

Studies of treatment of wastewater to produce green energy by using Microbial Fuel Cell - A Review

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Abstract— Environmental protection and energy crisis are two major challenges human beings are facing today. As the energy sources decrease and the climate conditions change, demand for new and clean sources of energy has increased. Microbial fuel cell (MFC) represents a promising technology for sustainable energy production. Microbial fuel cell is one of the best alternative sources of green energy production which add wastewater to the list of renewable resources of energy. In this review, microbial fuel cell and its working have been briefly reviewed. Also different substrates that can be used in MFC and different factors affecting the performance of MFC have been briefly reviewed.

Keywords— Microbial Fuel Cell, Wastewater Treatment, Electricity, Anaerobic treatment, COD Removal, Green energy, Biological Treatment

1. INTRODUCTION

Increasing global energy demands and over consumption of non-renewable resources of energy have led to search and use of renewable and cost-effective sources of energy. At present, global energy requirements are mostly dependent on fossil fuels. Combustion of fossil fuels also has serious negative effects on environment due to CO₂ emission like global climate change, environmental degradation and health problems. This has intensified the search for alternatives to replace fossil fuels [1,2,3]. One of the renewable and green energy sources for the production of electricity is fuel cells (FC) [4,6]. Microbial fuel cells (MFCs) are a special type of FCs that has dual advantage. The microbes added convert organic matter into electricity and at the same time purify wastewater, thus may offset the operating costs of wastewater treatment plant [5,6]. The microbial fuel cell (MFC) is a new form of renewable energy technology that can generate electricity from what would otherwise be considered waste [7].

While the concept of bioelectricity generation was first demonstrated nearly a century ago, MFCs need to be considered as new technology. Biofuel cells conducted with yeast and bacteria that needed chemical mediators to be added to the reactor were very unlikely to have practical applications. Thus, modern MFCs can be considered to have only emerged in 1999 with the finding of electricity generation without the need for exogenous mediators. [8]

MFC converts organic matter present in wastewater into electricity through the catalytic activity of microbes. The energy present in C–C bonds of organic matter is directly converted into electricity. The electrons produced during the oxidation process are transferred to the anode from where they flow through the external circuit thus generating electricity. The electrons are transferred to the anode either through direct bacterial contact to the anode or through the use of mediators especially electrodes. [9]

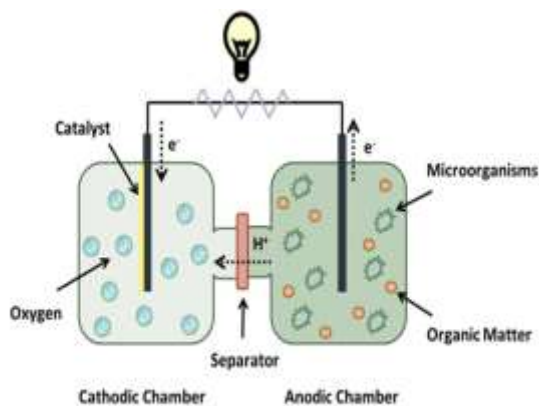
Oxidation half- reaction (Anode chamber):

Biodegradable matter + bacteria \longrightarrow CO₂ + H⁺ + e⁻ (anaerobic condition)

The electrons travel across the external circuit connected with an external resistance and reaches the aerated cathode where the electrons and the protons along with the molecular oxygen produce water completing the reduction half-reaction.

Reduction half-reaction (Cathode chamber):

H⁺ + e⁻ + Oxygen \longrightarrow H₂O (Aerobic condition) [10].



Cathode: $6O_2 + 24H^+ + 24e^- \rightarrow 12H_2O$ Anode: $C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$
Scheme of a double-chamber MFC using glucose as substrate. [11]

2. STUDIES ON DIFFERENT SUBSTRATES USED IN MFC:

In MFCs, substrate is regarded as one of the most important biological factors affecting electricity generation. A variety of substrates can be used for bioelectricity generation in MFCs such as saccharides, organic acids, alcohols as well as inorganic substances e.g. sulphate. In addition, there is a significant research interest towards complex materials i.e. industrial and municipal waste streams, which are potential starting materials of power generation in MFCs because of their high organic matter content [12].

