Chapter 10
Microbial Fuel Cell-Based Process for Wastewater Treatment and Power Generation

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Abstract Biotechnology is constantly explored to develop methods for wastewater treatment to have a clean environment. Discharge of untreated wastewaters in the soil and water environment is the major cause of environmental pollution in soil and surface and groundwater bodies. Current wastewater treatment technologies are not sufficient to meet the ever-growing demands due to rapid industrialization and population growth, and they are also energy-consuming and cost-intensive. Therefore, it is necessary to develop an energy-efficient treatment method. The rise in global energy demand is projected to increase by 37% by 2040. As the conventional energy sources are also depleting at a fast rate, it is necessary to adopt renewable energy to meet the demands of future energy scenario. Microbial fuel cell (MFC) is a

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technology in which electricity is generated from wastewater using microorganism as a biocatalyst, simultaneously achieving wastewater treatment. In this system, microorganism mediates the direct conversion of chemical energy stored in biodegradable organic matter of wastewater into electrical energy. Many researchers have developed a variety of MFC-centered hybrid wastewater treatment plants at a pilot scale, for the treatment of wastewater from different industries such as dye, brewery, and dairy industries, domestic wastewater, and landfill leachate. Irrespective of the potential of MFC as a renewable energy source and its wide applicability for wastewater treatment, the technique is not yet established successfully for field applications. Low-energy performance and excessive internal resistance are the limiting factors in its practical application. Researchers have performed multiple strategic attempts to minimize these factors by developing efficient reactor designs for minimizing internal resistance, stacking multiple reactors into one enlarge system (modularization). Modularization is one of the common strategies followed by researchers for pilot-scale MFC setup. This prevents the unnecessary distance between anode and cathode and enhances COD removal rate. Also, using various forms of electrodes such as carbon brushes, nickel foam, etc. to provide large surface area and modification of electrodes using nanomaterials have shown power density enhancement. This chapter discusses the potential applications and practical limitations of MFC for its effectiveness in wastewater treatment and contaminant removal and energy generation at bench and pilot scale.

Keywords Microbial fuel cell · Waste water treatment · Bioelectricity · Internal resistance · Power generation

10.1 Introduction

Clean water and electricity are one of the basic human requirements, but unfortunately these are denied to large swathes of world population. The rise in energy demand of the world is projected to increase by about 37% by 2040 (International Energy Agency). The current sufficiency in the supply of different energy resources available for the short term may paint an image of the future with an easy and clear path to sustainable energy development and also hide different challenges involved in doing so. The rise in the usage of different energy resources varies based on the risk of disruption involved in supply and the harm their usage can cause to the environment. For example, the growth in liquefied natural gas has been highest of those of all the fossil fuels at about more than half while the usage of coal is seen to decline. Along with the energy resource crisis, the problem of waste generation makes the situation even worse, especially wastewater. There is an increasing demand for freshwater across the globe. The usage of freshwater has tripled over the past 50 years. It is increasing by 64 trillion liters every year as per data by UN, UNESCO, and FAO. As per a report published by Central Pollution Control Board

(CPCB) of India, in March 2015, the sewage generation from urban areas in the country is estimated at 61,948 million liters per day (mld), against which a sewage treatment capacity of 23,277 mld is available with us. The remaining untreated sewage either flows into rivers and other water bodies or percolates into the ground. Wastewater treatment is an energy-intensive process and requires lots of energy each year for treatment. According to an estimate, 0.349 kWh of electrical energy per cubic meter of wastewater is required for activated sludge processes in the USA (Oh et al. 2010). There is a strong nexus between water and energy. For example, water and wastewater utilities consume 3% of the electricity in the USA, which accounts for 35% of the total municipal energy budgets. Activated sludge (aerobic digestion) is one of the well-established processes and has been used in most wastewater treatment systems. Although it is an efficient process, it is chemical- and energy-intensive with high capital and significant operational cost (Lu et al. 2017).

