Basic Introduction to Microbial Fuel Cells

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1 What is Microbial Fuel Cell?

The Microbial Fuel Cell (MFC) is a bio-electrochemical device which is used to generate electricity in other words; MFC is a kind of bio-electrochemical fuel cell system that generates bioelectricity by the metabolic activities of the microorganisms [1–5]. The generated electricity by the decomposing organic substance travels from anode to cathode through an external circuit [6–9]. MFC is a promising technology for renewable energy production in specific applications such as remediation of pollution or cleaning up the wastewater. There are many other applications of MFCs in the field of energy and environment [10–15]. In microbial fuel cell, the organic substances are degraded by the microorganisms and hence produce the electron. The external circuit connected with an anode and cathode is placed to collect this electron and continue the current. In the previous research, it was observed that this MFC method can be used to clean the wastewater, bioremediated sulfide contaminated sediment, and consequently bioelectricity generation. The benefit of this method is that it can generate bioelectricity while cleaning the environment [16–19]. Moqsud et al. [3] showed that MFC can also generate electricity from the organic waste in a compost type MFC. Since then, other researchers are trying to use this novel technology to generate bioelectricity by recycling the organic waste [4, 5, 20–23]. Figure 1 shows the schematic diagram of the microbial fuel cell which was used in the laboratory. The anode and cathode relate to the external circuit. The resistance was also used to complete the external circuit for the power output.

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2 Major Parts of a Microbial Fuel Cell

2.1 Essential Components of MFCs

The main three components of the MFC are anode, cathode, and if needed the membrane or the separator. The anode is developed with different carbon type materials. Figure 1 shows the different types of anode materials such as carbon fiber, carbon felt, and bamboo charcoals. The shape of the anode materials is also varied. For the case of cathode, it is also possible to use the same materials as anode. However, as it was mentioned before cathode needs some oxygen to generate the electricity. So, the cathode chamber should be provided with the oxygen. The separator of the MFC is related to the membrane of the MFC. This part is costly as most of the time the separator is made of high-cost membrane which ultimately decrease the sustainability of the total process.

Among all shaped MFCs, the cube reactor is popular among the researchers due to its user-friendly anode and cathode chambers. Single chamber and double chamber MFCs are developed for the research purpose of the wastewater treatment. However, the shape of the MFC reactor is varied based on its purpose and the materials used inside the reactor such as rectangular shaped, circular shaped, and cylindrical shaped. Figure 2 shows the schematic diagram of the MFC which is generally used with the solid biomass. The anode and cathode are separated by the biomass and most of the time the specific separator does not need to explore the bioelectricity generation. As mentioned earlier, the separator did not need for all different types of MFCs.

There are different types of Microbial Fuel Cells. The single chamber and the double chamber microbial fuel cell are the common types of microbial fuel cells [24–29]. Normally, the single chamber MFC has two parts such as the anode part and cathode part [1, 4, 30–33]. The anode part is responsible for the more production of electricity as the electrons are released in this part due to the biodegradation of the

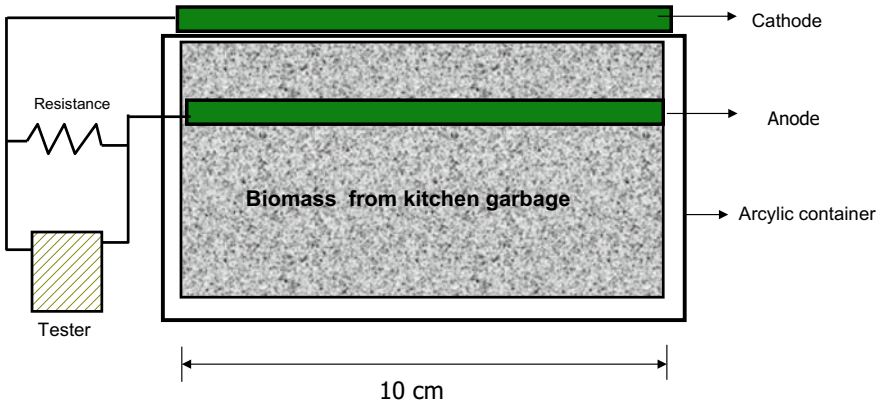

Fig. 1 Schematic diagram of microbial fuel cell. Adapted from Ref. [11] with penance permission

