Designing the Shape of Graphite Anode for Microbial Fuel Cells to Increase its Efficiency

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Abstract - *Microbial fuel cell (MFC) technology has the potential to become a renewable energy resource by degrading organic pollutants in the wastewater. The performance of MFC depends on kinetics of electrode reactions within the cell. The design of the electrode has a major role in improving the working of the microbial fuel cells. The electrode is designed in such a way that it increases the surface area of the electrode as well as decreases the amount of materials used for the electrode hence reducing the cost of operation and making it a cheaper method than the previous models.*

Key Words: Microbial fuel cells, Anode, Cathode, Graphite

1. INTRODUCTION

A microbial fuel cell (MFC), or biological fuel cell, is a bio-electrochemical cell that drives an electric current. This current is derived by utilizing bacteria. MFCs can be differentiated into two categories: mediated and unmediated. The first MFCs were developed in the early 20th century which is used as mediator. Unmediated MFCs developed in the year 1970s. In this MFC the bacteria have cytochromes on their outer membrane which are electrochemically active redox proteins and can transfer electrons directly to the anode. In the 21st century MFCs used commercially for wastewater treatment.

A microbial fuel cell (MFC) is a device that converts chemical energy into electrical energy by the microbial action. These cells are constructed using bio-anode and/or a bio-cathode. A membrane is present in most of the MFCs that separates the compartments of the anode (where oxidation takes place) and the cathode (where reduction takes place). The electrons produced in MFC during oxidation are transferred directly to a redox mediator species. The electron flux is moved to cathode and the charge balance of the cell is compensated by ionic movement inside the cell, usually across an ionic membrane. Most MFCs uses an organic electron donor that is oxidised to produce CO_2, protons and electrons. In the cathode reaction, it uses various electron acceptors that influence the reduction of oxygen. However, other electron acceptors, including metal recovery by reduction, water to hydrogen, nitrate reduction and sulphate reduction.

Reactions of MFC:

At Anode:

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

At Cathode:

$4H^+ + O_2 + 4e^- \rightarrow 2H_2O$

2. WASTEWATER TREATMENT

MFCs are used in waste water treatment to generate energy utilizing anaerobic digestion. This process will also reduce pathogens. However, it requires temperature of above 30^0C and requires an extra process to convert biogas into electricity. Spiral spacers are used to increase electricity generation by forming helical flow in MFC.

3. ELECTRODE MATERIAL AND DESIGN

The selection of suitable electrode material is a crucial for the performance of MFCs in terms of bacterial adhesion, electron transfer and electrochemical efficiency. There are methods to increase the power production using various carbon-based materials such as carbon paper, carbon felt, carbon fiber as well as carbon nanotube-based composites. To apply the MFC technology in practice, the material cost should be reduced and should maximize the power densities. The cathode materials should have catalytic properties for oxygen reduction.

Although the criteria's to select materials in MFC for the anode and cathode are different, in general both anode and cathode should possess the following properties:

- <u>Surface area and porosity:</u>

The output power of MFCs is influenced by the surface area of electrodes. The Ohmic losses are directly proportional to the resistance of electrode. The easiest way to reduce the resistance is to increase the surface area by keeping the volume same, and thus increases the efficiency of MFC. Further, a high surface area provides more sites for reactions and enhancing electrode kinetics in MFC. However, porosity will decrease the electrical conductivity of the material.

- Electrical conductivity:

In MFC the electrons which are released from microbes will travel in the external circuit after passing through the anode. The electrode material with high electrical conductivity makes the electron flow with less resistance. In same time, the interfacial impedance should be low to facilitate the electron transfer. At the cathode, the ionic conductivity is also required to facilitate triple phase boundary reaction.

- Stability and durability:

The reduction and oxidation environment in an MFC may lead to the swelling and decomposition of the materials. The high surface roughness in electrode increases the durability of the electrode material but there are chances in the increase in fouling, thus performance of the MFC gets decreased. Therefore, the materials used as electrodes in MFCs should be durable as well as stable in both acidic and basic environment.

- Cost and accessibility:

The electrode material cost influences the cost of MFC to a great extent. To make the MFC commercialize, the material should be cost effective, sustainable and easily available. Some metals like platinum are highly expensive, non-durable and non-sustainable as well. Non-precious metal materials such as composites might be an alternative to substitute precious metals in electrodes in the future. In addition, materials should have biocompatible properties which are used for anode in MFCs. These superior biocompatible material will improve the bacterial adhesion and hence the life of the MFC also increases.

4. ANODE MATERIAL

The anode material significantly impacts the biofilm formation and the electron transfer between the microorganism and the electron acceptor. Various materials which are used in an MFC are carbon rods, carbon cloth, carbon fiber, stainless steel mesh are summarized in the following sections.

