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Development of electrodes for use in Microbial Fuel Cells for wastewater treatment and power generation

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ABSTRACT

At the pace technology and population are rising, an energy crisis is a self-fulfilling prophecy. To comply with these energy demands, millions of tonnes of fossil fuels are being exhausted while simultaneously degrading the environment. The solution to these problems is the use of renewable energy sources amongst which Microbial Fuel Cells are an emerging field of study. A Microbial Fuel Cell (MFC) is a device that converts organic matter to electricity using microorganisms such as bacteria as the biocatalyst. The objective of the study was to develop electrodes for Microbial Fuel Cells and test the voltage produced by it and to test the reduction in Chemical Oxygen Demand (COD) in waste water sample. A single step Phase Inversion Technique of PVDF is used for electrode fabrication because it enables electrode preparation at room temperature, without the need for additional heat treatment. Usage of MFCs offers the dual benefit of power generation and wastewater treatment. Upon development, MFCs can find application in the form of biosensors in regions where battery replacement is difficult.

Keywords: Microbial Fuel Cells, COD, Power generation, Wastewater treatment.

1. INTRODUCTION

Microbial Fuel Cells (MFC) are devices that can be used to produce electricity using microbes to break down organic matter. Commonly, MFCs are dual chambered where the chambers are separated by a membrane. In an MFC, electricity is generated from the anaerobic oxidation of organic matter by bacteria. There are three ways by which microorganisms can transfer electrons to the anode: using exogenous mediators, using mediators produced by the bacteria, or by direct transfer of electrons from respiratory enzymes (i.e., cytochromes) to the electrode [1]. The fundamental requirements for an electrode include a high surface area, porosity, strength, toughness, high electrical conductivity. Apart from these physical characteristics, it needs to have stability under operating conditions. Since MFCs deal with a microbial environment, the electrode material should also be biocompatible.

2. LITERATURE REVIEW

The defining characteristic of an MFC involves microbial catalyzed electron liberation at the anode and subsequent consumption of the electron at the cathode. MFCs are being constructed using variety of materials, and in an ever increasing assortment of configurations. Microbial Fuel Cells are being studied for bioelectricity generation. Performance of MFCs is mainly influenced by several factors such as supply and consumption of oxygen in cathode chamber, oxidation of substrates in anode chamber, electron shuttle from anode compartment to anode surface, and permeability of the Proton exchange membrane (PEM)[2].

A review of the substrates used in Microbial Fuel Cells compiled an extensive list of the different substrates that have been worked with. Different waste water samples were listed including lignocellulosic biomass, synthetic wastewater, brewery wastewater, starch processing wastewater, dye waste water, landfill leachates, cellulose and chitin. The ability of the bacteria to oxidize a substrate and transfer the electrons liberated from this oxidation to the cathode is found to have a direct influence on the amount of current produced. The complexity of the substrate appears to be related to the maximum power density [3].

Electrochemical optimization of anode can occur through enlargement of the specific electrode surface, or the insertion of redox mediators in either the electrode or in the feeding solution. [4]. A study on composite materials for polymer electrolyte MFCs compiled a list of different composites that can be used as electrode material. A study on enhancement of performance and capacitance behavior of an anode suggested that adding Fe3O4 into the anode improved the performance of Microbial Fuel Cells (MFCs) [5]. We took upon ourselves to try different combinations involving PbO2, MnO2, activated carbon and TiO2 for the cathode and graphite powder and Fe3O4 in various proportions for the anode [6]. A single step fabrication method using phase inversion process of polyvinylidene fluoride (PVDF) was studied. It describes a process that enables cathode preparation at room temperatures, without the need for additional heat treatment. [7]. Another such study on MFCs to convert carbohydrates to electricity was conducted on three sources of carbohydrates: an artificially prepared glucose solution, a plant extract and an artificial wastewater solution. This study has demonstrated that continuous Microbial Fuel Cells yield much lower power outputs when compared to batch systems. It was also observed that up to 50% of the COD present in the influent was removed as electricity[8]. Hence, studies were planned in a batch setup to ensure maximum power generation accompanied with COD removal.

E. coli was chosen due to the results of preliminary studies on E. coli microbial fuel cell and on electrode taming of the biocatalyst. A mediator Microbial Fuel Cell (MFC) was constructed by using E. coli as biocatalyst and new methylene blue as the electron mediator. The capabilities of the MFC were even better than those reported in the literature so far for E. coli MFCs [9].

