ijCEPr

International Journal of Chemical, Environmental and Pharmaceutical Research

Vol. 5, No.1, 8-12
January - April, 2014

Microbial Fuel cell: A New Approach of Wastewater Treatment with Power Generation

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Article History:
Received: 18 April 2014
Accepted: 24 May 2014

ABSTRACT
Production of energy resource while minimizing the waste is one of the best ways for sustainable energy resource management practices. Application of Microbial Fuel Cells (MFCs) may represent a completely new approach to wastewater treatment with production of sustainable clean energy. The increase in energy demand can be fulfilled by Microbial Fuel Cell (MFC) in future. In recent years, researchers have shown that MFCs can be used to produce electricity from water containing glucose, acetate or lactate. Studies on electricity generation using organic matter from the wastewater as substrate are in progress. Waste biomass is a cheap and relatively abundant source of electrons for microbes capable of producing electrical current outside the cell. Rapidly developing microbial electrochemical technologies, such as microbial fuel cells, are part of a diverse platform of future sustainable energy and chemical production technologies. It is the innovative research area for production of energy source from waste water. Microbial fuel cells (MFCs) represent a completely new long term, affordable, accessible and ecofriendly approach to waste water treatment with production of sustainable energy.
Keywords: Bioelectricity production, Industrial Wastewater treatment, Microbial fuel Cell etc.

INTRODUCTION
Researchers in the fields of Biological and Environmental Engineering have shown a real potential to apply microbial fuel cell technology to wastewater treatment. Motivations of their work were based on the economic, environmental, and social needs for sustainable wastewater treatment systems and renewable energy. Microbial fuel cells are devices that directly convert chemical energy to electricity through catalytic activities of microorganisms [3, 13, and 15]. Electricity has been generated in MFCs form various organic compounds including Carbohydrates, proteins and fatty acids [12]. One of the greatest advantages of MFCs over conventional fuel cells like hydrogen and methanol fuel cell is that a diverse range of Organic material can be used as fuels. A microbial fuel cell (MFC) is a device that converts chemical energy to electrical energy with the aid of microorganisms [4, 16].
The study of MFC was firstly performed by M.C Potter in 1911 to generate electricity from *E.Coli*. Hydrogen can be used in the MFC which is produced by the fermentation of glucose by *Clostridium butyricum* as the reactant at the anode of the hydrogen and air fuel cell. [2, 18] the current design and concept of MFC is an ideal design to produce bioelectricity through microorganisms [1, 9]. It is now known that the electricity can be produced directly from the degradation of organic matter in the microbial fuel cell.
Sugar when consumed by the microorganisms under aerobic condition they produce carbon dioxide and water, but when oxygen is not present the end product is carbon dioxide, protons and electrons as described below.

$$C_{12}H_{22}O_{11} + 13H_2O \rightarrow 12CO_2 + 48H^+ + 48e^-$$

The experimental microbial cells were electrochemically inactive. So the electron transfer from microbial cells to the electrode was facilitated by mediators such as methyl orange.
But the mediators MFC not require a mediator but uses electrochemically active bacteria and fungus to transfer electrons to the electrode (electrons are carried directly from the respiratory enzyme to the electrode). Among the electrochemically active bacteria are *Shewanella putrefaciens, Aeromonas hydrophila*, etc. Some bacteria, which have Pilli on their external membrane, are able to transfer their electron production via these Pilli. Mediator-less microbial fuel cells can, besides running on wastewater, also derive energy directly from certain aquatic plants. These include reed sweet grass, cord grass, rice, tomatoes, lupines, and algae. These microbial fuel cells are called Plant Microbial Fuel Cells. In plant-MFC power is thus derived from a living plant (in situ-energy production), this variant can provide extra ecological advantages. Whereas fungus plays major role in synthesizing extra cellular

enzymes such as cellulose, lignin peroxidase (LiP), Manganese peroxidase (MnP), lacase (Lac). for degradation of organic matter.

MATERIALS AND METHODS

Microbial fuel cell (MFC) system

MFCs are being constructed using a variety of materials and in an ever increasing diversity of conFig.-urations. These systems are operated under a range of conditions that include differences in temperature, pH, electron acceptor, electrode surface areas, reactor size and operation time. It was only recently discovered that the respiratory enzymes of certain iron reducing bacteria span their outer membrane allowing a direct transfer of electrons to the external metals such as Fe(III) or Mn(IV) .The attachment of these bacteria to carbon electrodes results in electron transfer to the anode, with oxygen reduction at cathode .Power generated in various types of MFCs operated using mixed cultures currently achieve substantially greater power densities than those with pure cultures [7, 11, 15] .