4.1 Conventional carbon-based materials

Carbonaceous materials such as carbon cloth, carbon paper, carbon felt graphite rods, graphite brushes, and reticulated vitreous carbon are widely used as anodes in MFCs. These materials have high electrical conductivity, specific surface area, biocompatibility, chemical stability and low cost. Different electrode materials used as anodes.

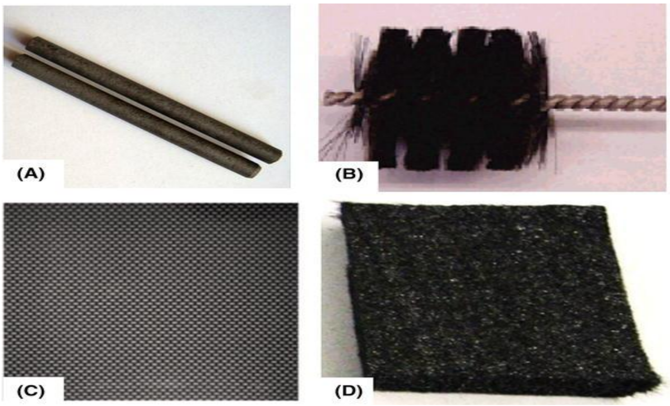

Fig -1: (A) Typical graphite rod electrode, (B) carbon fibre brush electrode, (C) carbon cloth electrode, (D) carbon felt electrode

5. FACTORS AFFECTING THE ANODE

Resistance

Thickness:
If we give input energy in the form of heat or radiation we need to have more electrons density of the metal, but as the microbes act as the source of electrons the thickness may not effect the conductivity of the metal.

Length:
Resistance is directly proportional to the distance of the path (length) in which the electrons travel. Hence, wires are placed at different locations such that it reduces the distance to travel by the electrons hence reduces resistivity of the metal.

$$\mathbf{R = (constant). L/A}$$

Efficiency:
As the anode surface area increases to double times the normal surface area the generation of current from an MFC should also be increased to double (theoretically).

6. EFFECT OF ELECTRODE PROPERTIES ON ELECTROCHEMICAL REACTIONS

The rate of a basic electrochemical reaction on a bare electrode (i.e. without a catalyst) will be influenced by the electron transfer kinetics between the target compound and the electrode. Some electrode materials are able to catalyze reactions and reduce the activation resistance for transfer of electrons while most increase performance by increasing the total available reactive surface area. In MFCs, carbon-based electrodes are often used and performance enhancements have been largely attributed to the increase in surface area (e.g. carbon nanotubes, graphene). As for conductivity, it is largely determined by the density of the material. The conductivity of an electrode is a function of areal wt (i.e. mass/geometric area) so that a larger areal weight will increase the conductivity of the electrode and reduce the ohmic resistance.

7. EFFECTS OF ELECTRODE MATERIALS

Electrodes play a very crucial role in the efficiency of an MFC. In fact, the electrons produced by bacteria are transferred on the anode surface and on the cathode surface and an electrochemical reduction reaction takes place. Hence, the electrode surface is very important in the overall performance of an MFC. The higher electrode surface area enhances the performance of MFCs. Electrode materials commonly used as anode and cathode includes graphite, carbon paper and carbon cloth.

Many studies focus on the fabrication of electrode materials to improve MFCs performance. The very poor performance of the currently working MFCs for large-scale application gives low efficiency of electricity generation which is caused by the limited surface area of electrodes (Qiao et al., 2007). Progresses in nanotechnology and nanomaterial sciences have brought evolutionary developments in the MFC technology. This is ascribed to the fact that materials exhibit different and unique properties at nano-scale in comparison with their macro-scale forms (Klabunde and Richards, 2009).

The low performance of MFCs leads to the low velocity of the electron transfer and low conductivity process caused by the high electrical resistance of conventional electrode materials. Various microorganisms are used in the anode chamber includes pure or mixed cultures (Logan, 2009).

8. APPLICATIONS OF MFC

Electrochemically active biofilm has potential applications in production of bioelectricity, biogas, platform chemicals, etc. along with bioremediation and biosensor design.

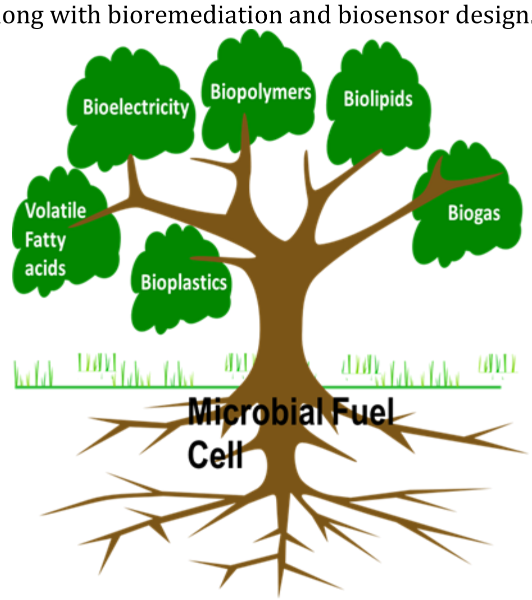

Fig -2: Applications of MFC

- <u>Bioelectricity</u>

The best known application of microbial fuel cell is to generate electricity by oxidizing biodegradable organic matter in the presence of microorganisms as a biocatalyst in fuel cell type setup.