3. METHOD

3.1. Cathode fabrication

The cathode was fabricated using the phase inversion technique. 15 g of PVDF was dissolved in 90 ml of N,NDimethylacetamide with constant stirring for 4 hours using a magnetic stirrer. Two batches of catalyst mixtures were prepared. For the first batch, lead dioxide, manganese dioxide and graphite were weighed in the ratio of 4:2:2 and mixed. To this 15 ml of the PVDF-DMA solution was added and thoroughly mixed. The catalyst-binder paste was coated on stainless steel mesh of dimensions 4 cm x 7 cm and then dipped in distilled water for 30 minutes. The cathode was left to dry for 24 hours. For the second batch of cathodes, titanium dioxide, manganese dioxide and activated carbon were mixed in the ratio of 2:1:1 and were used as catalysts.

3.2. Anode fabrication

The anode was also fabricated using the phase inversion technique. 15 g of PVDF was dissolved in 90 ml of N,N Dimethylacetamide with constant stirring for 4 hours using a magnetic stirrer. Graphite and magnetite (Fe3O4) were mixed in the ratio of 4:2 and used as catalyts. To this 15 ml of the PVDF-DMA solution was added and thoroughly mixed. The catalyst-binder paste was coated on stainless steel mesh of dimensions 4 cm x 7 cm and then dipped in distilled water for 30 minutes. The anode was left to dry for 24 hours. An aluminium sheet of dimensions 4 cm x 7 cm was also used as anode and studied.

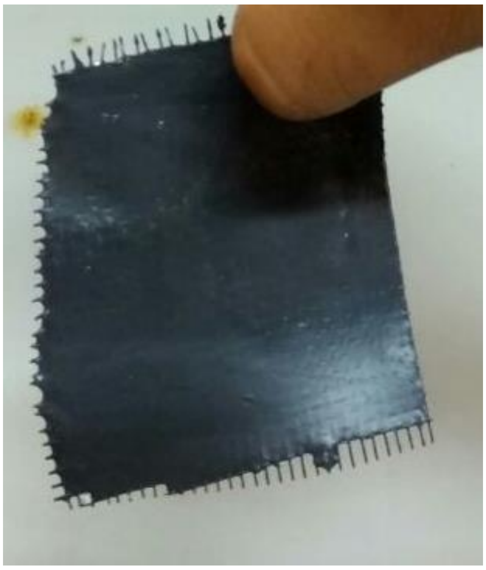

Fig. 3.3.1: Cathode after fabrication using phase inversion

3.3. Experimental procedure

The two half cells were cleaned thoroughly and connected to each other, with a Nafion-117 membrane separating the contents of the 2 cells. The setup was tested for leaks. The cathode chamber was filled with 400 mL of distilled water and the anode chamber was filled with 400 mL of the wastewater sample. E. coli was inoculated into the anode chamber. The electrodes were dipped into their respective chambers and the electrical connections were made.

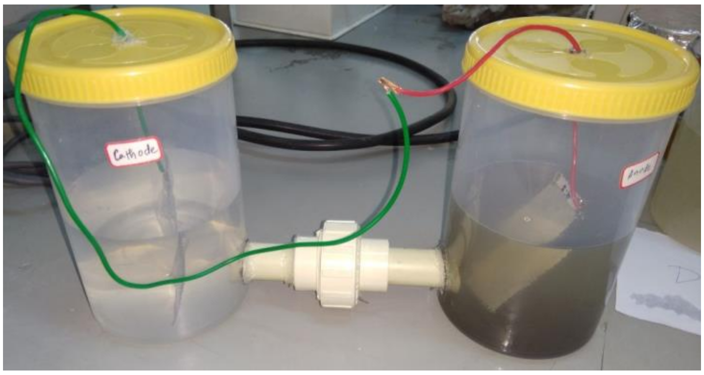

Fig. 3.3.3: Experimental setup under study

The bacteria were given 5 hours to grow in the anode chamber and then the potential difference produced is measured periodically and the results were tabulated.

