2063-5346

section A - Review paper

Microbial Fuel Cells: A Sustainable Approach towards Wastewater Treatment as well as Bioenergy Generation.

Ankita Saxena[1]*, Varsha Gupta[1], Sonika Saxena[2]
[1]Department of Microbiology, JECRC University, Jaipur, (Raj), India
[2]Department of Biotechnology, Dr. B. Lal Institute of Biotechnology, Jaipur, (Raj), India
*Corresponding author E-mail: ankitasaxena6900@gmail.com

Article History: Received: 18.11.2022 Revised: 15.02.2023 Accepted: 22.03.2023

ABSTRACT

Providing clean and affordable water to satisfy human necessities is a grand challenge of the 21stcentury. Worldwide, environmental concerns related to water cleanliness are not restricted to developed countries alone but are the most fundamental human and environmental requirements. Currently, waste water treatment remedies are not acceptable to satisfy the water sanitation needs. As rapid industrialization and urbanization, releases various toxic compounds into the waterbodies, polluting both fresh and marine water resources. So, to conquer this problem bioremediation is the process which is used to neutralizing the toxic compounds present in the natural waterbodies. Several processes have been proposed for the wastewater treatment but most of them have some limitations like high cost effective, poor capacity etc. Bioremediation is the process which is widely used for the wastewater treatment. Recently, great attentions have been paid to microbial fuel cells (MFCs) because of their slight operating conditions and using various types of biodegradable substrates as fuel. Microbial fuel cells (MFCs) have been considered and intensively studied as a favorable technology to attain sustainable wastewater treatment. This review summarizes the possibility of MFCs as an alternative and effective tool to generate energy via various fuel sources.

Keywords: Bioremediation, Bioenergy, Energy recovery, Microbial fuel cells, Waste water treatment

INTRODUCTION

A foremost problem at the global is related with the demand and quality of water[1]. This creates problem because, there is very small amount of water is left and, on the other hand, the mishandling of wastewater leads to economic, social and environmental issues[2-3]. In last years the discharge of wastewater has increased from the urban population. Water has turn out to be a basic component of present natural environmental and economic policies, so there is a need to clean the contaminated water bodies to complete the fundamental necessities of the populace[3]. The controlling of urban and commercial wastewater is the simplest resolution for the decontamination and purification of effluents. However, it is noteworthy to recognize toxic movement of some substances that can slow down the purification process and even destroy the activity of the microorganisms engaged with the water purification[4]. The treatments designed for the purification of wastewater include different types of processes such as physical, chemical and biological steps that enable to improve the polluted water and, in few cases, return it to clean water[3].

The method of purification of water is divided according to the components of wastewater biodegradability:

1) Primary treatment involves removal of large solid contaminants such as cans, rags, bottles, etc., It also involves removal of the suspended solid particles and the carbon-based matter by physical separation by using different methods like gravity, chemical sedimentation, or filtration;

2) Secondary treatment involves the removal of approximately 90% of the organic matter, converting it into a sedimentable organic floc (an accumulation of organic matter, bacteria and minerals). This procedure is completed by the usage of special biological techniques like activated sludge, aerated lagoons, trickling filters, bio-discs, stabilization ponds, etc.;

3) Tertiary treatment is the final cleaning process that improves wastewater quality before it is reused, recycled or discharged to the environment. Tertiary treatment involves the removal of microorganisms to reduce the possibility of disease transmission when the treated water is discharged and during this treatment nutrient like nitrogen and phosphorus are also removed to prevent the eutrophication of receiving water bodies.

Wastewater treatment is not a single problem for the developing countries however it continues to be the basic sanitation need to protect the surroundings and the water forms that serve as drinking water sources around the globe[5].

Bioremediation is described as the process through which the biological or carbon-based wastes are degraded biologically under measured conditions. By definition, "Bioremediation is the use of microorganisms to degrade environmental pollutants into less toxic forms"[6]. Research has shown that bioremediation can be an effective method to tackle waste water due to the ability of microorganisms to survive, adapt, and flourish into various types of environments, including wastewater[7-10].

As energy supply, wastewaters contain the large potential in the form of biodegradable organic matters like sanitary waste water, food processing wastewater, swine wastewater, corn stover etc[11-13].

