



RENEWABLE ENERGY INNOVATIONS

Biofuels, Solar, and Other Technologies

Edited by
Alok Patel and Amit Kumar Sharma

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Microbial Fuel Cells – A Sustainable Approach to Utilize Industrial Effluents for Electricity Generation

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Abstract

Microbial fuel cell (MFC) makes an appearance as a fascinating technology for green electricity, and more importantly, it is suitable for simultaneously assisting power generation with wastewater treatment. Recently, major trends follow a technology that fulfills energy demands with minimum waste generation. MFC is a technology which proposed to capitalize on waste as a substrate (industrial effluents, sludge, urea, agricultural waste, etc.) and generate electrical energy. Work done in the area of fuel cells has many configurations and variations based on types of substrate utilized, microorganism associated with electrodes, mediators requirement, and architecture of microbial fuel cell. The most common microbial fuel cells are: two compartments or H-shaped MFC, Single compartment or cube-shaped MFC, Up-flow MFC, Stacked MFC, Sediment MFC in wetlands and their variations. However, as compared to conventional power generation methods, power densities are significantly less in MFC. Therefore, the challenge is to improve MFC efficiency and to reduce the cost of this technology. At the current stage, it is difficult to use them in real-world applications. Efforts are being made to develop a commercial prototype in the coming years.

Keywords: Microbial fuel cells, microorganisms, wastewater, power generation, sustainable energy

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Abbreviation

MFC	Microbial fuel cells
BOD	Biological oxygen demand
COD	Chemical oxygen demand
CE	Coulombic efficiency
H ⁺	Proton
e ⁻	electron
PEM	Proton exchange membrane
LED	Light emitting diode

1.1 Introduction

Microbial fuel cells (MFCs) is a technology which utilizes microorganism as the biocatalysts for the oxidation of inorganic/organic matter and produces current. Bacteria produce electrons inside a cell passed to the anode and traveled towards the cathode [1]. Another modification of the system is the application of enzymes instead of in situ growth of the microorganism, so this is considered as enzymatic biofuel cells [2]. It is found in studies that MFCs that utilize mixed cultures achieve more increment in power densities than pure cultures [3, 4]. Multiple varieties of materials have been used in the construction of MFC, and hence increasing diversity in the MFCs configurations working under various parameters like at different temperatures, pH, electron surface areas, electron acceptor, duration of operation, and reactor size [1]. MFC is an ideal method for generating renewable electricity from biomass. This biomass can utilize bio-wastes (containing protein, carbohydrate, etc.) obtained from the complex organic source of human/animal waste and food processing wastewaters [5–7]. In some early studies, the addition of mediators/electron shuttles (for carrying electrons from cells to the electrode) was proven for noteworthy increment in power densities [8, 9]. Only certain bacterial species can a dissimilatory iron reduction if exogenous mediators are not present there [10, 11], so power production without chemical mediators is a rare trait. Bacteria that can transfer extracellular electron without mediators are known as Exoelectrogen [12]. Some classes of Proteobacteria, Acidobacteria, and Firmicutes have been found active in electrical current generation [12]. *Pichia anomala* (a yeast) contains redox enzyme in the

outer membrane of the cell [13], and a cyanobacteria *Synechocystis sp.* has conductive appendages known as nanowires [14]. These nanowires help to build mediator-less MFCs, which are considered to be more useful as compared to mediators containing fuel cells [15, 16]. Synthetic mediators used in MFCs are toxic as well as expensive. MFCs includes mainly two electrodes: [a] Anode (negative terminal), and [b] Cathode (positive terminal) [17]. Electrodes are placed within one- or two-chambered MFC, primarily separated by a proton exchange membrane [17]. Two-chamber MFC needs additional expense in terms of aeration for providing oxygen at the cathode. Power output is affected by cathode efficiency by using mediators like ferricyanide [17, 18]. Graphite electrodes in their solid form are relatively more expensive than graphite felt and carbon cloth; also, the utilization of air-driven cathodes minimizes the requirement of energy for air sparging in water [19]. The power density of MFCs is much less as compared to other fuel cells. If we want to consider it as a commercial and economical way of power production, then it is needed to reduce the cost of the construction and operation of MFCs. Utilizing wastewater for making this technique commercial, sustainable, and economical is a further area of research in wastewater treatment [20, 21]. Hydrogen production and photosynthetic algae fuel cells utilizing wastewater for biological fermentation and algae production, respectively, caught much attention as a technique for producing some products like hydrogen, algae for biodiesel production simultaneously with wastewater treatment [22, 23].

