J. Saf. Environ. Health Res. 1(1): 23–26, Autumn 2016
DOI: 10.22053/jsehr.2016.33384

ORIGINAL RESEARCH PAPER

Producing Renewable Energy from Municipal Wastewater Treatment Using a Bio–electrochemical System

Nasser Mehrdadi[1],Gholamreza Nabi–Bidhendi[1], Hamid Reza Tashauoei[2], Behnam Vakili[3],Mahdi Asadi–Ghalhari[4*]

[1]Department of Environmental Engineering, Faculty of Environment, University of Tehran, Tehran, Iran.
[2]Department of Environmental Health Engineering, School of Public Health, Islamic Azad University Tehran Medical Branch, Tehran, Iran.
[3]Office of Improvement on Wastewater Operation Procedures, National Water and Wastewater Engineering Company, Tehran, Iran.
[4]Research Center for Environmental Pollutants and Department of Environmental Health Engineering, Qom University of Medical Sciences, Qom, Iran.

Received 12 September 2016; Revised 10 October 2016; Accepted 5 November 2016; Available online 27 December 2016

ABSTRACT: Concurrent renewable energy production and wastewater treatment are two main reasons for using microbial fuel cells (MFCs). In this study, real wastewater was used for treating and power generation by air cathode microbial desalination cells (ACMFC). The total duration of voltage generation by ACMFC was about 151.9 ±23.2 h. The maximum voltage produced from municipal wastewater treatment was 270 mV. The maximum power and current density calculated as 103 mW/m^2 and 382 mA/m^2, respectively. The change percentage of EC in wastewater obtained 28.87 ±9.77. The average change percentage of pH at the beginning and end of a fed–bacth phase in wastewater was about 7.3 ±0.34. The COD removal efficiency of wastewater was about 81.40 ±0.74%. The columbic efficiency was obtained 68.58 ±7.95.

KEYWORDS: *Microbial Fuel Cell, Wastewater Treatment, Bio–electrochemical, Columbic Efficiency*

Introduction

In recent years, the global energy crisis has accelerated due to excessive use of fossil fuels [1, 2]. One of the processes that consumes considerable energy (depending on the technology used) is wastewater treatment. For example, activated sludge process uses 0.28 to 0.71 kWh/m^3 of wastewater treated [3].

Because of high consumption of energy by conventional wastewater treatment systems, a technology is needed to use wastes (wastewater) and transform it into a useful energy [4, 5]. The energy content of wastewater is about 9.3 times greater than the energy needed to treat it [6, 7].

Microbial fuel cell (MFC) is one of the best technologies that extracts energy from organic matter within wastewaters by microorganisms and converts biochemical energy into electricity [8–13]. Electric current is generated due to movement of electrons from the anode to the cathode [12, 14]. Generated protons in wastewater chamber cross over a cation exchange membrane and enter the catholyte chamber and combine with oxygen and convert to water (Fig. 1)[1].

This energy is an economically and environmentally friendly technology [15–19]. Researchers have generated maximal current and power density with MFCs about 0.1 A, and 40 W/m^3, respectively, in fed–batch mode operation and with a synthetic wastewater [20].

Thus, wastewater treatment has the greatest potential for the practical application of MFCs [21].

MFCs have several advantages in comparison to conventional aerobic treatment such as useful electricity producing and no need for electricity because no aeration is used and production of sludge is greatly reduced [3]. It seems that the ACMFC can be used successfully in the future because it simultaneously produces energy and less sludge (0.07 – 0.16 g VSS/g COD) than conventional activated sludge processes (0.35 – 0.45 g VSS/g COD)[22]. So, it can reduce sludge production by 50 – 70% which in turn may reduce 20 – 30% of the plant operation cost and sludge disposal.

In most cases of the MFC studies, synthetic wastewater were used. Acetate, glucose, starch, and sucrose have been the choice of substrate for electricity generation [23–26].

The aim of this study is to evaluate the air cathode microbial fuel cells (ACMFC) performance in municipal wastewater treatment and power generation simultaneously.