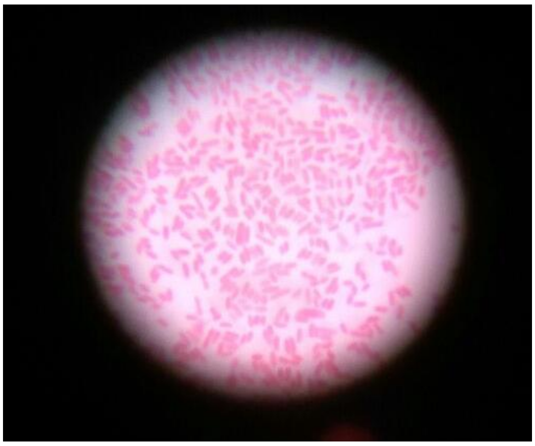

Fig. 3.3.2: Gram staining of microbial culture to confirm the presence of E. coli

The reduction in the chemical oxygen demand (COD) was measured. The procedure was repeated for different combinations of the anode and cathode.

3.4. Analysis

The potential difference offered by the cell was measured and tabulated. To analyze the extent of wastewater treatment, the reduction in the chemical oxygen demand (COD) was measured.

4. RESULTS AND DISCUSSION

4.1 Mapping of voltage readings

Table 4.1: Voltage readings of different catalyst combinations

Batch 1 **Cathode: G:PbO_2:MnO_2** **Anode: Aluminium**		**Batch 2** **Cathode: G:PbO_2:MnO_2** **Anode: Aluminium (sparged)**		**Batch 3** **Cathode: G:PbO_2:MnO_2** **Anode: Graphite:Fe_3O_4**		**Batch 4** **Cathode: AC:TiO_2:MnO_2** **Anode: Aluminium**	
Time (h)	Voltage (mV)	Time (h)	Voltage (mV)	Time (h)	Voltage (mV)	Time (h)	Voltage (mV)
0	732	0	1030	0	220	0	180
1	705	25.3	1070	0.75	265	0.75	130
2	680	71.5	1420	18	392	18	147
3	645	77.5	1348	25	426	25	163
4	740	78.5	1275	42.5	614	42.5	324
5	765	96.5	1170	47.5	653	47.5	490
6	770	124.5	1006	67	689	67	584
7	792	169.5	953	73	680	73	593

8	840	92.5	497	92.5	485
9	680	96	460	96	436
16	582	117.5	403	117.5	368
17	990	121.5	387	121.5	346
20	1000				
26.5	910				
44.5	940				
50.5	1011				
72.5	930				
188	640				
214	440				