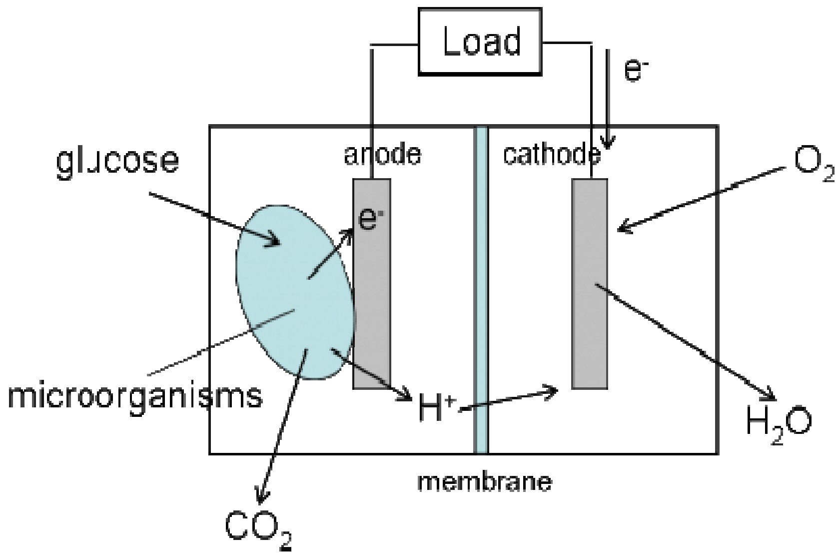

Fig.-1: Schematic diagram of working of Microbial Fuel Cell.

Working of MFC

The MFC for wastewater treatment is an engineered system designed to support a non defined mixed culture of microbes in the anode chamber. These MFCs transform (treat) organic substrates (in wastewater) through oxidation-reduction reactions and transport electrons through an electric circuit for the generation of electric power. The oxidation reactions occur in the anode compartment where bacteria metabolize organic substrates to generate energy for cell maintenance and biomass synthesis. Bacteria, which are capable of extracellular electron transfer (called elec-tricigens), can respire with the solid electrode, while conserving energy by oxidizing organic molecules, such as acetate, completely to carbon dioxide

The electrons transfer from the anode electrode via an external circuit to the cathode electrode to participate in a reduction reaction. MFC cathodes have a number of different configuration and catholyte fluid options.

The working principle of a microbial fuel cell: substrate (in wastewater) is metabolized by bacteria, which transfer the gained electrons to the anode electrode through three mechanisms: direct cell contact, shuttling via electron mediators (red/ ox), or shuttling via nanowires. Electrons flow from the anode (negative pole) to the cathode (positive pole) via an electric circuit and power is generated because of an external resistor (R). Cation transfer from the anolyte to the catholyte ensures electro-neutrality when a cation-exchange membrane is installed. On the cathode, oxygen is reduced to form hydroxide ions with protons available from water (O_2 þ 4 e^- þ 2 H_2O 4 OH^-).

MFC systems vary widely as a function of the inoculums, substrate, and reactor, ranging from < 1 mW/m^2 with lactate and pure culture to 3600 mW/m^2 with glucose and mixed cultures of microbes [8]. However most results with carbon electrodes generally report power generation rates of 10-100mW/m^2.

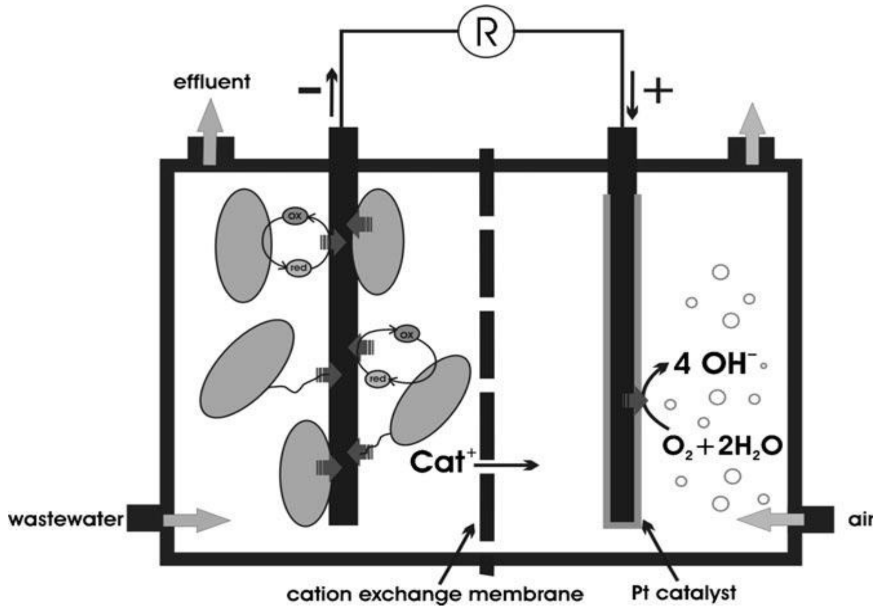

Fig.-2: Working of MFC

Table-1: Maximum power densities in various MFCS using mixed culture reported by different group of scientists.