To overcome these problems, microbial fuel cells (MFCs) offer a potential solution as they can concurrently be used for wastewater treatment and electricity generation. MFCs have long been considered as an attractive technology for converting various organic wastes directly into electricity using electrogenic bacterial cells in the anode compartment. Most MFCs have been operated using anaerobic or facultative aerobic bacteria which oxidize various organic components including glucose, sewage sludge, brewery waste, dairy waste, and petroleum hydrocarbon. The performances of the MFCs vary with its configuration, electrode configuration, bacterial community, and specific substrate concentration (Lu et al. 2017). Apart from producing electricity, MFC can also be used as efficient wastewater treatment technology and water quality monitoring. In wastewater treatment technology, MFCs have advantage over other technologies in that it can also treat high soluble BOD content wastewater (Waller and Trabold 2013) and produce less sludge. So, various researches are focused to commercialize MFC technology due to its advantage over other technologies of treating wastewater.

Preliminary reports concerning the use of MFC for wastewater treatment were mostly focused on MFC with low volumetric capacity (less than 1 L) and using synthetic wastewater. However, for commercialization purposes, it requires scaling-up, and studies are needed on pilot scale using real wastewater or operated in treatment plants. Recently, various studies have focused on scaling-up MFCs. For example, a 90L MFC was built by stacking anode and cathode modules into a reactor vessel which was reported to produce 0.056 kWh/m^3 energy and 171±8.4 mW/m^2 power densities from each module and reached 87.6% COD removal efficiency while treating brewery wastewater (Dong et al. 2015). Zhang et al. (2013a, b) designed two 4 liter tubular MFCs to treat primary effluent wastewater and reached 65–70% COD removal efficiency in the continuous mode of operation at a HRT of 11 h, and the maximum energy production was 0.0255 kWh/m^3.

It is a common approach to stack multiple small reactors to form a bigger system, as this greatly reduces the internal resistance, and the total volume capacity of the reactor can be increased by just increasing the number of each single reactor. This also offers the advantage as each reactor can function and be maintained as an independent unit. Zhuang et al. (2012a, b) reported the energy output and COD

Fig. 10.1 Basic design of a microbial fuel cell
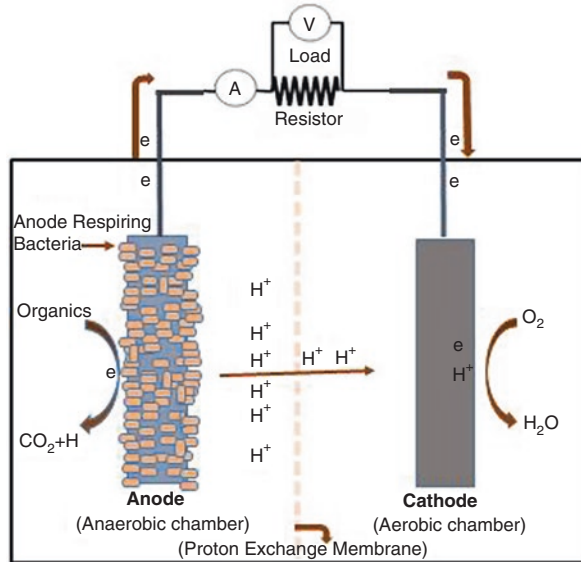
removal of 6 W/m^{3}and 87/1%, respectively, by stacking 40 tubular units in MFCs with 10 L volumetric capacity while treating brewery wastewater. Ge et al. (2013) stacked 96 tubular MFC modules to build an MFC system with 200 L liquid volume to treat primary effluent wastewater and obtained maximum power density of 6.4 W/m^3. These studies show that the stacking of small segmented reactors might be measured as a suitable option for scale-up. This approach would be better for maximizing the power production of systems; however, minimizing internal resistances and energy losses due to fluid flow and reducing dead space are difficult to achieve.