2. PRINCIPLE OF MICROBIAL FUEL CELLS:

"MFC was a powerful technology which was used for treating wastewater since 1911"[14] and it was known to be a completely different method for energy generation in the form of electricity or hydrogen gas[15]. Presently, the microbial fuel cell (MFC) technology is one of the furthermost attractive technologies for production of renewable energy and simultaneous treatment of wastewater. By the definition, microbial fuel cells are devices that utilise bacteria as the catalysts to oxidize organic and inorganic matter to generate current. To construct these electrochemical cells either a bio-anode and/or a bio-cathode are used as electrodes along with a membrane which separates both the anode (where oxidation takes place) and the cathode (where reduction takes place). In the anode compartment, during the oxidation process the electrons are produced which are then directly transferred to an electrode or to a redox mediator species. From the anode electrode these electrons are then moved towards the cathode electrode. During the whole process the charge balance of the system is maintained by the ions movements.

2.1 Proton exchange membranes (PEM):

In Microbial Fuel Cells technology, neutrality between both the chambers of MFC is a very significant for its effective process attained by the PEM to facilitate the proton ions across the membrane. Proton Exchange Membranes are the main component of the MFC which separates the anode and cathode chambers as well as transfer the protons to the cathode chamber from anode chamber to sustain the electric current.

PEM should have the following characteristics as PEM surface area plays a very important role in MFC power generation:

- cost effective
- proton conductivity increased
- mechanical strength increased
- durability against heat and chemicals
- Electronically resistive.

The total surface area of PEM limits the power output. There are various types of PEM that has been used in MFC technology include Nafion, Ultrex[17] and salt bridge[18].

One of the effective features of any PEM is its water absorbing capacity along with its conductivity. Capacity of water absorption affects the mode of protons across the membrane which is essential for the functioning of the fuel cell, as well as it also affects the mechanical properties of the membrane[19].

Apart from PEM, salt bridge is another simplest form of PEM which can also be used in MFC. The salt bridge is made up of ionic salt such as KCl or NaOH which is melted with agar and casted into a cylindrical substance and allowed it for solidification for 15-20 minutes. After proper solidification the salt bridge is in between the two MFC chambers acting as a PEM to facilitate the transfer of proton ions from anode chamber to the cathode chamber. 5% concentration of salt in the salt bridge is enough to produces maximum power density of 84.99 mW/m^3 whereas is another study conducted by[18] varies the concentration of agarose in a salt-bridge MFC and concluded that 10% of agarose concentration acts as optimal for the generation of current as well as voltage generation[20].

Anode: $C_6H_{12}0_6 + 6H_20 \longrightarrow 6C0_2 + 24H^+ + 24e^-$

Cathode: $60_2 + 24H+ + 24e^- \longrightarrow 12H_20$

$C_6H_{12}0_6 + 60_2 \longrightarrow 6C0_2 + 6H_20$ + Electrical Energy

Sometimes, due to direct electron transfer from microbe to anode electrode reduces the efficiency because of which in electrochemically inactive microbial cells some exogenous mediators (like thionine, methyl vilogen, humic acid etc.) are used. These exogenous mediators act as shuttles for electrons, which diffuses the electrons to the anode electrode and then again diffusing back to the bacterial cells. Sometimes these mediators are toxic to the microorganisms. The potency of the MFC in energy generation has been widely studied. However, wastewater can be considered as probably the best sources as a substrate for energy generation, and supplements for plants[21-22]. Thus, Microbial fuel cell (MFC) has the capacity to treat wastewater along with generation of electricity and referred to be the best way to overcome the water and energy problems[23].

3. MICROORGANISMS USED FOR MFC:

Mainly wastewaters are used as a power source in MFCs. Most MFCs use wastewater as a power source. Such consortia in the anode chamber should have functions similar to the communities of methanogenic anaerobic digesters, except those microorganisms capable of transferring electrons to the electrode replace methanogens. Such micro-biosensors are called anodophilic (Anodophilic consortia).

Geobacter[24] and Shewanella species[25] account for the majority of the microbial population that have been utilized in MFC technology. Photosynthetic bacteria can also be used effectively in a MFC for electric power generation. Most important feature of using photosynthetic bacteria in MFCs is the exclusion of carbon dioxide from the atmosphere due to photosynthesis together with generation of bioelectricity[26].