Material and methods

Reactor construction

The main body of the pilot was built using sheets of Plexiglas in thicknesses of 0.5 – 2 cm having holes with 5 cm in diameter created on the sheets. After inserting the electrodes, useful volume of wastewater and catholyte chamber were 40 and 20 mL, respectively. Wastewater and catholyte chamber were separated using a CEM (Ultrex CMI7000, Membrane International). The chambers were clamped together with gaskets. Heat treated carbon graphite (450 °C, 30 min) with a dimension of 3×3×0.5 cm was used as an anode electrode. Before using, the anode electrode was placed in HCl 1 M solution and then washed with deionized water to remove minor metals for 48 hours. Carbon cloth (30% wet–proofed, BASF, US) with four polytetrafluoroethylene (PTFE) diffusion layers on the air side (to prevent waterless due to water driven across the cathode) and 0.5 mg/cm^2 of Pt on the water side was used as an cathode electrode with dimension of 3 cm in diameter [27].

*Corresponding Author Email: masadi@muq.ac.ir
Tel.: +98 2537 842 227; Fax: +98 2537 833 361
Note. Discussion period for this manuscript open until January 31, 2017 on JSEHR website at the "Show Article"
http://dx.doi.org/10.22053/jsehr.2016.33384

Electrodes were connected using titanium wire to the external circuit [28, 29].

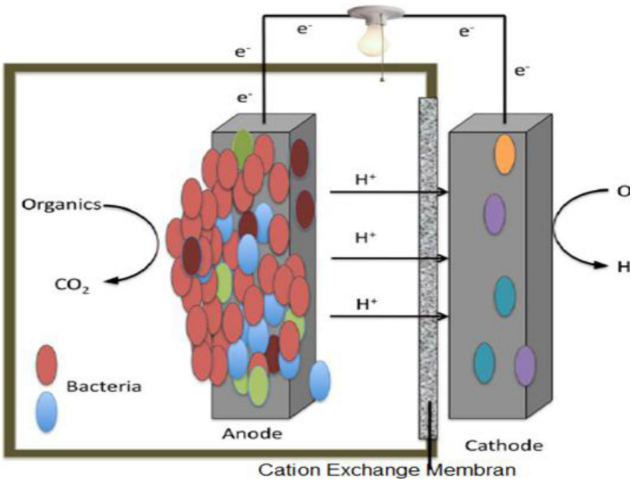

Fig. 1. Diagram of an ACMFC (Franks and Nevin 2010)

Operating conditions

Firstly, wastewater chamber was fed with municipal wastewater (real wastewater) and the cathode chamber was fed by 50 mM KH_2PO_4/K_2HPO_4 buffer solution (PBS) with pH equal to 7. Before connecting to the external resistance, the ACMFC was allowed to reach the maximum open circuit potential (OCP). Then, polarization curve obtained with the connection of ACMFC to the variable external resistance (from 50 to 20000 Ω). Based on obtained curve, the external resistance fixed at 1000 Ω. In operation phase voltage across the external resistor was recorded every 1 min with a data acquisition system (model 2700, Keithley Instruments, Inc. OH). ACMFC was operated as MFC and in fed–batch mode at ambient temperature (25 °C)[13]. Solutions in the cathode and anode chambers were replaced when the voltage decreased to <30 mV.

Analyses and calculations

According to Eq. 1 and Eq. 2, the power (P, mW/m^2) and current density (I, mA/m^2) were calculated.

$$P = \frac{V^2}{AR} \quad (1)$$

$$I = \frac{V}{AR} \quad (2)$$

Where, V is the voltage measured in mV, A is the projected surface area of the cathode (m^2), and R is the external resistor (Ω).

Columbic efficiency (CE) was calculated as Eq. 3:

$$c_E = \frac{8\int_0^{tb} Idt}{FV_{An}\Delta COD} \quad (3)$$

Where, 8 is a constant used for COD, based on MO_2= 32 gram/mole, 4 electrons exchanged per mole of oxygen, F is the Faraday's constant (96485 C/mole–electrons), V_{An} is the volume of wastewater chamber, and ΔCOD is the difference between inlet and outlet COD of wastewater. Columbic efficiency defined as the fraction (or percent) of electrons recovered as current versus that in the starting organic matter [3].

Results and discussion

The total duration of voltage generation by ACMFC was about 151.9 ±23.2 hours. As shown in Fig. 2 under 1000 Ω resistance condition (based on polarization data), and three stage operation (in fed–batch mode), the maximum voltage produced from municipal wastewater treatment by ACMFC was 270 mV. At this time, the maximum power and current density calculated as 103 mW/m^2 and 382 mA/m^2, respectively. In a similar study, maximum power density obtained 28 mW/m^2 with domestic wastewater and 262 ±10 mW/m^2 with glucose as a substrate using ACMFC [30]. So, using ACMFC in animal wastewater treatment, the maximum power density of 261 mW/m^2 was obtained (with 0.35 mg/cm^2 Pt coated on the cathode). Because Pt as a catalyst can reduce the cathodic reaction activation energy, the reaction rate increases [31]. Very fluctuations were shown in voltage generation by ACMFC. It seems that this change in comparison to synthetic wastewater can be due to the existence of some electron acceptors in real wastewater. Different results have been obtained in similar studies [20, 32].