Electrode configuration and positioning is another great challenge in making MFC a scalable technology. Frequently used electrodes can be categorized according to their configurations, the plane electrode and the three-dimensional electrode. Carbon cloth and carbon paper come under plane electrode, whereas carbon brushes/felt comes under three- dimensional electrodes. A good configuration and properties for anodes include a large surface area for bacterial adhesion and efficient current collection.

This chapter focuses on design and operation of MFCs, with emphasis on its application in wastewater treatment (Fig. 10.1).

10.2   MFC: Design and Operation

Many MFC designs have been proposed and operated in laboratory with different reactor configurations. Various designs have different positioning of basic components of MFC such as anode, cathode, and separator. Below is the short introduction about the components of MFC.

10.2.1 Components of MFC

The main components of MFC include the electrodes, i.e., cathode and anode, and the separator which is a semipermeable membrane which allows the exchange of protons.

10.2.2 Electrodes

Electrode is the significant component in determining the performance and cost of MFC. Electrode design is one of the challenging problems in making MFCs a cost-effective and scalable technology. A variety of carbonaceous material are used as electrodes.

10.2.3 Anodes

Anode materials are responsible for the electron transfer efficiency which is an important factor for MFC performance. A large variety of carbon materials are used as anode in MFC due to their conductivity, chemical stability, cost-effectiveness, and biocompatibility.

(a) Granular carbon/graphite – It is generally used as an anode in MFC for its high surface area and porosity. Graphite granules of diameter between 1.5 and 5 mm provide an estimated surface area between 817 and 2720 m^2 m^{-3} of the reactor volume, which is much higher than flat electrodes (Rabaey et al. 2005). This type of anode configuration is achieved by filling the anodic chamber with carbon/graphite granules. Tubular reactor is the best suited configuration for using granule anode. Although granular anodes facilitate good energy output, filling the reactor with granules decreases the volume of the anodic chamber. Moreover, clogging of pores in the electrode may be due to suspended solids in wastewater which may hinder the long-term continuous use of reactor.

(b) Carbon cloth – It is the most common material for plain electrodes and can be used in most of the single-chamber MFC configuration due to its flexible nature. In tubular MFC configuration, carbon cloth wrapped around the tube acts as cathode, which is only possible due to its flexible nature. Kim et al. (2010) used carbon cloth as anode in tubular MFC by wrapping around a perspex cylinder and fitted centrally in the tube reactor.

(c) Carbon brushes – High surface area and efficient electron collection properties make carbon brush an ideal electrode material for MFC (Wei et al. 2011). It was first testified by Logan et al. (2007). The brushes were made of carbon fibers looped into a twisted core of two conductive titanium wires. The diameter and mass of fibers affect the performance of MFC. Liu et al. (2013) investigated that

the smaller diameter brush facilitates more energy output, but the effect of fiber
loading on energy output was not clear. However, studies do indicate that dense
fiber loading leads to clumping and causes hindrance in bacterial access to fiber
surface as well as substrate access into the fiber interior. Zhang et al. (2013a, b)
used carbon brushes (100 cm long) as anode in tubular MFC deployed in the
primary effluent of municipal wastewater treatment plant.

10.2.4   Cathode

The electrons produced in the anodic chamber are transferred to the cathode via
external circuit where reductions of electrons occur. In dual-chamber MFC, ferri-
cyanide is used as electron acceptor and converted to ferrocyanide. In single-
chamber MFCs, water is formed by reduction reaction in the presence of atmospheric
oxygen. Oxygen is most commonly used as electron acceptor due to its high affinity
to acquire electron and easy availability, and its end product is only water. Graphite,
carbon, and steel are commonly used as a cathode electrode (Fan et al. 2007).
Reduction potential of graphite and carbon is very low, and it usually leads to high
over-potential. So, platinum is used as catalyst for oxygen reduction reaction at the
cathode, but due to its high cost, it is limited to lab scale only. Many researchers
focused on using alternative to platinum catalyst to low-cost metal such as Fe (III),
cobalt complexes (Cheng et al. 2006), and manganese oxide (Rhoads et al. 2005).