The voltage generated in the MFC is linearly decreasing in time[27]. A mixture of biowaste can actually lead to more generation of the recovered current than any one-component MFC. In MFC working on complex substrates and wastewater, biofilm is formed on the anode, containing, in addition to well-known electro-genes (Geobacter, Shewanella), a complex association of microorganisms. A sufficiently wide range of microorganisms can transfer electrons to the electrode, including representatives of the families Geobacteraceae, Alteromonadaceae, Clostridiaceae. The microorganisms found in the association may not participate in the direct transfer of electrons to the electrode, but rather be symbionts of the electro-genes in this association. The composition of microorganisms inoculated from such a complex substrate as wastewater varies depending on many factors: the substrate used the culture method (batch or flow); anaerobic conditions and severity of the conditions even in the cathode chamber.

According to[15] , some metal-reducing bacterial species have been reported to transfer the electrons directly to the anode. These types of bacterial species are known as to be Axenic bacterial cultures. These types of Metal-reducing bacteria are mostly found in sediments, where they commonly use insoluble electron acceptors such as Fe (III) and Mn (IV). Another type of bacterial species in MFCs is known as mixed bacterial cultures. In MFCs mixed bacterial cultures have more important advantages over axenic cultures like high resistance against process disturbances, substrate consumption rates become high, smaller substrate specificity and increase in power output. Commonly these types of electrochemically active mixed bacterial cultures are cultivated either from sediment (both marine and lake sediment) or from activated sludge from wastewater treatment plants[15].

Table 1 Different types of Microorganisms used in MFC for the treatment of wastewater with different substrates

Micro-organisms used in MFC	**Substrate/carbon source**	**Voltage, V**	**Ampeage, mA (current) resistance, Ω**	**Electrodes - anode/cathode**	**Reference**
Enterobacter sp. (anaerobic)	Wastewater	5°C -0.4V 10°C –0.39 V 25°C – 0.4 V	5°C – 5×103 mA 10°C–3×103 mA 25°C–4×103 mA	anode - carbon brush, cathode-carbon paper	(28)
Klebsiella oxytocf (facultative anaerobic^{-})	Palm oil mill effluent (POME)	0.207 V	80 mA/m^{2}	carbon paper	(29)
Pseudomonas mendocina (obligate anaerobic^{-})	Glucose	0.627 V	19.68 mA/cm^{2}	graphite cloth	(30)
Saccharomyces cerevisiae (facultative anaerobic^{+})	glucose, sucrose, starch	glucose–0.183 V, sucrose–0.170 V, starch – 0.125 V	glucose–0.65 mA, sucrose–0.64 mA, starch – 0.24 m	nickel plate	(31)

4. VARIOUS SUBSTRATES USED FOR THE GENERATION OF ELECTRICAL ENERGY:

Mostly organic compounds are used as anodic substrates as they are electron sources for production of electricity in MFCs. Substrates can greatly affect the anode potential, the bacterial community, and the quality of the treated effluent, along with the energy recovery. A different type of substrates, such as acetate, glucose, various wastewaters, etc. have been studied in MFCs for generation of electricity.

Organic substrates can be used for anaerobic digestion by the microorganisms in production of bioelectricity. Usage of Domestic wastewater can also be used for constant production of bioelectricity[32]. Oil wastewater can also be used for bioelectricity production[33-34]. Waste sludge can be an operative substrate in bioelectricity generation attached with production of hydrogen[35-36]. The waste of fruit and vegetable were also used as a substrate for micro-organisms in a single-chambered MFC[37].

Table 2 Different types of microbial fuel cells (MFCs) used for the treatment of wastewater utilising various substrates

Type of Substrate	Type of MFC	Reference
Glucose	dual chambered air–cathode MFC with Graphite plates as electrodes	(38)
Alcohol distillery wastewater	Two chambered microbial fuel cells with Carbon fiber paper	(39)

Domestic wastewater	Single-chamber air cathode MFC	(40)
Domestic wastewater plusolive mill wastewater	Single-chamber air cathode MFC	(41)
Synthetic wastewater	air cathode microbial fuel cell with two different types of separators (Zirfon and Fumasep)	(20)
Brilliant red X-3B containing wastewater	couple microbial fuel cell (MFC) with a continuous flow constructed wetland (CW).	(42)
Synthetic wastewater with Escherichia coli as the active bacterial component	two-chamber mediator microbial fuel cell	(43)
Wastewater having congo red azo dye degradation	air-cathode single-chamber MFCs	(44)
Dye processing wastewater.	single chamber air cathode microbial fuel cell (MFC)	(45)

5. TYPES OF MICROBIAL FUEL CELLS

1) Mediator microbial fuel cell:

These types of fuel cells are mostly electrochemically inactive. Mainly electron switch from microbial cells to the electrode is assisted with the aid of using mediators along with thionine, methyl viologen, methyl blue, humic acid, and neutral red[46]. Most to be had mediators are highly-priced and toxic.