- <u>Biogas</u>

In MECs, the organic substrates, such as complex mixtures of biomass including municipal, animal wastewater, etc. can be utilized by electroactive microorganisms for production of biohydrogen and biomethane. Biological hydrogen production is considered as an attractive option in the frame of renewable and sustainable technologies. Exploitation of wastewater as a substrate for production of H_2 with simultaneous wastewater treatment is an effective and attractive way of tapping clean energy from renewable resource in a sustainable approach. This provides dual environmental advantages in the wastewater reduction from raw material and reduction of pollution from product (H_2) utilization.

- <u>Bio-Lipids</u>

The scarcity of the fossil fuel reserves in the globe encourages attentive investigation and development of eco-friendly & renewable energy alternatives to fulfill the growing energy demands. Biodiesel is the most promising alternative to the fossil fuels since its production is sustainable, non-toxic and energy efficient. Many oleaginous microorganisms belongs to the genera of fungi, yeast, bacteria and microalgae can accumulate lipids more than 20% of dry biomass especially triacylglycerols (TAGs), which are the main materials for biodiesel production sometimes up to an extent of 70% of their biomass weight under specific cultivation conditions (Ratledge. 1989; Sheehan et al., 1998). Therefore, biogenic waste can be considered as a potential feedstock for biodiesel production in bio-refinery.

- <u>Platform chemicals</u>

During the oxidation of organic materials in the wastewater, electrochemically active biofilm (EAB) transfer the electrons to the anode which flows to the cathode, where it can be used for the production of valuable products. The EAB formed on the anode electrode can produce bioplastics (polyhydroxybutyrate (PHB), polyhydroxyalkanoates (PHA)), short chain carboxylic acids (VFA - C2-C6), biosolvents (alcohols), amino acids and lactic acids from organic substrates. Production of polyhydroxyalkanoates (PHA) was reported at the cathode under microaerophilic conditions

- <u>Biopolymers</u>

The ease of synthesis, flexibility and durability of synthetic plastics has made them one of the most used materials in a variety of industrial and day-to-day domestic applications (Puyol et al., 2017). On the other hand, economic and environmental need exists for the development of sustainable renewable based biobased polymers (Amulya et al., 2015). These biobased polymers have gained momentum not only due to their biodegradability but also due to their thermoplastic properties that are similar to petroleum derived plastics (Reddy et al., 2013). Polyhydroxyalkanoates (PHAs) are group of biopolymers synthesized by various prokaryotic microorganisms as energy and carbon reserve materials in response to nutrient limiting or stressful conditions (Reddy et al., 2014). Taking into account, the abundance, diversity and lack of proper treatment approach, use of wastewater for PHA production is propitious approach, which provides dual benefits of waste remediation with simultaneous value addition.

9. FUTURE PROSPECTS

In View of the above observations a new structure was designed with practical assumptions by using various Computer Aided Design tools which has an increased surface area theoretically and decreasing the quantity of the material used hence decreasing the cost effectiveness of the electrode.

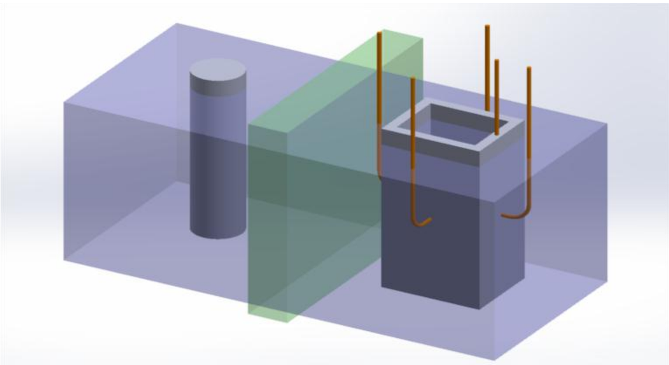

Fig -3: Assumptions of the MFC chamber with new design of the anode

10. CONCLUSION

- Efficiency of the MFC increases.
- If the surface area increases it will be able to generate more amount of current.
- As the surface area is increased more amount of biofilms forms on the surface and more amount of wastewater gets treated at a time hence increasing the efficiency to treat more waste water in less time.
- From the design by using less amount of graphite we can reduce the cost of operation.
- It is economic by using less amount of graphite.

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