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Microbial Fuel Cells: It's Applications

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Abstract: Microbial fuel cell (MFCs) uses bacteria to convert organic waste material or chemical energy into electrical energy. These technologies represent various multi-disciplinary approaches for alternate source of energy. By the use of bacteria MFCs turn the energy stored in chemical bonds into the electric current that can use without the need for combustion. The basic working principle of MFCs is based on tenets microbial physiology which is coupled with electrochemistry. The structural design of MFCs consists of components such as cathode, electrolyte, and anode. Electricigens such as *Geobacter* species are able to oxidize organic matter to CO_2. By the use of MFCs electricity is generated by treating urban waste water. MFCs have various practical applications such as waste water treatment, hydrogen production, bioremediation, environmental biosensors etc.

Key words: MFC, *Geobacter spp.*, Electrochemistry, Waste water.

1. Introduction:

Microbial fuel cells are devices that convert chemical energy into electrical energy, using bacteria as a catalyst to oxidize organic and inorganic matter without the inefficiencies that arise from combusting fuel to produce electricity [1]. MFCs provide new opportunities for the energy production from reduced biodegradable compounds. They are unique subset of fuel cells that take advantage of microbial metabolism to generate fuels for commercial fuel cells or electricity directly.

1.2 Microbial Fuel Cell Principle:

The main components of microbial fuel cells are:

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1. Anode
2. Electrolyte
3. Cathode

A typical MFC consists of two compartments

a. Anodic half cells
b. Cathodic half cells

MFC is dissimilatory metal reduction [2,3] they are separated by a salt bridge, selectively permeable or specific membrane. The anodic chamber consists of the microbes that are suspended under anaerobic conditions in the anolyte and the cathodic chamber consists of electron acceptor like oxygen. From the process of oxidation the electrons released are conveyed to the anode. Electron transfer to the anode can be accomplished by indirect transfer using shuttling agents or electron mediators, through direct transfer by bacterial structures called, nanowires or directly by the cell. These electrons are directed to the cathode across an electrical circuit and for every electron conducted,a proton is transported across the cathode membrane for completion of the reaction and sustaining the electric current.

1.3. Design of Microbial Fuel Cell:-

Variety of scalable designs for constructing an MFC has proposed by researchers. The traditional, dual chambered (H- shaped) MFC is commonly adopted configuration, in which two chambers are connected by means of a tube containing a separator membrane [4].Initially reactors used a salt bridge as ion exchange channel between the cathode and anode chamber and these were replaced by cation/ proton exchange membrane. The best known designs include an up flow tubular type MFC, [5] a flat plate design, [6] and a U-tube MFC[7].

A sediment-type MFC, that uses sediments and overlying water as anode and cathode respectively, has recorded power densities as 55mW/m² with sea water. [8].

Fig 1: Two Chambered MFC Design

A

B

2. Microbiology of MFC:-

In the new emerging field of microbial ecology, electrochemically active microbes are still in its infancy. These are based on anodophilic bacteria and possible interspecies electron transfer. Such bacteria are referred to as exoelectrogens [9].

Exoelectrogens are those microorganisms that have the ability to transfer electrons exocellularly. Exoelectrogens utilized have been researched now-a-days in the development of MFCs that has potential to convert the organic material such as activated sludge from waste water treatment into ethanol, electric current and hydrogen gas etc.

Transfer of electrons exocellularly are in three ways:

1. Self- produced mediators
2. Membrane bound electron carrier
3. Nanowires (connective appendages)

Nanowires introduce a new dimension to study extracellular electron transfer. These are conductive, pilus- like structures, and are identified. Electricigens are the micro-organisms that are able to oxidize organic matter to CO_2 at the same time that electrons are transferred to electrodes. Electricigens have ability to convert organic detritus and renewable biomass into electricity without consumes the fuel wasting energy in heat form. The ability of *Geobacter* species is to oxidize organic compounds completely with electrode that serve as electron acceptor, and to conserve energy to support growth from this metabolism, represents a novel form of microbial respiration. The capacity to conserve energy from this metabolism for the sustainability of long- term of microbial fuel cell is essential. Hence microorganisms that conserve energy from electron transfer to a referred to as electricigens[10]. In species like *Geobacter sulfurreducens* PCA, *Shewanella oneidensis* MR-1, a phototrophic *Cyanobacterium synechocystis* PCC6803, and the thermophilic fermenter *Pelotomaculum thermopropionicum* appeared to be involved directly in extracellular electron transfer [11, 12]