Reactor type	Fuel used	Power (mW/m^2)	Reference
Single chamber	Glucose	766	4
Single chamber	Domestic wastewater	464	5
Two chamber	Glucose	860	13
Two chamber	Acetate	480	4
Up flow	Sucrose	560	2

Table-2: Maximum power densities in various MFCS, using pure culture reported by different group of scientists.

Strain	Reactor Type	Fuel used	Power (mW/m^2)	Reference
Escherichia Coli	Single chamber	Complex substrate	600	18
Shwenella Putrefaciens	Single chamber	Glucose	355.5	2
Geobacter sulfurreducens	Double chamber H-type	acetate	13	3
Shwenella Putrefaciens	Double chamber H-type	glucose	33.4	2

RESULTS AND DISCUSSION

Classic MFC designs include the single-chamber air-cathode MFCs (SCMFCs) developed by Liu and Logan, which for the first time eliminated the membrane and therefore significantly reduced system internal resistance and cost (Fig.-3A) [6, 12,18] (Tubular MFCs) with different flow patterns simplified construction processes and optimized systems with increased electrode surface area and reduced system resistance [2,4]. A baffled air-cathode microbial fuel cell (BAFMFC) was designed to increase organic loading rate (Feng et al., 2010), and stacked MFCs were able to increase direct voltage or current output while also enhance substrate oxidation [1,3]. Other MFC systems used in wastewater applications include submersible MFCs (SBMFCs) [15, 20], which may convert the information of

substrate concentration, toxicity, or dissolved oxygen concentration into electronic signals as MFC sensors.
The main advantages of using MFCs in wastewater treatment come from the savings of aeration energy and sludge disposal. For traditional activated sludge systems, aeration can amount to 45–75% of plant energy costs, so the conversion of aeration tank to MFC units is very beneficial because it not only eliminates aeration energy consumption, studies also showed that the MFC can produce 10–20% more energy that can be used for other processes [7,9] . The reported maximum power density from lab scale air-cathode MFCs has reached 2.87 kW/m^3, making it promising for commercialization development [8,10], even though the system scale up remains a major challenge. Another main benefit of MFC systems is the low biomass production. The MFC is a biofilm based system, and the cell yield of electro-chemically active bacteria (0.07–0.16gVSS/g COD) is much less than the activated sludge (0.35 – 0.45 gVSS/gCOD), so it can reduce sludge production by 50 – 70% [12], which in turn may reduce 20–30% of the plant operation cost. Other benefits may include nutrient removal and the production of value-added products, such as caustic solutions for disinfection, or H_2 and biogas for energy, which will be discussed more extensively in the following sections.

Wastewater Treatment with MFCs
Lab-scale MFCs have been operated on synthetic (e.g., sucrose, glucose, acetate) and real wastewater (e.g., municipal, hospital, brewery, animal wastewater). Hexose, butyrate, and acetate were chosen here as model components for a complex wastewater with a diverse composition of organic compounds. The MFC half reactions with these substrates are:

$$C_6H_{12}O_6 + 6H_2O \rightarrow 6CO_2 + 24H^+ + 24e^-$$

$$CH_3CH_2CH_2COOH + 2H_2O \rightarrow 2CH_3COOH + 4H^+ + 4e^-$$

$$CH_3COOH + 2H_2O \rightarrow 2CO_2 + 8H^+ + 8e^-$$

The removal of reducing equivalents (electrons) from the anode chamber is basically similar to decreasing the chemical oxygen demand (COD) concentration from the wastewater. Therefore, the calculation of the coulombic efficiency for the organic substrate oxidation in the anode chamber is performed based on the amount of BOD or COD removed by the mixed culture in the anode chamber and the electric current generated
In about one decade of research and development, the functionality of MESs has expanded dramatically and the performance has improved exponentially. However, despite the many different functions discovered, there are many remaining challenges before this technology can be implemented in larger scale. Taking MFCs as an example, the power density has increased by orders of magnitude, from less than 1 mW/m^3 to 2.87 kW/m^3 (or 10.9 kA/m^3) (Fan et.al., 2012), primarily due to the advancements in reactor architecture, material, and operation, which relieves the physical and chemical constraints of the system. The projected wastewater treatment capacity of MFCs can reach 7.1 kg chemical oxygen demand (COD)/m^3 reactor volume/day, which is even higher than conventional activated sludge systems (~0.5–2 kg COD/m^3 reactor volume/day) [15,16]. However, there are still many challenges that need to be addressed before the technology can be applied in commercial scale. The replacement of expensive metal catalysts and membranes with cheaper alternatives has dramatically reduced the reactor costs, but the overall cost of MESs is still considered expensive for wastewater treatment, unless an estimated threshold of internal resistance b 40 mΩ m^2 in combination with a current density around 25 A/m^2 can be reached. The overall benefits to be realized from MFCs provide great incentives for continued innovations and create sustainable future for wastewater treatment.

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