10.2.5   Separator

Separator is employed in MFC to physically separate the anodic and cathodic cham-
bers or cathode for a single-chamber MFC and migration of proton from anodic to
cathodic chambers. Various types of separator have been extensively studied for
MFC including cation-exchange membrane (CEM) (Kim et al. 2010; Zhang et al.
2013a, b), anion-exchange membrane (AEM), microfiltration membrane (MFM),
ultrafiltration membrane (UFM), and salt bridge. Separator has large contribution in
the cost of MFC. In the study conducted by Ge et al. (2016), separator (CEM) con-
tributed to 60% of the total cost (Table 10.1).

Two of the basic designs of MFC are single-chamber MFC and dual-
chamber MFC.

Table 10.1 The basic components of a typical microbial fuel cell

Components	Materials
Anodic chamber	Glass, plexiglass, acrylic sheet, polycarbonate
Cathodic chamber	Glass, plexiglass, acrylic sheet, polycarbonate
Anode	Graphite, graphite felt, carbon cloth, carbon brush, carbon felt, carbon paper, Pt, steel mesh, Pt black, aluminum mesh
Cathode	Graphite, graphite felt, carbon cloth, carbon brush, carbon felt, carbon paper, Pt, steel mesh, Pt black, aluminum mesh
Proton-exchange system	Nafion membrane, Ultrex, polyethylene, polystyrene-co-divinylbenzene, salt bridge, cation-exchange membrane porcelain septum
Mediator	Neutral red, humic acid, thionin, methyl blue, methyl viologen

Fig. 10.2 Schematic diagram of single-chamber microbial fuel cell
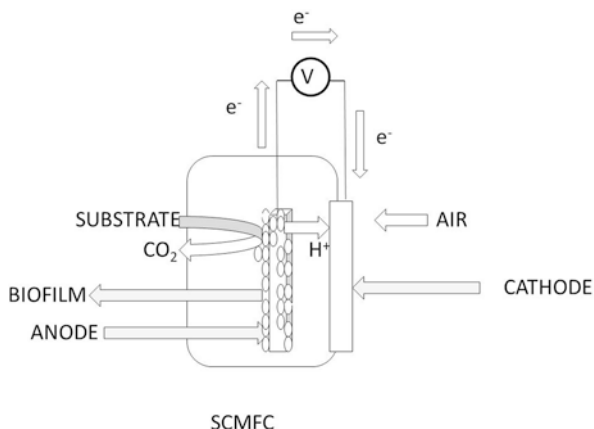
10.2.6 Single-Chamber Microbial Fuel Cells (SC-MFCs)

SC-MFC offers simpler and cost-saving designs which only have an anodic chamber and cathode directly facing the air. This is the simpler type of MFC in which cathode is manifested directly to air and is now widely used. Nowadays researchers have shown that oxygen can act as terminal electron acceptor that eliminates the necessities of catholyte solution. Liu and Logan (2004) designed the first SC-MFC of cylindrical shape having anode placed inside it and cathode wrapped outside. A single-compartment MFC was designed by Park et al. (2018) consisting of a rectangular chamber having anode inside it and cathode which is directly exposed to the air. Cheng and Logan (2011) designed a SC-MFC consisting of a cylindrical structure with anode placed into it, and a cathode made of carbon cloth material coated with platinum was enclosed around the reactor. In single-chamber MFC, stacking MFCs is more easily achieved and offers higher voltage/current (Fig. 10.2).

10.2.7   *Dual-Chamber Microbial Fuel Cells (DC-MFCs)*

The traditional two-compartment MFC has "H" shape, in which a proton-exchange membrane (PEM) is used to separate the anodic chamber and the cathodic chamber. Sometimes salt bridge is also used that allows the protons to cross the membrane to cathode. This kind of MFC is used for the study of the basic parameter of microbial fuel cells such as electrodes, biofilms, proton-exchange membrane, and substrates. Dual-chamber MFCs are generally larger in size due to the presence of extra chamber; the distance between two electrodes (anode and cathode) is more, thus causing high internal resistance. Also the chemicals used in cathodic side should be environment-friendly. The use of membranes in DC-MFCs prevents the diffusion of oxygen from cathode to anode. Zhang et al. (2010) constructed a plate-shaped DC-MFC in which cation-exchange membrane (CEM) is used to separate the anode and cathode, and potassium ferricyanide was used as the electron acceptor to complete the circuit (Table 10.2).