3. Electricigens:

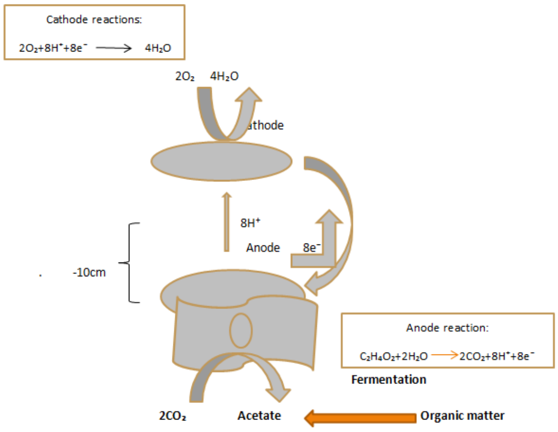
Several electricigens outside the *Geobacteriaceae* are described such as:

1. Pseudomonas
2. Shewanella putrefaciens
3. Rhodoferax ferrireducens
4. Desulfobulbus propionicus

R. ferrireducens was isolated from subsurface sediments as a $Fe^{\square +}$ reducer; oxidize sugars such as glucose, lactose, fructose and xylose to CO_2 with the recovery of 80% of electrons derived from sugar oxidation as electricity [13].

Desulfobulbus propionicus electricige*n* is discovered from molecular analysis of the anode surfaces of sediment microbial fuel cell. Electrodes harvesting electricity from sediments with high concentrations of sulphide were colonized by microorganisms in the family *Desulfobulbaceae*[14].

Fig 2: Sediment Fuel Cell

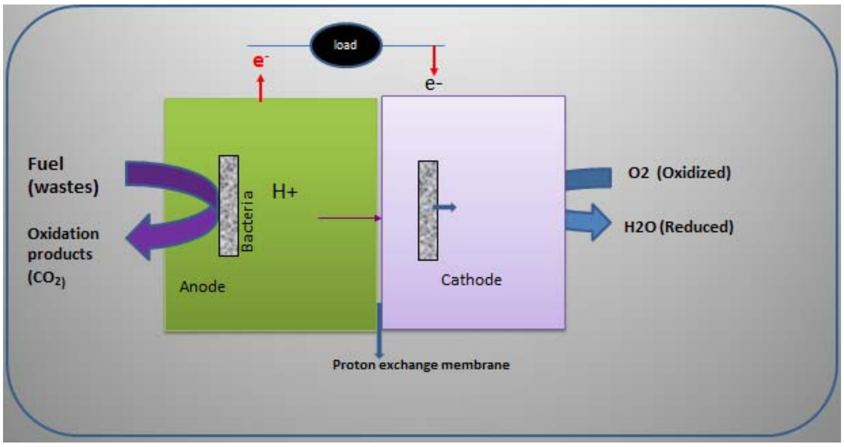


Organisms in the family *Geobacteriaceae* can oxidize acetate and other fermentation products, and transfer the electrons to graphite electrodesin the sediment. These electrons flow to the cathode in the overlying aerobic water where they react with oxygen.