Wastewaters from chemical, distillery, brewery industries, pharmaceutical industry, textile, petrochemical, vegetable oil, food industries, animal carcass waste water, swine waste water, municipal waste water and domestic wastewater could be treated using aerobic or anaerobic MFC. Sulphide, ammonia, nitrate, nitrite, perchlorate, chlorinated compounds, copper, mercury and iron could be effectively removed by MFC [9].

Table 1: List of wastewater used as substrate in MFC studies.

Substrate	MFC Type		Power generation	References
Swine	Single chamber		261mW/m ²	[13,14]
	Two chamber		45mW/m ²	
Saline domestic sewage sludge	Two chamber		41W/m ³	[15]
Nitrogen-containing organic compounds (pyridine and methyl orange)	single-chamber air-cathode MFCs	Single MFC	502.5±17mW/m ²	[16]
		Two MFC connected in series	401.6±23 mW/m ²	
Paper recycling wastewater+ 100mM PBS	Single chamber MFC		672±27 mW/m ²	[17]
Urine	Two chambered		8mA/m ² ± 0.5mA/m ²	[18]
Lemon peel waste	Dual chamber		371 ± 30 mW/m ²	[19]
Domestic	Air-cathode		422mW/m ²	[13,20]
Leachate	Air-cathode		344mW/m ²	[13,21]
Starch	Air-cathode		239,4mW/m ²	[13,22]
Beer Brewery	Air-cathode		205mW/m ²	[13,23]
	Single chamber		170mW/m ²	

3. STUDY ON EFFECT OF PARAMETERS:

3.1 Effect of temperature:

Temperature is an important wastewater characteristic, but most studies have examined performance at a single temperature, with typical temperatures chosen of room temperature or higher (20–35°C). When temperatures have been varied during a study, different results have been obtained relative to impact of temperature on performance, although in almost all cases lowering the temperature reduced performance. In two different studies with single-chamber MFCs operated in fed-batch mode, the power density decreased by 10% when the temperature was reduced from 32°C to 20°C [24,25,26]. In another study with a single-chamber MFC operated with continuous mode, the power density decreased by 21% when the temperature decreased from 35°C to 24°C, but only by 5% when the temperature was decreased from 30°C to 24°C [24,27]. In contrast, it was reported that when using a two-chamber MFC with a ferricyanide cathode, that the power density was reduced by 39% when for a temperature decrease from 30°C to 22°C, and that there was no appreciable power generation at 15°C [24,28]. In another two-chamber MFC study with a dissolved oxygen (DO) catholyte, however, current increased from 0.7mA to 1.4mA when the temperature decreased from the range of 20–35°C to 8–22°C [24,29]. In a study it shows that upper temperature limit for MFC operation is 40°C and lower temperature limit is -5°C. [30]

3.2 Effect of pH:

In a batch study, MFC have shown the best performance at anodic pH 7 and its performance decreases with increase in alkalinity and acidity of the substrate solution and show minimum voltage generation of 6.2 and 10.9 mV and minimum power generation of ~53 and ~3 mW/m² at anodic pH 5 and 9, respectively.[31]

3.3 Effect of initial COD:

In a batch study, it is shown that that both voltage and power density increase with increase in time and become almost stable after around 5–6 days of operation for all the initial COD values. This is because of the adaptation of microbes in new environment. Voltage and power density in MFC increase with increase in initial COD value, reaches maximum at the initial COD value of around 1500 mg/L and then decreases. Maximum voltage and power density achieved after ~7 days of operation with 1500 mg/L initial COD are 14.8 mV and ~272 mW/m², respectively.[31]

3.4 Effect of metal ions:

3.4.1. Effect of Chromium (Cr⁶⁺):

In a study, it is shown that both voltage and power density generation in MFC initially increases with increase in Cr⁶⁺ concentration upto 7 mg/L and decreases thereafter. The maximum voltage and power density generation after around 5 days of operation under the optimum concentration of Cr⁶⁺ (7 mg/L) are ~490 mV and ~508 mW/m², respectively. These values are ~33 times and ~1800 times higher than the corresponding values of voltage and power density generation in absence of Cr⁶⁺. [31]