organic matters. The cathode part is the part in where the electron receives the oxygen and produce the water molecule. Normally, it is designed as a manner so that it can receive the oxygen properly. Most of the time, the cathode is placed on the surface to get enough oxygen during the process of bioelectricity generation [34–36]. Secondly, another important part of MFC is the electrode materials and their connection with the copper wire. The external circuit made of the copper wire, resister, and data logger is another major component for electricity generation from the MFC [37–41]. The MFC cell is normally an enclosed cell in where the biomass and other organic substances can be set up. The biomass, sediment, and soil are placed inside the cell. Sometimes, there are covers on the surface of the cell to protect it from the external disturbances [42–44]. Microbial fuel cell can be made in different ways. If it is made for plant microbial fuel cell (PMFC) then plant will be an essential part of that MFC [4]. In the case of the sediment microbial fuel cell (SMFC), the sediment will be the essential part of it (Moqsud 201). Nevertheless, the main objective of all the MFCs is to generate bioelectricity with the help of the bacteria and the major components are the same or nearly similar to all of the different types of MFCs. Figure 2 shows

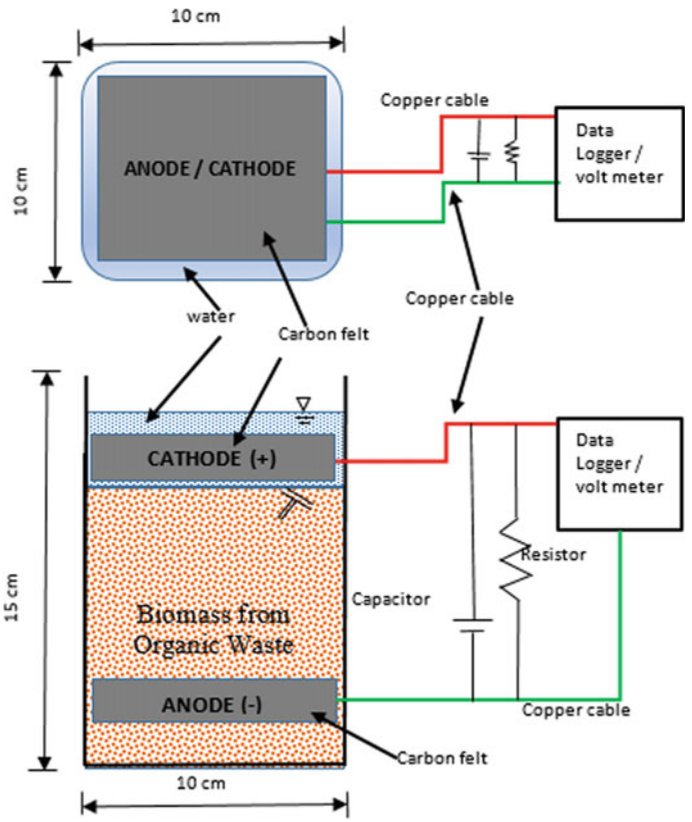

Fig. 2 Schematic diagram of the MFC showing its different parts

the schematic diagram of the microbial fuel cell. It is seen that the essential parts of the MFC is not much changed from the MFC showed earlier; however, it has some other important parts which are widely used. The additional things added in plant microbial fuel cell (PMFC) are plants and the sun. Both the sun and the plants are important parts of the PMFC. Microbes and the electromotive bacteria are also very important parts of the power generation from the microbial fuel cell. The various geo-bacteria, *Shewanella,* and the other microbes play a major role to generate the bioelectricity generation.

2.2 Electrode Materials Used in the Microbial Fuel Cell

Generally, the carbon materials are used for the microbial fuel cells. The reason of using the carbon materials is that it is a conductive material, and it can be a durable material. The carbon material is very good and does not react much with the other materials even in the different medium [45, 46]. Commonly used electrode materials are carbon fiber, carbon felt, graphite felt, carbon brush, and carbon cloth. The different types of carbon materials are used for the different types of purposes. To choose the best carbon material is one of the challenges for the construction of an efficient microbial fuel cell in different environmental conditions. Some researchers use bamboo charcoals as the electrode materials in the MFC [47–50].