4. Mechanism of Electron Transfer to Electrodes:

The ability of electricigens to produce electricity is related to their capacity to transfer electrons onto extracellular electron acceptors like $Fe^{\square+}$ and Mn^{4+} oxides as well as humic substances. One of the most awful barriers to microorganisms transferring electrons onto $Fe^{\square+}$ or electrodes is non-conducting lipid membrane system. It serves as an insulator, separating cytoplasm where electrons are extracted from organic matter during central metabolism from outside the cell where final electron transfer takes place. *G. sulfurreducens* transfers electrons that are derived from central metabolism onto extracellular $Fe^{\square+}$ oxides begin to emerge a series of C-type cytochromes associated with the inner membrane, periplasm and outer membrane might interact to transfer electrons to the outer surface of membrane. The presence of specialized pili is required for growth on $Fe^{\square+}$ oxides that are localized to one side of the cell. Pili are the electrical conductive between the cell and $Fe^{\square+}$oxides [15]. *G. sulfurreducens* form close contact between the cells and anode, little more than a monolayer on the surface of electrodes. Under these conditions there can be the production of current in the absence of pili providing the cells to retain the ability to produce outer- membrane cytochromes, OmcS. The conductive pili are essential for the development of thicker biofilms and high current production level. The pili are involved in electron transfer to the anode for cells and not in direct contact with anode surface [16].

Fig 3:Electricity Production in Cathode



4.1. Nanowires:

Nanowires are appendages that are electrically conductive and are being produced by large number of bacteria most probably from the *Geobacter* and *Shewanella*. These wires constitute a complex nanoweb structure between the anode surface and the microbial community. The nanowires are of, only 3-5 nanometers in width, quite durable and more than thousand times long as they are wide. Nanowires are required for the long- range extracellular transfer of electrons. *G. sulfurreducens* produces cytochromes. The genetic studies and gene expression analysis suggests that the outer surface cytochromes OmcE and OmcS are involved in electron transfer to the anode surface. The species of *Geobacter* produces fine, hair like structures known as pili.

4.2. Working of MFC:

Microbial fuel cells work by allowing bacteria to grow by catalysing chemical reactions and harnessing and of energy is stored in the form of ATP (adenosine triphosphate). MFCs allow the bacteria to oxidize and reduce organic molecules. Bacterial respiration is a redox reaction in which the electrons move around. In some bacteria, substrates are reduced, oxidized and transfer of electrons through respiratory enzymes by NADH. A MFC consists of anode and cathode separated by a specific membrane. MFC works in three ways:

- Electron transfer by mediators
- Direct electron transfer through bacteria outer membrane enzymes
- Electron transfer via pilus-like nanowires.

5. Mechanism of Electricity Production using Urban Waste Water by MFC:

The biological fuel cells can convert chemical energy of organic matter directly into electricity. Number of biological fuel cells is there that include processes that use primary fuel usually organic matter such as corn husks, urban waste water, whey etc to generate hydrogen or ethanol which then are used as a secondary fuel within a conventional fuel cell.

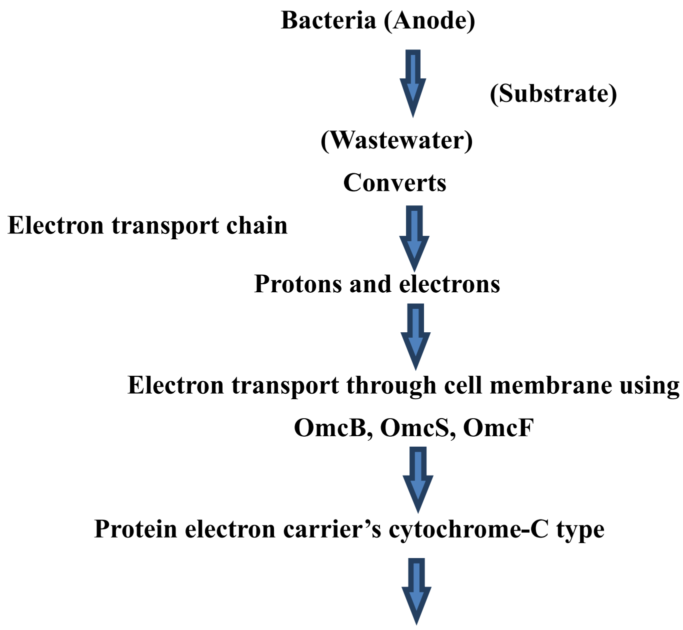
i. The cells which generate electricity directly from organic fuel such as glucose that use either enzymes or complete microorganisms, electron mediators are oftenly need to transfer electrons from microorganisms to electrode.