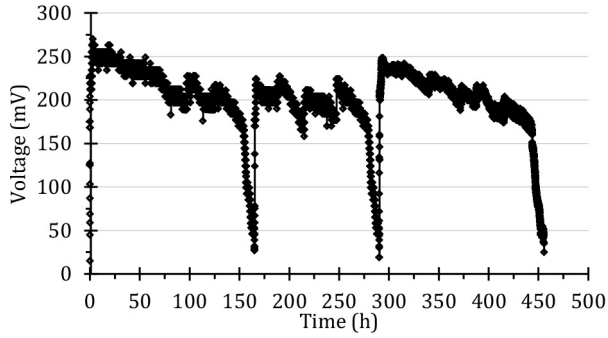

Fig. 2. The voltage produced by ACMFC in 50mM PBS.

The amount of power generation depends on many factors such as the type of electrode and its area, the distance between electrodes, type of wastewater, catholyte and electron acceptor in catholyte, etc. For example, if ferric cyanide is used as electron acceptor, power density increases by 1.5 to 1.8 times compared to dissolved oxygen [33]. But, toxicity of ferric cyanide (it can pass into the anode chamber across the CEM) and the need for its replacement led us to use air cathode in this study. Oxygen is suitable electron acceptor because of high oxidation potential, availability, sustainability, and the lack of a chemical waste product. Pt catalysts are usually used to increase the rate of oxygen reduction [34].

As described in Table 1, the COD removal efficiency of wastewater by ACMFC was about 81.40 ±0.74%. So it seems ACMFC can meet the standards of wastewater disposal some deal. In addition to the production of electrical energy and no need for energy consumption, the sludge produced by this system is less than conventional wastewater treatment such as activated sludge process. Also, change percent of EC in wastewater at the end of each cycle was obtained 28.87 ±9.77. So, pH and EC of catholyte haven't a significant change (change percent of EC and pH was 14.95 ±2.75% and 2.38 ±0.81%, respectively. Average change percent of pH at the beginning and the end of a fed–batch phase in wastewater was about 7.3 ±0.34. Because the proton transport through the cation exchange membrane is slower than its production rate in the anode and its consumption rate in the cathode chambers, thus pH decreased in wastewater chambers and increased in catholyte chambers [1]. In this study, because of the less change in pH of wastewa-

Table 1. Changes in inlet and outlet of pH, EC and COD in wastewater and catholyte

	pH		EC (mS/m)		COD (mg/L)	
	in	out	in	out	in	out
Wastewater	6.87 ±0.1	6.4 ±0.2	2341.5 ±22.5	3016.7 ±206.0	308.3 ±7.6	57.3 ±2.5
Catholyte	7.0 ±0.0	8.1 ±0.1	7321.7 ±2.9	8416.7 ±202.1	–	–

ter, it seems that decreasing the voltage produced can be due to decreasing of the COD in wastewater.

Based on the current calculated from voltage produced and COD removal by ACMFC, the columbic efficiency was obtained 68.58 ±7.95. In similar study columbic efficiencies obtained using glucose as substrate was 40 – 55% (CEM) and with wastewater was 28%.

Conclusion

The result of this research showed the remarkable COD removal of MFC for municipal wastewater and it seems that his system could be a method for treating wastewater in the future. Because ACMFC generates voltage with decreasing the cost of equipment such as electrodes, membranes, weirs, etc. this system can be replaced by conventional wastewater treatment such as activated sludge processes. A suggestion for the future research can be control of the fluctuation in voltage generation and achieve a stable voltage in real wastewater treatment. The main advantages of MFCs in wastewater treatment are producing energy. About 45 – 75% energy in conventional activated sludge systems is consumed by aeration, whereas the ACMFC can produce about 10 – 20% energy in addition to no need energy for aeration. Also, this generated energy can be used for other processes [35].

Acknowledgements

The authors wish to express their gratitude to Fumatech Company for their kindness in providing cation exchange membranes.