2) Mediator-free microbial fuel cells:

In Mediator-free fuel cells electrochemically active microorganisms are used to facilitate the electrons to electrode. These types of MFCs are much less properly characterized, which include the type of micro-organism used with-inside the device, form of ion-exchange membrane and device conditions (temperature, pH, etc.) Mediator-free microbial fuel cells can run on wastewater and derive strength at once from some plant life and O_2.This configuration is known as a plant microbial fuel cell. Possible plants include reed sweet grass, cord-grass, rice, tomatoes, lupines and algae.

3) Double-Chamber microbial fuel cells:

This type of MFC has the simplest design amongst all Microbial Fuel Cells[50-52] . In this, one compartment is used as anode whiles the other compartment as cathode which is parted by PEM. Basically in two-chamber Fuel Cell, definite medium or substrate in the anode compartment and defined solution in cathode compartment are used for energy generation. Double-Chamber microbial fuel cells are mostly operated in a batch mode. Such types of MFCs can be used to generate energy in the remote sensing areas.

4) Single-Chamber microbial fuel cells (SCMFC):

Single-chamber MFCs are made up of single chamber only which contains both the compartments i.e. anode and cathode. The design of the single chamber microbial fuel cells is very much similar to Hydrogen Fuel cells. As in hydrogen fuel cells cathode compartment and PEM are directly connected. Similarly, in Single-chamber MFCs the anode compartment is either placed very far or close to cathode compartment which is separated by PEM. During the process the cathode takes oxygen directly from the atmosphere. In this the wastewater that needs to be treated is placed into the anode chamber with catalysts if required, and the cathode chamber is directly exposed to air for oxygen[53-55].

6. APPLICATIONS OF MICROBIAL FUEL CELL TECHNOLOGY

Although MFCs have been studied as an alternative energy source, their application is presently limited to certain areas. With further improvements in design, cost effectiveness and performance efficiency based on these near-term applications, it would be possible to scale-up and use MFCs as a renewable energy resource.

6.1 Wastewater Treatment

The MFCs have shown the potential to treat different industrial, urban or domestic wastewaters[56]. The process of wastewater treatment involves safe disposal or recycling of water that is highly polluted or contains toxic substances. In later years, different types of wastewaters were used in MFCs for their treatment and bioenergy production[57-64]. On one side of the picture, MFC technology can be used to treat the wastewater, while on the other side, the wastewater can be used to provide the substrate as the carbon source for bacterial growth and hence for the end products of the oxidation process, that is, electrons and protons for sustainable bioelectricity generation[65].

6.2 **Microbial fuel cells for Electricity Generation**

It is quite known by maximum of the research that the MFCs are executed for the generation of electricity[66]. In MFC there are two chambers out of which one chamber acts as anode where as another chamber acts as cathode and both the chambers are separated by a membrane known as PEM. In anode chamber the organisms the waste substrates into the protons, electrons and carbon dioxide is produced that move toward the cathode chamber by PEM and electrical connection[67-70]. Both the chambers of MFCs are connected electrically with a multimeter and a resistance for voltage and power measurements. Higher the waste is oxidised more the electrons are produced results into the higher columbic efficiency and higher power output.

6.3 **Microbial fuel cells as biosensors**

The application of MFC technology besides electricity generation and wastewater treatment is its use as a biosensor for pollutant detection in water[55]. The operational monitoring system of water is necessary to continue the usage of waste-waters from industries or community to save the marine atmosphere along with the health of public. It has been proved that a MFC can be used as successful biosensor which can detect the organic compounds as well as pollutants in the wastewaters[71-72]. Normally, biosensors need a transducer but MFC itself behaves as a transducer. In the "MFC-based biosensor", the exo-electrogens in the anode chamber serve as a signal generator or biological recognition element whereas electrodes and PEM (if used) acts as the transducer. The main advantage of the MFC biosensor is its long-term stability. This is because the exo-electrogenic biofilms extend the lifespan of sensing element and curtail the replacement of sensing elements.