3.4.2. Effect of Iron (Fe³⁺) Concentration:

In a study, it is shown that both voltage and power density generation in MFC initially increases with increase in Fe³⁺ concentration up to 10mg/L and decreases thereafter. The maximum voltage and power density generation after around 5 days of operation under the optimum concentration of Fe³⁺ (10 mg/L) are ~321 mV and ~193 mW/m², respectively. These values are ~22 times and ~709 times higher than the corresponding values of voltage and power density generation in absence of Fe³⁺. [31]

3.4.3. Effect of Zinc (Zn²⁺) Concentration:

In a study, it is shown that both voltage and power density generation in MFC initially increases with increase in Zn²⁺ concentration up to 8 mg/L and decreases thereafter. The maximum voltage and power density generation after around 6 days of operation under the optimum concentration of Zn²⁺ (8 mg/L) are ~135 mV and ~7 mW/m², respectively. These values are ~9 times and ~26 times higher than the corresponding values of voltage and power density generation in absence of Zn²⁺. [31]

3.5. Effect of agarose concentration in salt bridge of dual chambered MFC:

In a study on performance of MFC with agarose concentrations 7,8,9,10,11 and 12 %. MFC with 10% agarose have produced maximum voltage and current and one with 12% produced minimum. The voltage developed showed a comparative hike from 7% agarose concentration to 10% concentration, and this could be due to the reason that as the concentration of agarose increases, the gel is highly polymerized, inhibiting the inter mixing probability of the two separated chamber fluids. Highly polymerized gel also prevents the entry of native and molecular oxygen from the aerobic chamber to the anaerobic chamber through the salt-bridge passage, maintaining the anaerobic conditions of the anode chamber. But a decrease in voltage production was observed for 11% and 12% agarose concentration, as the salt-bridge is highly polymerized reducing the pore size, hindering the movement of proton across the bridge.[10]

It was observed that there is an increase in current production as the concentration of agarose increases from 7% to 10%. This was due to effective proton transfer and as the gels is highly polymerized; it prevents the diffusion of oxygen from the cathode chamber to anode chamber through the salt-bridge, thus maintaining a better anaerobic environment in the anode chamber encouraging the growth of anaerobic bacteria for increased electrons release [32,10]. But there was a decrease in current production for 11% and 12% agarose concentration as the extremely polymerized gel prevents the effective movement of protons, increasing the concentration of protons in the anode chamber, reducing the pH, making the anodic environment highly acidic for the microbes to survive [10].

3.5 Effect of spacing between anode and cathode on power production:

In a study under variable external resistance, the power density has increased with decrease in distance between the electrodes. Maximum power density of 10.9, 8.6, and 7.4mW/m² was observed at electrode spacing 20, 24 and 28 cm, respectively. The maximum power density was observed at external resistance between 900 ohm and 1200 ohm. Decrease in power density was observed with increase in resistance beyond 1200 ohm, indicating importance of external load for controlling power production. These results suggest that, at higher external resistance the electron transfer through the external circuit to the cathode might be the limiting factor. In addition, this suggests that, ML–MFC should be constructed by placing electrodes as close as possible to increase power output.

4. CONCLUSION:

With the above review following conclusion may be drawn:

- Microbial fuel cell (MFC) is a promising technology may be proved in future to fulfill the needs of energy.
- It is also a promising technology for treatment of wastewater as well as alternative sources of green energy production.
- Its power production is still low for the practical applications therefore further extensive studies will be required for practical applications.