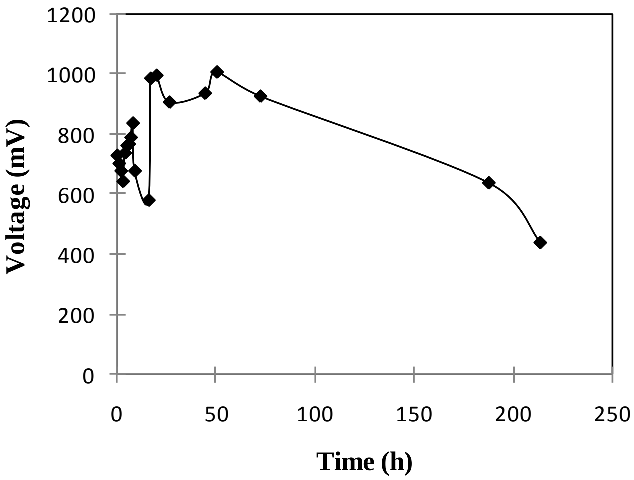

Fig. 4.1: Voltage map of Batch 1

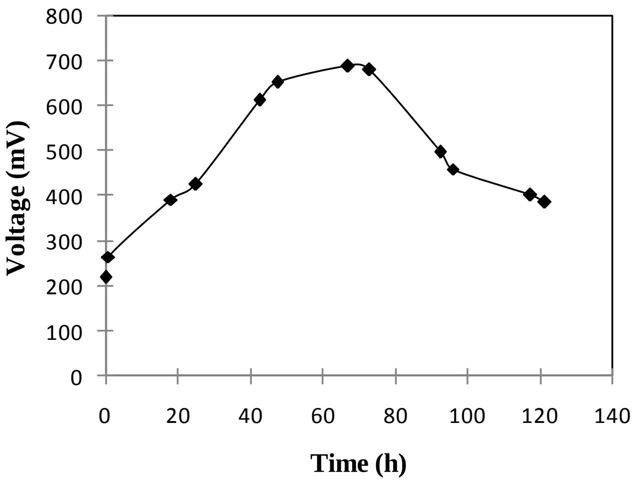

Fig. 4.2: Voltage map of Batch 2

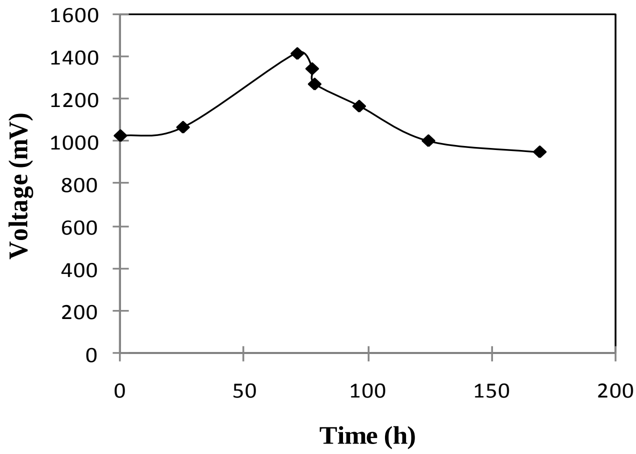

Fig. 4.3: Voltage map of Batch 3

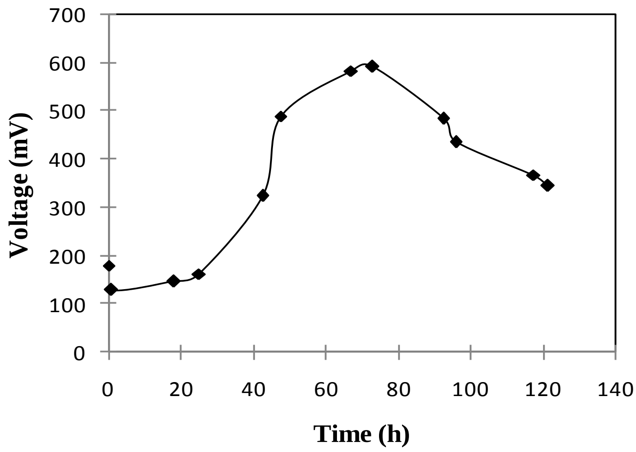

Fig. 4.4: Voltage map of Batch 4

This study developed and tested electrodes to be used in Microbial Fuel Cells utilizing E. coli as the biocatalyst. The results obtained using Lead Dioxide catalyst in the cathode was found to be better than those obtained using Titanium Dioxide. For the anode, Aluminum was found to produce better results compared to the Graphite-Magnetite electrode.

4.2 Reduction in Chemical Oxygen Demand

Table 4.2: Tabulation of maximum voltage obtained and the extent of COD reduction

	Batch 1 Cathode: G:PbO_2:MnO_2 Anode: Aluminium	**Batch 2 Cathode: G:PbO_2:MnO_2 Anode: Aluminium (sparged)**	**Batch 3 Cathode: G:PbO_2:MnO_2 Anode: Graphite:Fe_3O_4**	**Batch 4 Cathode: AC:TiO_2:MnO_2 Anode: Aluminium**
Maximum Voltage (mV)	1011	1420	681	593
COD reduction (%)	66.7	80.02	20.01	40.07

5. CONCLUSION

A Microbial Fuel Cell is a device which converts chemical energy, i.e., the organic matter into electrical energy by using microorganisms as a biocatalyst. Microbial Fuels Cells, today, have a lot of potential applications in various fields. This study was conducted to find and test different combinations or electrodes and measure the potential developed by them. Furthermore, this study tested the reduction in COD of the waste water after being used to produce current.

The findings of the study show at there is current being produced and there is a reduction in the COD of the sample. The current produced is dependent on the combination of catalysts added, i.e., the current depends on the electrodes being used. The study also shows that COD of waste water can indeed be reduced simultaneously with the production of current.

Technologies that utilize microbial metabolisms to break down organic matter in order to produce electrical current could be a promising solution for both power generation and waste management in the future. Our sewage could be our future source of energy. For this to happen, lots of research, time and effort are to be concentrated on MFC technology.

Future work could involve finding with a combination of new electrodes or finding the right bacteria or group of microorganisms that will increase the voltage developed and decrease the COD further or decreasing the resistance offered by the membrane by developing alternative membranes.

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