7.CONCLUSION

Mainly, this review summarizes the current reports on application of MFCs for the remediation of several pollutants as well as for current generation. MFC technology can also be focused towards future application in sustainable energy generation and biosensor application. In the early years, simple substrates like acetate and glucose were usually used, however in recent years' researchers are using more alternative substrates with an aim of consuming waste biomass or treating wastewater on one hand and enhancing MFC output on the other. Although MFCs were carried out intensively over the past years, limited achievement has been reported in practical application because of some limitations and challenges. Therefore, MFC technology has yet to find the viable success in environmental applications.

8. ACKNOWLEDGEMENTS

I would like to thank my Guide Dr. Varsha Gupta, Associate Professor and Head, Department of Microbiology of JECRC University, Jaipur, and my Co-Guide Dr. Sonika Saxena Associate Professor and Vice Principal, Department of Biotechnology of Dr. B. Lal Institute of Biotechnology, Jaipur for their constant support, guidance and valuable suggestions to improve the paper.

CONFLICT OF INTEREST:

The authors declare that they have no conflict of interest.

9. REFERENCE

1. Sierra C. Calidad del Agua, evaluación y diagnóstico. – Universidad de Medellín, Colombia. 2011.
2. Monroy H.O. Manejo sustentable del agua en México. – Revista. UNAM. Mx 2013, 14(10), 1-15.
3. Peña M., Ducci J., & Zamora V. Tratamiento de aguas residuales en México. – Banco Interamericano de Desarrollo, División de Agua y Saneamiento. IDB-TN-524. 2013.
4. Osorio R.F., Torres R.J.C., & Sánchez B.M. Tratamiento de aguas para la eliminación de microorganismos y agentes contaminantes. – Ed Díaz de Santos, Albanzas 2. Madrid, España. 2010.
5. McCarty P. L., Bae J., & Kim, J. Domestic Wastewater Treatment as a Net Energy Producer–Can This Be Achieved? Environmental Science & Technology, 2011, 45(17), 7100–7106.
6. Heerden E., van, Williams. Peter, Ojo, E., Kuloyo, K., & Posthumus, R. Bioremediation: Small Solution to Big Problems, Natural and Agricultural Science, 2010.
7. Palma H., Killoran E., Sheehan M., Berner F., & Heimann K. Assessment of microalga biofilms for simultaneous remediation and biofuel generation in mine tailings water, Bioresource Technology, 2017, 234, 327– 335.
8. Singh D.P., Kothari R., & Tyagi V.V. Emerging Energy Alternatives for Sustainable Environment, The Energy and Resources Institute (TERI). 2016.