References

[1] Z. Du, H. Li, T. Gu, A state of the art review on microbial fuel cells: a promising technology for wastewater treatment and bioenergy, Biotechnology advances, 25 (2007) 464–482.
[2] V. Kiran, B. Gaur, Microbial fuel cell: technology for harvesting energy from biomass, Reviews in chemical engineering, 29 (2013) 189–203.
[3] B.E. Logan, Microbial Fuel Cells, John Wiley & Sons, 2008.
[4] M. Ghangrekar, V. Shinde, Performance of membrane–less microbial fuel cell treating wastewater and effect of electrodedistance and area on electricity production, Bioresource Technology, 98 (2007) 2879–2885.
[5] V. Oliveira, M. Simões, L. Melo, A. Pinto, Overview on the developments of microbial fuel cells, Biochemical Engineering Journal, 73 (2013) 53–64.
[6] M. Elimelech, W.A. Phillip, The future of seawater desalination: energy, technology, and the environment, science, 333 (2011) 712–717.
[7] M. Asadi, N. Mehrdadi, G. Nabi, Simultaneous desalination of sea water and electricity production with new membrane technology, Air-Cathode Microbial Desalination Cells, Current World Environment, 10 (2015) 115.
[8] E. Mahendiravarman, D. Sangeetha, Increased microbial fuel cell performance using quaternizedpoly ether ether ketone anionicmembrane electrolyte for electricity generation, International Journal of Hydrogen Energy, 38 (2013) 2471–2479.
[9] B. Min, J. Kim, S. Oh, J.M. Regan, B.E. Logan, Electricity generation from swine wastewater using microbial fuel cells, Water research, 39 (2005) 4961–4968.
[10] R.K. Goud, P.S. Babu, S.V. Mohan, Canteen based composite food waste as potential anodic fuel for bioelectricity generation in single chambered microbial fuel cell (MFC): bio–electrochemical evaluation under increasing substrate loading condition, International Journal of Hydrogen Energy, 36 (2011) 6210–6218.
[11] L. Huang, J.M. Regan, X. Quan, Electron transfer mechanisms, new applications, and performance of biocathode microbial fuel cells, Bioresource Technology, 102 (2011) 316–323.
[12] W.–W. Li, G.–P. Sheng, X.–W. Liu, H.–Q. Yu, Recent advances in the separators for microbial fuel cells, Bioresource technology, 102 (2011) 244–252.
[13] X.–c. Quan, Y.–p. Quan, K. Tao, Effect of anode aeration on the performance and microbial community of an air–cathode microbial fuel cell, Chemical Engineering Journal, 210 (2012) 150–156.
[14] P.D. Kiely, R. Cusick, D.F. Call, P.A. Selembo, J.M. Regan, B.E. Logan, Anode microbial communities produced by changing from microbial fuel cell to microbial electrolysis cell operation using two different wastewaters, Bioresource technology, 102 (2011) 388–394.
[15] Y. Sun, J. Wei, P. Liang, X. Huang, Electricity generation and microbial community changes in microbial fuel cells packed with different anodic materials, Bioresource technology, 102 (2011) 10886–10891.
[16] L. Xiao, J. Damien, J. Luo, H.D. Jang, J. Huang, Z. He, Crumpled graphene particles for microbial fuel cell electrodes, Journal of Power Sources, 208 (2012) 187–192.
[17] C.T. Matos, T.L. da Silva, Using multi–parameter flow cytometry as a novel approach for physiological characterization of bacteria in microbial fuel cells, Process biochemistry, 48 (2013) 49–57.
[18] P. Zhang, K. Li, X. Liu, Carnation–like MnO 2 modified activated carbonair cathode improve power generation in microbial fuel cells, Journal of Power Sources, 264 (2014) 248–253.
[19] B. Zhang, Z. Wen, S. Ci, S. Mao, J. Chen, Z. He, Synthesizing nitrogen–doped activated carbon and probing its active sites for oxygen reduction reaction in microbial fuel cells, ACS applied materials & interfaces, 6 (2014) 7464–7470.
[20] M. Di Lorenzo, K. Scott, T.P. Curtis, I.M. Head, Effect of increasing anode surface area on the performance of a single chamber microbial fuel cell, Chemical Engineering Journal, 156 (2010) 40–48.
[21] B.E. Logan, Simultaneous wastewater treatment and biological electricity generation, Water Science & Technology, 52 (2005) 31–37.
[22] P. Clauwaert, P. Aelterman, L. De Schamphelaire, M. Carballa, K. Rabaey, W. Verstraete, Minimizing losses in bio–electrochemical systems: the road to applications, Applied Microbiology and Biotechnology, 79 (2008) 901–913.
[23] B. Logan, S. Cheng, V. Watson, G. Estadt, Graphite fiber brush anodes for increased power production in air–cathode microbial fuel cells, Environmental science & technology, 41 (2007) 3341–3346.
[24] T. Catal, K. Li, H. Bermek, H. Liu, Electricity production from twelve monosaccharides using microbial fuel cells, Journal of Power Sources, 175 (2008) 196–200.
[25] J. Niessen, U. Schröder, F. Scholz, Exploiting complex carbohydrates for microbial electricity generation–a bacterial fuel cell operating on starch, Electrochemistry Communications, 6 (2004) 955–958.
[26] M. Behera, M. Ghangrekar, Performance of microbial fuel cell in response to change in sludge loading rate at different anodic feed pH, Bioresource technology, 100 (2009) 5114–5121.
[27] S. Cheng, H. Liu, B.E. Logan, Power densities using different cathode catalysts (Pt and Co TMPP) and polymer binders (Nafion and PTFE) in single chamber microbial fuel cells, Environmental science & technology, 40 (2006) 364–369.