REFERENCES:

- [1] Daniel, D.K., B.D. Mankidy, K. Ambarish and R. Manogari, "Construction and operation of a microbial fuel cell for electricity generation from wastewater", *International Journal of Hydrogen Energy*, 34(17): 7555-7560, 2009.
- [2] Fatemi, S., A.A. Ghoreyshi, G. Najafpour and M. Rahimnejad, "Bioelectricity Generation in Mediator-Less Microbial Fuel Cell: Application of Pure and Mixed Cultures", *Iranica Journal of Energy and Environment*, 3(2): 104-108, 2012.
- [3] M. Muthukumar, S. Shanmuga Priya, T. Sangeetha, "Impact of Salt on Bioelectricity Generation in a Dual-Chambered Microbial Fuel Cell Using Sago-Processing Wastewater", *Iranica J. Energy & Environ.*, 5 (4): 376-386, 2014.
- [4] Mostafa Rahimnejad, Ali Asghar Ghoreyshi, Ghasem Najafpour, Tahereh Jafary, "Power generation from organic substrate in batch and continuous flow microbial fuel cell operations", *Applied Energy*, vol. 88, pp. 3999–4004, 2011.
- [5] Lu, N., Zhou, S.G., Zhuang, L., Zhnag J.T., Ni J.R., "Electricity generation from starch processing wastewater using microbial fuel cell technology", *Biochem. Eng. J.*, vol. 43, pp. 246–251, 2009.
- [6] Rakesh, Chandra, Ujwal Shreenag Meda, R. Suresh, "Performance studies of microbial fuel cell", *IJRET: International Journal of Research in Engineering and Technology eISSN*, Volume: 03 Issue: 11, pp. 169-173, 2014.
- [7] Pranab K. Barua, D. Deka, "Electricity Generation from Biowaste Based Microbial Fuel Cells", *International Journal of Energy, Information and Communications Vol. 1, Issue 1*, pp.77-92, 2010.
- [8] Bruce.E.Logan, "Microbial Fuel Cells", John Wiley & Sons, Inc., Hoboken, New Jersey, 2008.
- [9] Umara Abbasi, Wang Jin, Arshid Pervez, Zulfiqar Ahmad Bhatti, Madiha Tariq, Shahida Shaheen, Akhtar Iqbal, Qaisar Mahmood, "Anaerobic microbial fuel cell treating combined industrial wastewater: Correlation of electricity generation with pollutants", *Journal of Cleaner Production* 11, 4406-4412, 2016.
- [10] Ramya Nair, Renganathan. K, S. Barathi, Venkatraman. K, "Performance of salt-bridge microbial fuel cell at various agarose Concentrations using hostel sewage waste as substrate", *International Journal of Advancements in Research & Technology*, Volume 2, Issue 5, pp.326-330, 2013.
- [11] F.J. Hernández-Fernández, A. Pérez de los Ríos, M.J. Salar-García, V.M. Ortiz-Martínez, L.J. Lozano-Blanco, C. Godínez, F. Tomás-Alonsob, J. Quesada-Medina, "Recent progress and perspectives in microbial fuel cells for bioenergy generation and wastewater treatment", *Fuel Processing Technology* 138, 284–297, 2015.
- [12] Laszo Kook, Tamas Rozsenberszki, Nandor Nemestothy, Katalin Belafi-Bako, Peter Bakonyi, "Bioelectrochemical treatment of municipal waste liquor in microbial fuel cells for energy valorization", *Journal of Cleaner Production* 112, 4406-4412, 2016.
- [13] Emre Oğuz Köroğlu, Bestamin Özkaya, Afşin Yusuf Çetinkaya, "Microbial Fuel Cells for Energy Recovery from Waste", *International Journal of Energy Science (IJES) Volume 4, Issue 1*, pp.28-30, 2014.
- [14] Min, B., Kim, J.R., Oh, S.E., Regan, J.M. ve Logan, B.E. "Electricity generation from swine wastewater using microbial fuel cells", *Water Research*, 39, 4961-4968, 2005.
- [15] Rengasamy Karthikeyan, Ammayaippan Selvam, Ka Yu Cheng, Jonathan Woon-Chung Wong, "Influence of ionic conductivity in bioelectricity production from saline domestic sewage sludge in microbial fuel cells", *Bioresource Technology* 200,845–852, 2016.