Based on the above criteria and components, many MFC reactor designs have been proposed and operated in the laboratory; despite the great efforts and research, they are still challenging for MFC to be used in practical application. Many MFC systems have been developed at milliliter scale, but in order for practical applications to be comprehended, it is required that it should be capable of treating large quantities of wastewater. System scaling-up is one of the major obstacles for MFC

Table 10.2 MFC components used in liter-scale reactors

S.No	Volume (L)	Anode	Cathode	Membrane	Reference
1.	90	Carbon brushes	Activated carbon and PTFE	Two layers of textile separator (glass)	Dong et al. (2015)
2.	72	Granular-activated carbon	Biocathode	Cation-exchange membrane (CEM)	Wu et al. (2016)
3.	0.22	Carbon cloth	Carbon cloth	CEM (CMI-7000)	Kim et al. (2010)
4.	2	Carbon brushes	Carbon cloth	CEM	Zhang et al. (2013a, b)
5.	1.8	Carbon brushes	Carbon cloth	CEM(CMI-7000)	Ge et al. (2013)
6.	72	Granular-activated carbon	Granular-activated carbon	CEM	Wu et al. (2016)
7.	120	Carbon felt	Stainless steel wool	Rhinohide membrane	Heidrich et al. (2014)
8.	250	Carbon brushes	Carbon mesh	Polypropylene porous plastic plate	Feng et al. (2014)
9.	45	GFB (graphite fiber brush)	Carbon cloth	Membrane not used	Hiegemann et al. (2016)
10.	4	Carbon brush	Carbon cloth	CEM	Zhang et al. (2013a, b)

to be used for practical application. It has been observed that there is a logarithmic relationship between power output and reactor volume. The declining power output in large scale is due to the fact that a proper mixing and large distance between anode and cathode hamper the electricity generation. For scaling-up MFC, research approaches the modularization strategies in which multiple reactors are stacked into one system.

10.2.8 Multimodule MFC Reactors

This is a promising configuration for scale-up, as optimal cross-sectional dimensions could be maintained while increasing the volume by extending the tube in the orthogonal dimension. This configuration geometric feature also helps in mass transfer with minimum pressure losses. Carbon brush anode is mostly used in tubular MFC either at the lab scale or pilot scale (Zhang et al. 2013a, b). Carbon cloth anode is used in tubular MFC by wrapping it on a thin pipe and fitted centrally on the tubular MFC. To increase the volume in tubular MFC, researchers generally vary the length of the tube, and the diameter of the tube is generally maintained at 3–6 cm. The size of the tube length has large impact on COD removal rate. In municipal wastewater treatment plant, 53% COD removal was observed by 100-cm-long tubular MFC (Zhang et al. 2013a, b), while in the laboratory, 49% COD removal is observed by 23-cm-long tubular MFC (Kim and Logan 2013). When raw sludge from primary sedimentation tank was used as substrate, about 69% COD removal was observed with 70 cm tube length.

10.3 Strategies for Improving Power Output

High MFC power output is due to the efficient harvesting of electrons from the anode and transferring them to the cathode, where it is finally accepted by oxygen within a certain limit of time. Wei et al. (2011) reported that to improve the performance of MFCs in terms of power generation, it is necessary to modify electrodes to increase their electron capturing capacity. Zhuang et al. (2012a, b) reported that to enhance the power generation and pollutant removal from wastewater, MFC units could be connected either in parallel or in series. Alatraktchi et al. (2014) reported a power density of 461.6 mW/m^2 using electrodes modified by coating them with gold nanoparticles, which was 1.88 times higher than the unmodified electrode (carbon paper). Wu et al. (2012) achieved a maximum power density of 320 mW/m^3 using white-rot fungus, which was significantly higher as compared to the abiotic control, i.e., 50 mW/m^3. Ren et al. (2013) reported that the charge and discharge frequency significantly influences the current output, COD removal efficiency, and charge recovery efficiency.