9. Sharma G.K., & Khan S.A. Bioremediation of Sewage Wastewater Using Selective Algae for Manure Production, International Journal of Environmental Engineering and Management, 2013, 4(6), 573–580.
10. Wuang S.C., Luo Y.D., Wang S., Chua P.Q.D., & Tee P.S. Performance assessment of biofuel production in an algae-based remediation system, Journal of Biotechnology, 2016, 221, 43–48.
11. Izadi P., & Rahimnejad M. Simultaneous electricity generation and sulfide removal via a dual chamber microbial fuel cell, Biofuel Research Journal, 2013, 1(1), 34–38.
12. Najafpour G., Rahimnejad M., Mokhtarian M., Ramli W.D., & Ghoreyshi A. Bioconversion of whey to electrical energy in a biofuel cell using Saccharomyces cerevisiae, World Applied Sciences Journal., 2010, 8, 1–5.
13. Sharma Y., & Li B. The variation of power generation with organic substrates in single-chamber microbial fuel cells (SC-MFCs), Bioresource Technology, 2010, 101(6), 1844–1850.
14. Potter M.C. Electrical effects accompanying the decomposition of organic compounds, Proc. R. Soc. Lond, B Biol. Sci., 1911, 84, 160–276.
15. Logan B.E., & Rabaey K. Conversion of Wastes into Bioelectricity and Chemicals by Using Microbial Electrochemical Technologies, Science, 2012, 337(6095), 686–690.
16. Bhatia S.K., Joo H.S., & Yang Y.H. Bio-waste-to-bioenergy using biological methods – a mini-review, Energy Convers. Manage, 2018, 177, 640–660.
17. Taskan E., Ozkaya B., & Hasar H. Effect of Different Mediator Concentrations On Power Generation in MFC Using Ti- TiO2 Electrode, International Journal of Energy Science (IJES), 2014, 4(1), 9-11.
18. Nair R., Renganathan K., Barathi S., & Venkatraman K. Performance of salt-bridge microbial fuel cell at various agarose concentrations using hostel sewage waste as substrate, Int J Advance Res Technol, 2013, 2(5), 326–330.
19. Chen G., Wei B., Luo Y., Logan B. E., & Hickner M. A. Polymer Separators for High-Power, High-Efficiency Microbial Fuel Cells, ACS Applied Materials & Interfaces, 2012, 4(12), 6454–6457.
20. Sevda S., Dominguez-Benetton X., Vanbroekhoven K., Sreekrishnan T. R., & Pant D. Characterization and comparison of the performance of two different separator types in air–cathode microbial fuel cell treating synthetic wastewater, Chemical Engineering Journal, 2013, 228, 1–11.
21. Abbasi T., & Abbasi S. A. Formation and impact of granules in fostering clean energy production and wastewater treatment in up flow anaerobic sludge blanket (UASB) reactors, Renew. Sustain. Energy Rev. 2012, 16(3), 1696-1708.
22. Tauseef S.M., Abbasi T., & Abbasi S.A. Energy recovery from wastewaters with high-rate anaerobic digesters, Renewable and Sustainable Energy Reviews, 2013, 19, 704–741.
23. Nikhil G.N., Krishna Chaitanya D.N.S., Srikanth S., Swamy Y.V., & Venkata Mohan S. Applied resistance for power generation and energy distribution in microbial fuel cells with rationale for maximum power point, Chemical Engineering Journal, 2018, 335, 267–274.
24. Rotaru D.E., Franks A.E., Orellana R., Risso C., & Nevin K.P. Geobacter: the microbe electric's physiology, ecology, and practical applications, Adv Microb Physiol, 2011, 19(59), 1-15.
25. Wang Z, Lim B, & Choi C. Removal of Hg2+ as an electron acceptor coupled with power generation using a microbial fuel cell, Bioresource Technology, 2011, 102, 6304–6307.
26. Rosenbaum M., He Z., & Angenent L.T. Light energy to bioelectricity: photosynthetic microbial fuel cells, Curr Opin Biotechnol, 2010, 21, 259–264.

27. Barua P. K., Deka D., & Tech M. Electricity Generation Bio-waste Based Microbial Fuel Cells, International Journal of Energy, Information and Communications, 2010, 1(1), 77 -92.
28. Tkach O., Liu L., & Wang A. Electricity Generation by Enterobacter sp. of Single-Chamber Microbial Fuel Cells at Different Temperatures, Journal of Clean Energy Technologies, 2016, 4(1), 36-42.
29. Islam M. S., Ali M. M., Ali M. L., & Rahman M. Z. Preliminary assessment of heavy metals in water and sediment of Karnaphuli River, Bangladesh, Environmental Nanotechnology, Monitoring & Management, 2016, 5, 27–35.
30. Sharma S.K., & Bulchandani B.D. Comparative Study of Various Substrate and Microorganisms in a Laboratory Designed Microbial Fuel Cell, International Journal of Research in Chemistry and Environment, 2012, 2(3), 168-174.
31. Choi J., & Ahn Y. Continuous electricity generation in stacked air cathode microbial fuel cell treating domestic wastewater, Journal of Environment Management, 2013, 130, 146–152.
32. Choi J., & Liu Y. Power generation and oil sands process affected water treatment in microbial fuel cells, Bioresour Techno, 2014, 169, 581–587
33. Jiang Y., Ulrich A.C., & Liu Y. Coupling bioelectricity generation and oil sands tailings treatment using microbial fuel cells. Bioresour Technol., 2013, 139, 349–354.
34. Choi J., & Ahn Y. Increased power generation from primary sludge in microbial fuel cells coupled with prefermentation, Bioprocess Biosyst Eng, 2014, 37(12), 2549–2557.
35. Ge Z., Zhang F., Grimaud J., Hurst J., & He Z. Long-term investigation of microbial fuel cells treating primary sludge or digested sludge, Bioresour Technol., 2013, 136, 509–514.
36. Logroño W., Ramírez G., Recalde C., Echeverría M., & Cunachi A. Bioelectricity generation from vegetables and fruits wastes by using single chamber microbial fuel cells with high Andean soils, Energy Procedia., 2015, 75, 2009–2014.
37. Rahimnejad M., Ghoreyshi A.A., Najafpour G., & Jafary T. Power generation from organic substrate in batch and continuous flow microbial fuel cell operations, Applied Energy, 2011, 88(11), 3999– 4004.
38. Huang J., Yang P., Guo Y., & Zhang K. Electricity generation during wastewater treatment: An approach using an AFB-MFC for alcohol distillery wastewater, Desalination, 2011, 276(1-3), 373–378.
39. Nimje V.R., Chen C.Y., Chen H.R., Chen C.C., Huang Y.M., Tseng M.J., Cheng K.C., & Chang Y.F. Comparative bioelectricity production from various wastewaters in microbial fuel cells using mixed cultures and a pure strain of Shewanella oneidensis. Bioresour. Technol., 2012, 104, 315-323.
40. Sciarria T.P., Tenca A., D'Epifanio A., Mecheri B., Merlino G., Barbato M., Borin S., Licoccia S., Garavaglia V., & Adani F. Using olive mill wastewater to improve performance in producing electricity from domestic wastewater by using single chamber microbial fuel cell, Bioresource Technology, 2013, 147, 246– 253.
41. Fang Z., Song H.L., Cang N., & Li X.N. Performance of microbial fuel cell coupled constructed wetland system for decolourization of azo dye and bioelectricity generation, Bioresource Technology, 2013, 144, 165-171.
42. Herrero-Hernandez E., Smith T. J., & Akid R. Electricity generation from wastewaters with starch as carbon source using a mediator less microbial fuel cell, Biosensors and Bioelectronics, 2013, 39(1), 194–198.
43. Huang W., Chen J., Hu Y., Chen J., Sun J., & Zhang L. Enhanced simultaneous decolourization of azo dye and electricity generation in microbial fuel cell (MFC) with redox mediator modified anode, Int J Hydrogen Energ., 2017, 42(4), 2349-2359.