3 Common Types of Microbial Fuel Cell According to Their Uses

There are different types of microbial fuel cells. Some MFCs are used for wastewater treatment, and some MFCs are used for bioremediation of contaminated soil or sediments. The main thing of the MFCs is the objective of its use and the medium of their uses. For example, if it is used for treatment of wastewater then it is used under the water environment. However, if it is used for soil/sediment then it can be used as the soil environmental condition. The name of the microbial fuel cell is referred to its uses such as if it is used in the sediment then it is called sediment microbial fuel cell (SMFC) as shown in Fig. 3.

3.1 Sediment Microbial Fuel Cell

In sediment microbial fuel cell, the anode is set inside the sediment and the cathode is set at the surface of the sediment. The organic matters are broken down by the geo-bacteria and the sulphate reducing bacteria (SRB) in the sediment and consequently

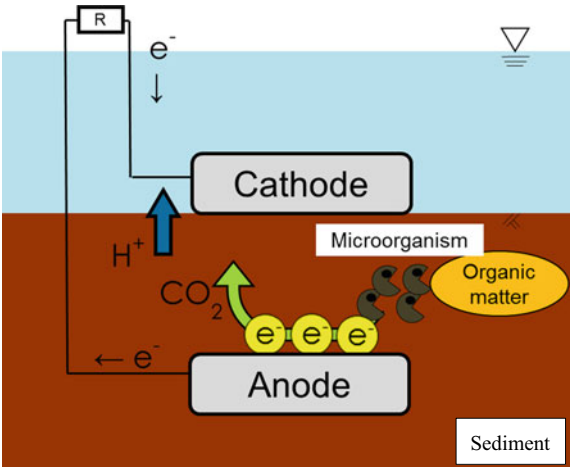

Fig. 3 Schematic diagram of the sediment microbial fuel cell (SMFC)

electron releases. The electron transfers from the anode to cathode and therefore electricity generates. The cathode is placed on the surface or near the surface of the sediment. The availability of oxygen needs to be confirmed at the cathode areas. The benefit of this type of MFC is the ability of purifying the contamination while generating the electricity which was found by Moqsud and Khong. Figure 3 shows the schematic diagram of the sediment microbial fuel cell.

3.2 Plant Microbial Fuel Cells (PMFCs)

Plant microbial fuel cells (PMFCs) are the kind of sediment microbial fuel cell in where plant is used to supply the bioelectricity [4]. The mechanism of plant microbial fuel cell is very interesting. The green leaves get the sunlight from the sun and produces the carbohydrates due to photosynthesis. The generated carbohydrates go to the root zone. More than 60% of the total generated carbohydrates are released at the rhizosphere in the nature. For this reason, the number of geo-bacteria are more in this area. The geo-bacteria use these carbohydrates as the food and grow their numbers. Electron is released while breaking this carbohydrate. The anode catches this electron and travels it to the cathode. This generates the bioelectricity in the plant microbial fuel cell. Figure 4 illustrates the schematic diagram of the plant microbial fuel cell. It is shown that the due to photosynthesis, carbohydrates are produced in the green leaves. The excess amount of carbohydrates are released to the root areas and the geo-bacteria break down this carbohydrate due to their regular activities at the rhizosphere.

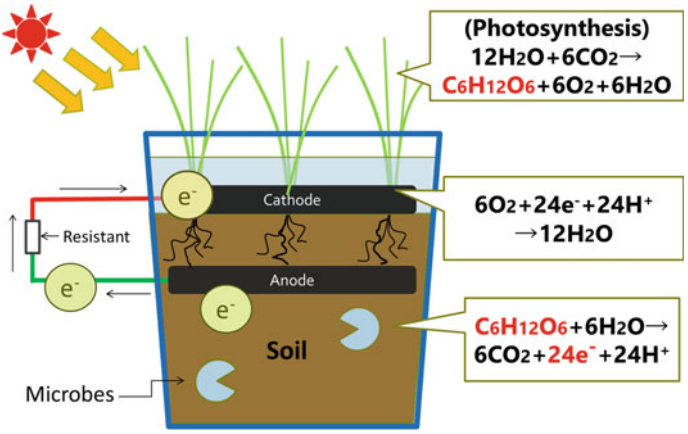

Fig. 4 Schematic diagram of the plant microbial fuel cell

3.3 Solid Waste Microbial Fuel Cells

The MFC in which the organic waste is used as the biomass is solid waste microbial fuel cell. Various types of solid organic waste can be used inside the MFCs. The bioelectricity generation can be possible by using almost all types of organic waste MFCs [50, 51]. Bioelectricity can be also generated by using bamboo waste and the kitchen garbage which has been confirmed in the experiments. This can be reduced the solid waste management problem in the world. The amount to organic waste is the major portion by considering the total solid waste; however, the total organic waste is not recycled properly both in the developing countries as well as industrialized parts of the world. So, if it is possible to generate bioelectricity by using organic waste then it will help to manage the solid waste management problem all over the world. Electricity from landfill leachate using microbial fuel cells has been also studied [30, 52, 53].