[28] Y. Qu, Y. Feng, X. Wang, J. Liu, J. Lv, W. He, B.E. Logan, Simultaneous water desalination and electricity generation in a microbial desalination cell with electrolyte recirculation for pH control, Bioresource technology, 106 (2012) 89–94.
[29] C.M. Werner, B.E. Logan, P.E. Saikaly, G.L. Amy, Wastewater treatment, energy recovery and desalination using a forward osmosis membrane in an air–cathode microbial osmotic fuel cell, Journal of Membrane Science, 428 (2013) 116–122.
[30] H. Liu, B.E. Logan, Electricity generation using an air–cathode single chamber microbial fuel cell in the presence and absence of a proton exchange membrane, Environmental science & technology, 38 (2004) 4040–4046.
[31] S. Yang, B. Jia, H. Liu, Effects of the Pt loading side and cathode–biofilm on the performance of a membrane–less and single–chamber microbial fuel cell, Bioresource Technology, 100 (2009) 1197–1202.
[32] B. Kim, Enrichment of microbial community generating electricity using a fuel-cell-type electrochemical cell, Applied Microbiology and Biotechnology, 63 (2004) 672-681.
[33] S.–E. Oh, B.E. Logan, Proton exchange membrane and electrode surface areas as factors that affect power generation in microbial fuel cells, Applied microbiology and biotechnology, 70 (2006) 162–169.
[34] B.E. Logan, B. Hamelers, R. Rozendal, U. Schröder, J. Keller, S. Freguia, P. Aelterman, W. Verstraete, K. Rabaey, Microbial fuel cells: methodology and technology, Environmental science & technology, 40 (2006) 5181–5192.
[35] H. Wang, Z.J. Ren, A comprehensive review of microbial electrochemical systems as a platform technology, Biotechnology advances, 31 (2013) 1796–1807.

AUTHOR(S) BIOSKETCHES

Mehrdadi, N., Ph.D., Professor, Department of Environmental Engineering, Faculty of Environment, University of Tehran, Tehran, Iran. Email: *mehrdadi@ut.ac.ir*

Nabi–Bidhendi, Gh., Ph.D., Professor, Department of Environmental Engineering, Faculty of Environment, University of Tehran, Tehran, Iran. Email: *ghhendi@ut.ac.ir*

Tashauoei, H.R., Ph.D., Assistant Professor, Department of Environmental Health Engineering, School of Public Health, Islamic Azad University Tehran Medical Branch, Tehran, Iran. Email: *h.tashauoei@nww.ir*

Vakili, B., MSc, Office of Improvement on Wastewater Operation Procedures, National Water and Wastewater Engineering Company, Tehran, Iran. Email: *bm_vakili@yahoo.com*

Asadi–Ghalhari, M., Ph.D., Assistant Professor, Research Center for Environmental Pollutants and Department of Environmental Health Engineering, Qom University of Medical Sciences, Qom, Iran. Email: *masadi@muq.ac.ir*

HOW TO CITE THIS ARTICLE

N. Mehrdadi, G. Nabi-Bidhendi, H.R. Tashauoei, B. Vakili, M. Asadi-Ghalhari, Producing Renewable Energy from Municipal Wastewater Treatment Using a Bio-electrochemical System, Journal of Safety, Environment, and Health Research, (2016) 23-26.

DOI: 10.22053/jsehr.2016.33384

URL: http://jsehr.net/article_33384.html