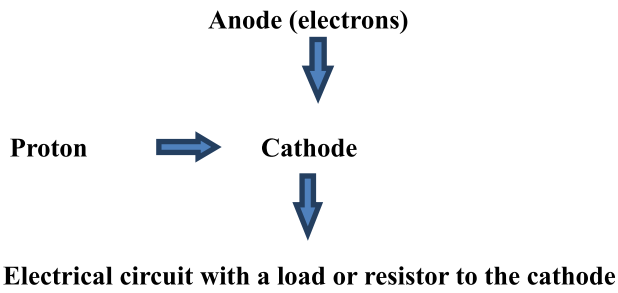
ii. Cells that combine the utilization of photochemically active systems and biological moiety to harvest energy from sunlight and convert it into electricity.

MFCs consist of fuel cells in which bacteria directly catalyze the conversion of organic matter into electricity without addition of mediators or artificial electron shuttles. Both one and two chamber MFCs are reported to obtain higher efficiencies. The power density produced by MFC is low and normally below $50Wm^{-2}$. Hence they are considered to have more potential of commercial application than some other kinds of biofuel cells due to their simplicity. They do not require artificial electron shuttles which are expensive and toxic to microorganisms. In this MFC is fed with urban waste water as a fuel.

Mechanism of Electricity Production

Figure 4





6. Applications of MFC:

6.1 Waste Water Treatment:

It is the most important foreseeable application of an MFC is waste water treatment. Exoelectrogens breakdown and metabolize the carbon rich sewage of waste water stream for the production of electrons that stream into a cheap conductive carbon cloth anode. The use of MFC is done in treatment system as a replacement for existing energy demanding bioreactor resulting in net energy- producing system. MFC based system provide an opportunity for better removal of BOD and nutrients. Applications of MFC are useful in such areas where septic tanks cannot be used because of the need of high BOD removal.

6.2 Environmental Sensors:

MFCs can be used as convenient biosensor for the waste water stream to power devices particularly in river and deep-water environments where it is difficult to routinely access the system for replacement of the batteries. The sediment fuel cells are developed for monitoring environmental systems such as ocean and rivers.

6.3 Bioremediation:

In bioremediation system the MFC is not used to produce electricity instead of that its power can be put into the system for desired reactions to remove or degrade chemicals like converting soluble U (VI) to insoluble U (VI). In this the bacteria not only donate electrons to an anode but also accept electrons from cathode. The uranium is precipitated onto a cathode due to bacterial reduction by poising the electrodes at -500mV, [17] when electrodes use as electron donors then nitrate can be converted to nitrite [18].

6.4 Hydrogen Production:

By the removal of oxygen at the cathode and adding it in a small voltage via bioelectrochemically assisted microbial reactor (BEAMR) process or the biocatalyzed electrolysis process the MFCs can be modified for the production of hydrogen gas(H_2).

7. Conclusion:

MFCs are evolving to become robust and simple technology for renewable energy production. The study of MFCs documents the feasibility of bioelectricity generation from waste water treatment with anode materials without any toxic mediators. This biological process is not very time consuming. They are useful in specialized applications as BOD sensing, powering underwater monitoring devices, hydrogen production, wastewater treatment, remote sensors, environmental bioremediation etc. The observed COD removal efficiency in anode chamber enumerates the functioning of MFCs as wastewater treatment unit in addition to renewable energy generation. These procedures are cost effective and environmentally sound and sustainable by the use of wastewater as substrate. Microbial fuel cell technology may qualify as a new core technology for the conversion of carbohydrates to electricity in years to come. The diverse range of bacteria is able to function and persists in an MFC to truly fascinate occurrence and understanding the knowledge of microbial ecology of biofilm and bacteria. [19, 20]

Conflict of interest

There is no conflict of interest concerning this paper.

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