Below are some of the given factors which should be considered while scaling-up MFC to get improved power output.

(a) *Internal Resistance*

It is one of the main factors that affects the power density in liter-scale MFC, and as already discussed, increasing the volume of reactor leads to increased internal resistance. The same will also occur in the multiple cell systems stacked up by combining small MFC modules in series or parallel connection (Zhuang et al. 2012a, b). Therefore, it is necessary to quantify the internal resistance of each component of MFC reactor to identify the limiting factors of the system (Fan et al. 2012). Many studies have been conducted to minimize the internal resistance by improving the reactor configuration (Dong et al. 2015; Feng et al. 2014), increasing conductivity of substrate (Zuo et al. 2014), adding ion-exchange resins to chamber (Zuo et al. 2014), and improving the electrode configuration. Feng et al. (2014) compared the internal resistance distribution between a lab-scale MFC module and a pilot MFC module with similar structure to identify the limiting factors during enlargement for further enhancing the performance in the application-oriented pilot MFC system and derived the following equation to identify the increase internal resistance during enlargement:

$$P_{p.\max} = E_{p.emf}^2 \div 4R_{p..real} = K \times E_{p.emf}^2 \div 4\left(R_{cubic} + fK\right)$$

where $P_{p.max}$ is the maximum power output from a pilot-scale MFC could be, E is the potential difference, K is the enlarge ratio of reactor cross-sectional area, and $R_{p,real}$ and R_{cubic} refer to the internal resistance in pilot and cubic reactors.

Zuo et al. (2014) mixed salt solution with influent to increase the conductivity of anolyte which decreased the internal resistance. The internal structure of MFC also greatly influences the internal resistance, thus indicating that abiotic factors such as catalysts, electrodes, electrolytes, and reactor types, along with biotic factors, should also be considered, if one wishes to optimize power generation.

(b) *Biofouling*

Bacterial consortia endeavor to grow on every surface in its surrounding area. Membrane is also exposed to the wastewater in the anode chamber, so biofilm formation on its surface is quite obvious, which leads to biodegradation of the membrane, i.e., biofouling. Biofouling of both membrane and cathode electrode over time decreases the current. Biofouling leads to a decrease in the surface area required for migration of ions to cathode and thus a decrease of the efficiency of MFC (Sonawane et al. 2013). It is one of the major problems in of MFC in the long run, especially when operated in wastewater treatment plant. Biofouling of cathode affects the power generation as it reduces the surface for oxygen uptake. Zhang et al. (2013a, b) observed that by simply washing the cathode with water, it quickly restored the current generation, but biofilm formation occurs quickly again once the

MFC is installed back. Biofouling is one of the serious problems that needs to be improved by developing new membranes with lower internal resistance or less subject to biofouling to achieve long-term performance of MFC.

(c) *Modularization*

Another tactic for improving power output in MFC is to stack multiple small reactors together to form a bigger system rather than having a singular large unit. This strategy is followed by most researchers to improve the power output at a large scale. Apart from electricity generation, COD removal efficiency also depends on the number of modules and reactor configuration. Dong et al. (2015) reported COD removal of 87.6%, at an HRT of 72 h, while Zhuang et al. (2012a, b) achieved 87.1% COD removal with an HRT of 48 h only, both using brewery wastewater. The volumetric capacity of the above two studies was 90 L and 10 L, respectively, but the reactor configuration was different. In the study by Dong et al. (2015), anode and cathode modules were placed in a single vessel, and in the report by Zhuang et al. (2012a), 40 units of tubular MFC were stacked to form a serpentine-type MFC. It should be noted that when 96 tubular MFC modules of total volumetric capacity of 200 L were used to treat primary effluent, 76.8% COD removal efficiency was achieved at an HRT of 18 h only (Ge et al. 2016). These efforts have proved that it is more appropriate to stack multiple MFC modules, since it allows maintaining minimum distance between anode and cathode, and each single reactor can function and be maintained independently. Although Haeger et al. (2014) constructed a single reactor instead of having modules in which anode and cathode are rolled up around a central manifold in a spiral fashion, the electrolytes flow through it producing power density of 170 W/m^3. These studies indicate that efficiency of MFC largely depends on its configuration, and more studies are required to achieve a module configuration in which maximum COD removal efficiency is achieved with a minimum HRT and maximum power production.