1.2 History of Microbial Fuel Cell

M.C. Potter (1911), a botany professor at the University of Durham, while working on microbial degradation of organic compounds, found that electric energy also generates during the degradation of compounds [24]. Later, this concept was applied to harvest the new source of power by the construction of a primitive MFC in 1931 using *E. coli* half cells and arranging these half cells into series, which generate potential up to 35 volts while the current generated by the system is only 2 mA [25]. For hydrogen production, *Clostridium butyricum* is used at the anode (glucose fermentation) [26]. After some time, synthetic mediators were used to enhance electron transfer towards the electrode from the bacterial cell. In the early 1980s, M. J. Allen and H. Peter Bennetto, two researchers in King's College London, studied fuel cells and explained microbial fuel cell mechanism [27]. In 1990, Habermann and Pommer constructed the first MFC wastewater treatment system, with a mixed culture of bacteria

in activated sludge; they reported that electrogenic bacteria produce natural mediators for electron transfer [28]. Electron conduction property of some soil bacteria/*Geobacter species* was found in 1994 [29] while in 2003 anodophilic property of *Geobacter* was found [30]. Direct electron transport in some bacteria occurs naturally via pili like nanowires [12]. In association with Fosters Brewing Company, the University of Queensland (Australia), in May 2007, designed an MFC (10 liters) to convert brewery wastewater into electricity and clean water [31]. It was a successful operation, and after that, the University of Queensland planned to develop a 600 gallon of the same MFC design for the brewery, and the estimated power production from the unit is 2 kilowatts [31]. MFCs are currently the most needful area in research for bringing out its true potential for power production by optimizing electrodes, microorganisms, mediators, and proton exchange membrane [1, 20, 21].

1.3 Principle of Microbial Fuel Cell

A general MFC has a single chamber or double chamber compartments containing a cathode and an anode as shown in Figure 1.1. At the anodic compartment, microbe utilizes chemical energy obtained from organic substrates via their cellular respiration pathways and transfer this energy into the form of electrical power. In the anaerobic environment inside the anode chamber, carbohydrates convert into protons, electrons, and carbon dioxide [32, 33]. Hence electrons are generated at the anode and

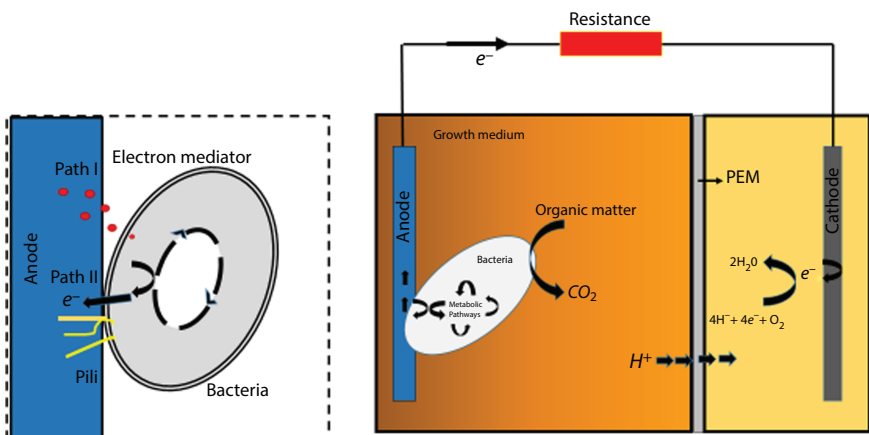
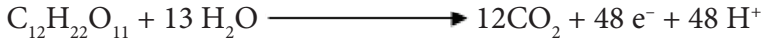


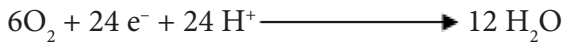
Figure 1.1 The basic mechanism of microbial fuel cells.

move towards the cathode via an external load. At the cathode, oxygen is reduced in contact with electron and proton, so a charge difference is created between the two electrodes and generates a little current, and the reactions occurring at the electrodes are the following [34]:

The reaction at the anode:



Reaction at cathode:



1.4 Material Used in MFC System

There are various factors such as electron transfer mechanism within the MFC chamber, Substrate, pH, Various MFC configuration, electrode material, and type of membrane used that influence MFCs performance. Figure 1.2 illustrates a general view of various essential components of microbial fuel cells.