- [16] Zhijun Wang, Baogang Zhang, Alistair G.L. Borthwick, Chuanping Feng, Jinren Ni, "Utilization of single-chamber microbial fuel cells as renewable power sources for electrochemical degradation of nitrogen-containing organic compounds", *Chemical Engineering Journal* 280, 99–105, 2015.
- [17] Liping Huang, Bruce E. Logan, "Electricity generation and treatment of paper recycling wastewater using a microbial fuel cell", *Appl Microbiol Biotechnol*, 80:349–355, 2008.
- [18] Ieropoulos, I., Greenman, J. and Melhuish, C., "Urine utilization by Microbial Fuel Cells: Energy fuel for the future", *Physical Chemistry Chemical Physics*, 14 (1). pp. 94-98. ISSN 1463-9076, 2011.
- [19] Waheed Miran, Mohsin Nawaz, Jiseon Jang, Dae Sung Lee, "Sustainable electricity generation by biodegradation of low-cost lemon peel biomass in a dual chamber microbial fuel cell", *International Biodeterioration & Biodegradation* 106,75-79, 2016.
- [20] Ahn, Y. ve Logan, B.E. "Effectiveness of Domestic Waste-water Treatment Using Microbial Fuel Cells at Ambient and Mesophilic Temperatures", *Bioresource Technology*, 101, 469-475, 2010.
- [21] Puig, S., Serra, M., Coma, M., Cabre, M., Balaguer, M.D. ve Colprim, J. "Microbial Fuel Cell Application in Landfill Leachate Treatment", *Journal of Hazardous Materials*, 185, 763-767, 2011.
- [22] Lu, N., Zhou, S.G., Zhuang, L., Zhang, J.T. ve Ni, J.R. "Electricity generation from starch processing waste-water using microbial fuel cell technology", *Biochemical Engineering Journal*, 43, 246-251, 2009.
- [23] Feng, Y., Wang, X., Logan, B.E. ve Lee, H. "Brewery Wastewater Treatment Using Air-Cathode Microbial Fuel Cells", *Environmental Biotechnology*, 78, 873-880, 2008.
- [24] Shaoan Cheng, Defeng Xing, Bruce E. Logan, "Electricity generation of single-chamber microbial fuel cells at low temperatures", *Biosensors and Bioelectronics* 26, 1913–1917, 2011.
- [25] Liu, H., S. Cheng, B.E. Logan, "Power generation in fed-batch microbial fuel cells as a function of ionic strength, temperature, and reactor configuration", *Environ. Sci. Technol.* 39(14):5488-5493, 2005.
- [26] Yujie Feng, Xin Wang, Bruce E. Logan, He Lee, "Brewery wastewater treatment using air-cathode microbial fuel cells", *Appl Microbiol Biotechnol* 78:873-880, 2008.
- [27] Hyunsoo Moon, In Seop Chang, Byung Hong Kim, "Continuous electricity production from artificial wastewater using a mediator-less microbial fuel cell", *Bioresource Technology* 97 621–627, 2006.
- [28] Booki Min, Oscar Benito Roman, Irini Angelidaki, "Importance of temperature and anodic medium composition on microbial fuel cell (MFC) performance", *Biotechnol Lett* 30:1213–1218, 2008.
- [29] Jadhav, G.S., Ghangrekar, M.M., "Performance of microbial fuel cell subjected to variation in pH, temperature, external load and substrate concentration.", *Bioresour. Technol.* 100(2), 717-723, 2009.
- [30] Jessica Li, "An Experimental Study of Microbial Fuel Cells for Electricity Generating: Performance Characterization and Capacity Improvement", *Journal of Sustainable Bioenergy Systems*, 3, 171-178, 2013.
- [31] Ravi Shankar, Prasenjit Mondal, and Shri Chand, "Simultaneous Generation of Electricity and Removal of Organic Load from Synthetic Wastewater in a Membrane Less Microbial Fuel Cell: Parametric Evaluation", *Environmental Progress & Sustainable Energy* (Vol.34, No.1), 2015.
- [32] Ghangrekar MM, Shinde VB, "Performance of membrane-less microbial fuel cell treating wastewater and effect of electrode distance and area on electricity production", *Bioresource Technol.* 98, 2879–2885, 2007.
- [33] M.M. Ghangrekar, V.B. Shinde, "Performance of membrane-less microbial fuel cell treating wastewater and effect of electrode distance and area on electricity production", *Bioresource Technology* 98, 2879–2885, 2007.