(d) *Use of Modified Electrodes*

Approaches to modify the surface of electrodes to enhance surface area and improve conductivity have recently gained popularity. Electrode configuration relates to flat electrode, three-dimensional electrode (carbon felt), and brush electrode. The surface properties of electrode material are one of the deciding factors that affect the bacterial attachment to anode and electron reduction at cathode. One of the approaches to enhance power production in MFCs is using modified electrode to facilitate electron transfer to the anode and improve bacterial adhesion capability (Wei et al. 2011). Strategies used to modified anode include (i) use of metal oxide/graphene as electroactive coatings for electrode, (ii) surface treatment with chemical or physical methods (iii), use of conductive polymer to enhance conductivity of electrode, (iv) and increase surface area by enhancing configuration such as carbon brush, carbon mesh, stainless steel mesh, etc. For cathode, generally flat electrode is used with platinum on carbon coating to enhance its activity.

(e) *Hydraulic Retention Time (HRT)*

HRT is one of the important parameters in the wastewater treatment process; it also greatly affects the operational cost and power generation in MFC (Akman et al. 2013). Excessively long HRTs in MFC reduce the organic loading rate, thereby causing fast depletion of substrate and reducing the cell performance, as the microbes attached to the anodic chamber could not receive sufficient electron sources to produce sufficient amounts of electrons, whereas shorter HRTs favor the development of non-exoelectrogenic microorganism, which causes reduction in the electrochemical performance, thus leading to lower columbic efficiency and less efficient COD removal. Also, when an excessively low HRT is applied to MFCs during the continuous wastewater inflow, it prevents the attachment of microbes to the anode surfaces, thus preventing the formation of confluent biofilm on anodic surface. In this way, HRT readily affects the power generation and effluent quality. In a continuous wastewater flow, MFC having HRT between 0.5 and 2 days, when HRT was decreased, enabled the organic load of the anode chamber to facilitate the microbes to generate more electrons by degrading organic matter, thus releasing more electrons and enhancing the power generation efficiency. Akman et al. (2013) and Hiegemann et al. (2016) reported the power density of 80, 82, and 73 mW/m² with HRT of 12, 22, and 44 h, respectively.

The effect of temperature on MFC performance is also reported. MFCs operated higher temperatures were reported to give better performance in terms of power generation than those which operated under ambient temperature conditions (Ahn and Logan 2010).

10.4   Application in Wastewater Treatment

The MFC technology utilizes the potential of exoelectrogenic bacteria by releasing the energy containing wastewater while simultaneously treating it. Many researchers have demonstrated power generation using wastewater as substrate and reported COD and pollutant removal simultaneously (Hiegemann et al. 2016; Akman et al. 2013). The microorganisms growing on the anode oxidize the organic matter content of wastewater and transfer the electrons generated to the anode. As the electrons flow from the anode to the cathode through an external circuit, a current is produced which is sometimes stored in capacitors. Therefore, MFCs can be one of the most promising technologies for getting renewable energy and treating wastewater with great eco-friendly benefits. Previously researchers mainly focused on optimizing the power generation and neglecting wastewater treatment; however, lately, attention is being given to both aspects.

Application of MFC in wastewater treatment was first demonstrated by Habermann and Pommerin (1991). Logan (2008) reported a maximum power generation of 330 kW/day using an MFC installed at the wastewater treatment plant of a food processing plant.

