Design Fabrication & Testing of Microbial Fuel Cell

Mr. Amarjit Maurya[1] Mr. Indresh Kumar[2] Mr. Prashant Singh[3] Mr. Qazi Haidar Ali[4] Mr.Vishwanath Gangwar [5]
[1,2,3,4,5]U.G Student
[1,2,3,4,5]Department of Chemical Engineering
[1,2,3,4,5]BBDNITM, Lucknow

Abstract— In an era of climate change, alternate energy source are desired to replace oil and carbon resources. Subsequently, climate change effect in some areas and the increasing production of bio fuels are also putting pressure on available water resources. Microbial fuel cell have the potential to simultaneously treat waste water for re use and to generate electricity, thereby producing to increasingly scarce resources. While the microbial fuel cell has generated interest in the waste water treatment field, knowledge is still limited and many fundamental and technical problem remain to be solved microbial fuel cell technology represent in new form of renewable energy by generating electricity from what would otherwise we considered waste, such as industrial waste or waste water etc..

Key words: Microbial fuel cell; anaerobic anode; aerobic cathode; bacteria; bioelectricity; chemical oxygen demand; biological oxygen demand; waste water; membrane

I. Introduction

A microbial fuel cell (MFC) or biological fuel cell is a bio-electrochemical system that drives a current by using bacteria and mimicking bacterial interactions found in nature. Microbial fuel cells can be grouped into two general categories, those that use a mediator and those that are mediatorless. The first microbial fuel cells, demonstrated in the early 20th century, used a mediator: a chemical that transfers electrons from the bacteria in the cell to the anode. Mediatorless microbial fuel cell s are a more recent development dating to the 1970s in this type of microbial fuel cell the bacteria typically have electrochemically active redox proteins such as cytochromes on their outer membrane that can transfer electrons directly to the anode. Since the turn of the 21st century microbial fuel cell s have started to find a commercial use in the treatment of wastewater.

Microorganisms catabolize compounds such as glucose, acetate or wastewater . It is a device that converts chemical energy to electrical energy by the catalytic reaction of microorganisms . A typical microbial fuel cell consists of anode and cathode compartments.

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

A. By KIM in 2008

KIM prepared cobalt naphthalocyanine by heat treatment for cathode catalyst to be used in MFC. Four different catalyst (carbon black, NPc/C, CoNPc/C, Pt/C) were compared and characterized using XPS, EDAX and TEM. the maximum power of CoNPc/C 64.7 mW/m^2 at 0.25 mA as compared with 81.3 mW/m^2 of Pt/C.

B. By XIE in 2010

Xie implemented a couple MFC system comprising of an oxic-bio cathode MFC (O-MFC) (and an anoxic bio cathode (A-MFC) For simultaneously removal of carbon and nitrogen from a synthetic waste water . Ammonium was oxidised to nitrate in (O-MFC) at cathode and nitrate was electrochemically denitrified in the A- MFC.

II. Designing, Fabrication & Testing of MFC

A. Two chamber Microbial Fuel Cell

This is the most widely used design consisting of two chambers with the anode and cathode compartments separated by an ion exchange membrane. This design is generally used in basic research and literature suggests that the power output from these systems are generally low due to their complex design, high internal resistance and electrode based losses.

B. Single chamber Microbial Fuel Cell

This design has only one compartment that contains both the anode and the cathode. The anode is either placed away or close to the cathode separated by proton exchange membrane. Liang et al. (2007) reported that if the anode is closer to the cathode, it reduces internal ohmic resistance by avoiding the use of catholyte as a result of combining two chambers and thus increases the power density. Compared to the two chamber MFC, it offers simple, cost effective design and produces power in a more efficient way. However, in the membrane-less configuration, microbial contamination and back diffusion of oxygen from cathode to anode without proton exchange membrane are the major drawbacks.