44. Karuppiah T., Pugazhendi A., Subramanian S., Jamal M. T., & Jeyakumar R.B. Deriving electricity from dye processing wastewater using single chamber microbial fuel cell with carbon brush anode and platinum nano coated air cathode, 3 Biotech (Springer), 2013, 8(10), 8:437.
45. Delaney G. M., Bennetto H. P., Mason J. R., Roller S. D., Stirling J. L., & Thurston C. F. "Electron-transfer coupling in microbial fuel cells. 2. Performance of fuel cells containing selected microorganism-mediator-substrate combinations", Journal of Chemical Technology and Biotechnology. Biotechnology, 2012, 34, 13–27.
46. Costa N. L., Clarke T. A., Philipp L.-A., Gescher J., Louro R. O., & Paquete C. M., Bioresour. Technol. 2018, 255, 308–317.
47. Choi, O., & Sang, B.-I. (2016). Extracellular electron transfers from cathode to microbes: application for biofuel production. Biotechnology for Biofuels, 9(1).
48. B. E. Logan, Nat. Rev. Microbiol. 2009, 7 (5), 375–381.
49. Kumar G., Bakonyi P., Kobayashi T., Xu K.Q., Sivagurunathan P., Kim S.H., Buitrón G., Nemestóthy N., & Bélafi-Bakó K. Enhancement of biofuel production via microbial augmentation: The case of dark fermentative hydrogen, Renewable and Sustainable Energy Reviews, 2016, 57, 879-891.
50. Slate A.J.; Whitehead K.A.; Brownson D.A.C.; & Banks C.E. Microbial fuel cells: An overview of current technology. Renew. Sust. Energ. Rev. 2019, 101, 60–81.
51. Santoro C., Arbizzani C., Erable B., & Ieropoulos I. Microbial fuel cells: From fundamentals to applications. A review, Journal of Power Sources, 2017, 356, 225–244.
52. Liu H. & Logan B.E. Electricity generation using an air–cathode single chamber microbial fuel cell in the presence and absence of a proton exchange membrane. Environ. Sci. Technol, 2004, 38(14), 4040–4046.
53. Binkley W.W., & Wolform M.L. Composition of cane juice and cane final molasses. In: Claude, S.H., Melville, L.W. (eds.) Advances in Carbohydrate Chemistry, 8, 291–314. Academic Press, New York 1953.
54. Vogl A., Bischof F., & Wichern M. Increase life time and performance of Microbial Fuel Cells by limiting excess oxygen to the cathodes, Biochem. Eng. J., 2018, 106, 139–46
55. Zhou M., Wang H., Hassett J.D., & Gu T. Recent advances in microbial fuel cells (MFCs) and microbial electrolysis cells (MECs) for wastewater treatment, bioenergy and bio products, J Chem Technol Biotechnol, 2013, 88, 508–518.
56. Abourached C., Catal T., & Liu H. Efficacy of single chamber microbial fuel cells for removal of cadmium and zinc with simultaneous electricity production, Water Research, 2014, 51, 228–233.
57. Guo K., Soeriyadi A.H., Feng H., Prévoteau A., Patil S.A., Gooding J.J., & Rabaey K. Heat-treated stainless steel felt as scalable anode material for bio electrochemical systems, Bioresource Technology, 2015, 195, 46–50.
58. Kumari S., & Mangwani S. Das, Low-voltage producing microbial fuel cell constructs using biofilm forming marine bacteria, Current Science, 2015, 108(5), 925–932.
59. Kaewkannetra P., Chiwes W., & Chiu T.Y. Treatment of cassava mill wastewater and production of electricity through microbial fuel cell technology, Fuel, 2011, 90, 2746–2750.
60. Li X., Zhu N., Wang Y., Li P., Wu P., & Wu J. Animal carcass wastewater treatment and bioelectricity generation in up-flow tubular microbial fuel cells: effects of HRT and non-precious metallic catalyst, Bioresource Technology, 2013, 128, 454–460.