Heilmann and Logan (2006) demonstrated electricity generation from protein-rich municipal wastewaters. They used three different protein-rich waste streams, i.e., bovine serum albumin, peptone, and slaughterhouse wastewater with three different BODs of 1100 mg/L, 500 mg/L, and 1420 mg/L, respectively, and reported power densities of 354, 269, and 80 mW/m^2, respectively, with BOD removal efficiencies of 90%, 86%, and 93%, respectively. They concluded that less complex protein generates more power than the complex protein. It may thus be concluded that the higher the complexity of wastewater, the lower will be the columbic efficiency. Zhuang et al. (2012a, b) constructed an MFC system of 10 L volume that consists of 40 individual tubular MFCs to treat synthetic wastewater and reported a maximum power density of 4.1 W/m^3.

Jiang et al. (2011) constructed a 16 L MFC module to treat municipal wastewater and achieved 80% of COD removal but reported low-energy generation due to excessive internal resistance. Zhang et al. (2013a, b) designed two tubular microbial fuel cells (MFCs) of volume 4 L to treat municipal wastewater and achieved similar COD removal efficiency of 65–70% with both types of MFCs. They used activated carbon powder as catalyst in one MFC while platinum along with carbon powder on other MFC. Both the MFCs removed 65–70% chemical oxygen demand at a hydraulic retention time of 11 h and reduced 50% suspended solids (Table 10.3).

10.5   Conclusion

MFC reactor design and configuration are the greatest challenges in making the MFC effective for power generation and COD removal efficiency. In wastewater treatment plant, COD removal is one of the important parameters, and it will be beneficial that the energy required for its treatment is obtained from the wastewater itself. Scaling-up MFC is still facing lots of challenges such as increasing internal resistance, dead space, biofouling, and long-term usability. Further studies on more optimization of reactor configurations are expected to address these challenges and enhance the potential of large-scale MFCs with conventional wastewater treatment systems.

Table 10.3 Performance of MFCs treating different wastewaters along with different operational modes

Volume (L)	Design	Power density	Operational mode	Recirculation rate (L/min)	Coulombic efficiency (%)	Substrate	Reference
250	Stackable horizontal MFC	116 mW each module	Continuous	N.A.	79	Domestic wastewater	Feng et al. (2014)
90	Stackable baffle	171 ± 8.4 mW/m² each module	Continuous	N.A.	84.7	Brewery wastewater treatment	Dong et al. (2015)
72	Stacked MFC	50.9 W/m³	Fed-batch	0.85	78–97	Synthetic wastewater	Wu et al. (2016)
1	Tubular	1.37 mW	Continuous	1.05	N.A.	Sucrose solution	Kim et al. (2010)
2	Tubular	0.37 W/m³	Continuous	0.2	N.A.	Primary effluent	Zhang et al. (2013a, b)
1.8	Tubular	6.4 W/m³	Continuous	0.15	69.8	Raw sludge	Ge et al. (2013)
1.6	Single chamber	6.8 W/m³	Batch	N.A.	N.A.	Domestic wastewater	Cheng and Logan (2011)
7.5	Two-chamber MFC stack	2-10 W/m³	Continuous	N.A.	69–97	Synthetic	Clauwaert et al. (2009)
10	Tubular MFC stack	6 W/m³	Continuous	N.A.	86.4	Brewery wastewater	Zhuang et al. (2012a, b)
4	Tubular MFC	NA	Continuous	0.17	65–70	Primary effluents	Zhang et al. (2013a, b)
3	Tubular stack	158 mW/m²	Fed-batch mode	N.A.	22	anaerobic sludge diluted with synthetic media	Yazdi et al. (2015)
45	Rectangular	10.92 mW	Continuous	N.A.	0.41	Mixed anaerobic sludge	Ghadge et al. (2016)
120	Stacked	N.A	Continuous	N.A.	41.2	Domestic wastewater	Heidrich et al. (2014)

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