Table 1.1 illustrates several components like bacteria, industrial effluents, electrode material, and substrates used in various microbial fuel cell studies [17, 35–47]. Studies show up to 98% COD removal efficiency by using starch processing effluent for bioremediation inside the microbial fuel cell.

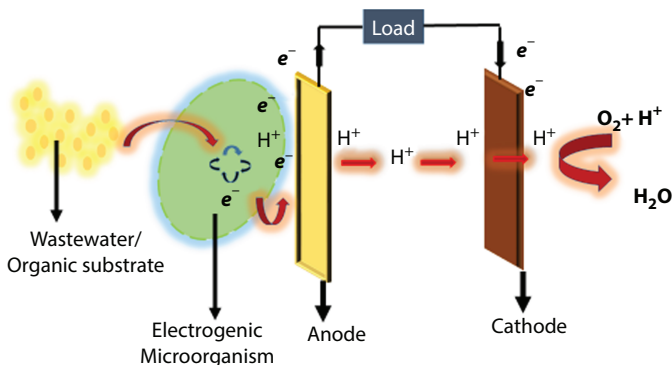


Figure 1.2 Basic components of microbial fuel cells.

Table 1.1 Power density obtained from various material used in different studies.

Bacteria	Anode material	Cathode material	Membrane	Substrate/ wastewater source	COD removal efficiency	Power density	Reference
Activated Sludge	Woven graphite felt	Woven graphite felt	–	Wastewater from a starch processing plant	98%	8 mW/m ²	[35]
Activated sludge (at the anode) <i>Chlorella vulgaris</i> (at the cathode)	Toray carbon cloth with 10% Teflon	Toray carbon cloth with 10% Teflon		Fruit processing industry effluent	60-80%	14.40 mW/m ²	[36]
Mixed culture/ Bacteria present in wastewater	Toray carbon paper	Carbon cloth	Polymeric proton exchange membrane (PEM)	Glucose and wastewater	–	146 mW/m ²	[37]

(Continued)

Table 1.1 Power density obtained from various material used in different studies. (*Continued*)

Bacteria	Anode material	Cathode material	Membrane	Substrate/ wastewater source	COD removal efficiency	Power density	Reference
Mixed culture/ bacteria present in wastewater	Toray carbon paper	Carbon cloth	No membrane	Glucose and wastewater	—	494 mW/ m ²	[37]
Mixed bacteria culture	Plain graphite rod	Plain graphite rod	Ultrex	Glucose	85%	2200 mW/ m ²	[38]
<i>Rhodofexax ferrireducens</i>	Plain graphite	Plain graphite	—	Glucose	—	8 mW/m ²	[39]
<i>Rhodofexax ferrireducens</i>	Woven graphite	Woven graphite	—	Glucose	—	17 mW/m ²	[39]
<i>Rhodofexax ferrireducens</i>	Graphite foam	Graphite foam	—	Glucose	—	33 mW/m ²	[39]
<i>Proteus vulgaris</i>	Glassy Carbon	Ferricyanide platinum	—	Glucose	—	4.5 mW/m ²	[40]

(*Continued*)

Table 1.1 Power density obtained from various material used in different studies. (Continued)

Bacteria	Anode material	Cathode material	Membrane	Substrate/ wastewater source	COD removal efficiency	Power density	Reference
<i>Proteus vulgaris</i> & <i>Escherichia coli</i>	Reticulated vitreous carbon plate	Platinum plate	Nafion	Glucose	–	85 mW/m ²	[41]
<i>Pseudomonas aeruginosa</i>	Plain graphite rod	Plain graphite rod	Ultrex membrane	Glucose	–	88 mW/m ²	[42]
<i>Escherichia coli</i>	Woven graphite	Woven graphite	–	Lactate	–	1.20 mW/ m ²	[17]
<i>Escherichia coli</i>	Plain graphite	Plain graphite	–	Lactate	–	91 mW/m ²	[17]
Activated sludge	Woven graphite	Woven graphite	–	Lactate	–	5.3 mW/m ²	[17]
Activated sludge	Plain graphite	Plain graphite	–	Lactate	–	788 mW/ m ²	[17]
Mixed consortium	Granular graphite	Granular graphite	–	Sucrose	50%	23 mW/m ²	[43]

(Continued)

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