61. Lamp J.L., Guest J.S., Naha S., Radavich K.A., Love N.G., Ellis M.W., & Puri I.K. Flame synthesis of carbon nanostructures on stainless steel anodes for use in microbial fuel cells, Journal of Power Sources, 2011, 196(14), 5829–5834.
62. Song R.B., Zhao C.E., Gai P.P., Guo D., Jiang L.P., Zhang Q., Zhang J.R., & Zhu J.J. Graphene/Fe3O4 nanocomposites as efficient anodes to boost the lifetime and current output of microbial fuel cells, Chemistry— An Asian Journal, 2016.
63. Yu Y.Y., Guo C.X., Yong Y.C., Li C.M., & Song H. Nitrogen doped carbon nanoparticles enhanced extracellular electron transfer for high-performance microbial fuel cells anode, Chemosphere, 2015, 140, 26–33.
64. Zhang P., Li K., & Liu X. Carnation-like MnO2 modified activated carbon air cathode improve power generation in microbial fuel cells, Journal of Power Sources, 2014, 264, 248–253.
65. Pant D., Van Bogaert G., Diels L., & Vanbroekhoven K. "A review of the substrates used in microbial fuel cells (MFCs) for sustainable energy production", Bioresource Technology, 2010, 101 (6), 1533–1543.
66. Orellana R., Leavitt J.J., Comolli L.R., Csencsits R., Janot N., Flanagan K.A., Gray A.S., Leang C., Izallalen M., & Mester T. U(VI) reduction by a diversity of outer surface c-type cytochromes of Geobacter sulfurreducens, Appl Environ Microbiol, 2013, 79, 6369–6374.
67. Bermek H., Catal T., Akan S.S., Ulutas M.S., Kumru M., Ozguven M., Liu H., Ozcelik H., & Akarsubasi A.T. Olive mill wastewater treatment in single-chamber air-cathode microbial fuel cells, World J Microbiol Biotechnol, 2014, 30, 1177–1185.
68. Kumar R., Singh L., & Wahid Z.A. Exo-electrogens: recent advances in molecular drivers involved in extracellular electron transfer and strategies used to improve it for microbial fuel cell applications, Renewable and Sustainable Energy Reviews, 2016, 56, 1322–1336.
69. Sonawane J.M., Yadav A., Ghosh P.C., & Adeloju S.B. Recent advances in the development and utilization of modern anode materials for high performance microbial fuel cells, Biosens. Bioelectron, 2017, 90, 558–76.
70. Xia C., Zhang D., Pedrycz W., Zhu Y., & Guo Y. Models for Microbial Fuel Cells: A critical review, J. Power Sources, 2018, 373, 119–131.
71. Kumar R., Singh L., & Zularisam A.W. Microbial fuel cells: types and applications. In Waste Biomass Management—A Holistic Approach, Springer International Publishing: Switzerland, 2017, 367–384.
72. Liu Z., Liu J., Zhang S., Xing X.H., & Su Z. Microbial fuel cell-based biosensor for in situ monitoring of anaerobic digestion process, Bioresource Technology, 2011, 102, 10221–10229.