4 Energy and Environment

The global energy demand is increasing, and the fossil fuels are decreasing day by day. We need to find the alternate source of energy for the future generation. To get the energy, the greenhouse gas has been released all the time which makes the environmental pollutions when the raw materials are the non-renewable sources. The consequent of this phenomenon is the global warming and the climate change. The trend of climate change is prominent in the recent years. The natural disasters have been increasing, and the loss of life and the properties are increasing in each year. To stop this global warming and climate change phenomenon, the use of environmentally

friendly sources for energy generation must be implemented as soon as possible. To meet the ever-increasing energy demand and to cope with the problems of global warming is the biggest challenges for the scientists and the engineers. Due to the extent of the accident of the nuclear power plant, people are searching for the green source of energy and the safe source of energy in the world in recent time. So, we need both green source of energy and at the same time safe source of energy for the future generation.

5 Future Energy Demand

The mother earth is ready to embrace the 4th industrial revolution now. The earth stands on the brink of a digitalization and technological revolution that will fundamentally change the way we live, work, and relate to one another. The scale, scope, and complexity of this revolution will be so enormous that the mankind did not predict before. The amount of energy demand is increasing faster than ever. Due to the use of internet and the artificial intelligence and wireless sensor networks for the smart cities and the automated automobile the energy demand will be increased soon [54]. The global population is increasing, and many countries are developing in a greater pace. This trend of increasing of energy is alarming and is an alert for the mother nature.

5.1 Renewable Energy's Future

The renewable energy is a good source of green energy which is good for the human and the environment. Solar energy, wind energy, thermal energy, and biofuels are some of the future substitutes of the fossil fuels. However, the current source of renewable energy is unable to meet the needs of the demand for the future. The additional demand may cause another trouble if the technologies will not be expanded. The renewable energy can solve the problem of global warming and the climate change related disasters in the future; however, there are many disadvantages of the renewable energy. The most prominent disadvantage of renewable energy is that it is affected by the weather conditions very much. For example, the solar power cannot work in the rainy days and wind power cannot work when there is no wind flow in the nature. So, the renewable energy will need a lot of development before it has been considered as the major source of green energy [55, 56].

5.2 Biofuels as the Renewable Energy

The first-generation biofuels are the fuels which are generally produced from the food grains such as soybean, corn, sugar cane, and other food products. However, the use of this huge amount of food is not a sustainable solution for the biofuels as there are millions of people who are hungry in the world. It is totally unnecessary to destroy the food products to fuel the car instead of feeding the millions of hungry children. The second-generation biofuel which is mainly by the different kinds of organic waste is not suitable and sustainable solutions either. This is because the amount of organic waste is not enough, and it cannot be possible to collect this huge amount of organic waste in a short period of time. The third-generation biofuels are also not popular yet due to the process of collecting the raw sources and the amount of energy collected from the unit amount of sources of algae.

5.2.1 Future of Biofuels

The future of MFCs is promising. The MFC is a green and safe source of energy. The other major benefits of MFCs are they can be used for environmental pollution removal, wastewater treatment, solid waste management, and desalination along with the bioelectricity generation. The MFC needs to be improved for the future and to use it as a large-scale production of the bioelectricity. Another noteworthy benefit of MFC is that it can be used 24 h without being affected by the weather condition or other external factors like other renewable energy. The various types of MFC can be used for the power source to the smart cities monitoring sensors to achieve the sustainable development goals and the 4th industrial revolutions [7, 57].

6 Conclusion and Future of Microbial Fuel Cells

The main objective of MFCs is to get the new source of bioelectricity by using the strength of microbes. Besides generating bioelectricity, MFCs can clean the polluted environment. MFCs can be a source of bioremediation. It can be used for powering the sensors to the smart cities. It can also power the environmental monitoring sensors. So, MFCs could be very essential part of the future generation to reduce the carbon emission and to clean the polluted environment.

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