cathodes used in microbial fuel cells. Electrochimica Acta 194, 441-447.
[54] Yu, E.H., Cheng, S., Scott, K., Logan, B.E., 2007. Microbial fuel cell performance with non-Pt cathode catalysts. Journal of Power Source 171, 275-281.
[55] Zhao, N., Jiang, Y., Morales, M.A., Treu, L., Angelidaki, I., Zhang, Y., 2018. Electricity generation and microbial communities in microbial fuel cell powered by macroalgal biomass. Bioelectrochemistry 123, 145-149.
[56] Zhu, X., Logan, B.E., 2013. Using single-chmaber microbial fuel cells as renewable power sources of electro-Fenton reactors for organic pollutant treatment. Journal of Hazardous Materials 252-253, 198-203.