C. MFC Test

MFC tests were conducted using a single chamber device constructed as previously described (fig.10), and operated with a 1000 X external resistor except as noted. MFCs were inoculated with domestic wastewater (pH of 7.3–7.6), chemical oxygen demand (COD of 200–300 mg/L) collected from the primary clarifier overflow at the Pennsylvania State University Wastewater Treatment Plant. The wastewater was replaced 3–5 times (i.e., over 72–120 h) to allow a bio- film to form on the anode surface, before the solution was switched to a solution containing glucose (500 mg/L) and a phosphate buffered nutrient medium (PBM) containing: NH_4Cl (0.31 g/L); NaH_2PO_4 & H2O (4.97 g/L); Na_2HPO_4 & H2O (2.75 g/L); KCl (0.13 g/L), and a metal (12.5 mL) and vitamin (12.5 mL) solution. The chamber was refilled each time the voltage decreased to less than 20 mV forming one complete cycle of operation. Polarization curves were used to obtain the maximum power density by varying the external resistance using a resistor box (RS-500, Elenco Electronics). All tests were conducted in a 30°C temperature-controlled room.

III. MATERIALS USED IN MICROBIAL FUEL CELLS

A. Chambers

Chambers are the plastic containers which is used for the materials storage like sludge and distilled water. In the two chambered microbial fuel cell, one acts as an anodic chamber and other as a cathodic chamber. In anodic chamber we use distilled water in which proper oxygen is supplied by air pump and in cathodic chamber we use the sludge in which all the microbes are present. An microbial fuel cells chamber should be a cylinder. Current microbial fuel cells chambers are custom-made machined cylinders with end caps. The substitute was a 2″ PVC pipe that purchased for $0.50.

B. Anode

Anodic materials must be conductive, biocompatible, and chemically stable in the reactor solution. Metal anodes consisting of non corrosive stainless steel mesh can be utilized , but copper is not useful due to the toxicity of even trace copper ions to bacteria. The most versatile electrode material is carbon, available as compact graphite plates, rods, or granules, as fibrous material (felt, cloth, paper, fibers, foam), and as glassy carbon. There are numerous carbon suppliers worldwide, for example ETEK and Electrosynthesis Co. Inc. (USA), GEE Graphite Limited, Dewsbury (UK), Morgan, Grimbergen (Belgium), and Alfa-Aesar (Germany). The simplest materials for anode electrodes are graphite plates or rods as they are relatively inexpensive, easy to handle, and have a defined surface area. Much larger surface areas are achieved with graphite felt electrodes which can have high surface areas (0.47 $m^2 g^{-1}$, GF series, GEE Graphite limited, Dewsbury, UK). However, not all the indicated surface area will necessarily be available to bacteria. Carbon fiber, paper, foam, and cloth (Toray) have been extensively used as electrodes.

C. Cathode

Due to its good performance, ferricyanide ($K_3[Fe(CN)_6]$) is very popular as an experimental electron acceptor in microbial fuel cells. The greatest advantage of ferricyanide is the low over potential using a plain carbon cathode, resulting in a cathode working potential close to its open circuit potential. The greatest disadvantage, however, is the insufficient reoxidation by oxygen, which requires the catholyte to be regularly replaced. In addition, the long term performance of the system can be affected by diffusion of ferricyanide across the CEM and into the anode chamber. Oxygen is the most suitable electron acceptor for an Microbial Fuel Cells due to its high oxidation potential, availability, low cost (it is free), sustainability, and the lack of a chemical waste product (water is formed as the only end product). The choice of the cathode material greatly affects performance, and is varied based on application. For sediment fuel cells, plain graphite disk electrodes immersed in the seawater above the sediment have been used.

D. Electrodes

The choice of electrode material affects the performance of microbial fuel cells. Various materials have been investigated as electrodes to increase the performance and power output of the microbial fuel cells. For anode, carbon cloth, carbon felt, graphite felt, carbon mesh and graphite fiber brush are frequently used due to their stability, high electric conductivity and large surface area. For cathodes, platinum (Pt), platinum black, activated carbon (AC), graphite based cathodes and biocathodes are used. Though platinum coated electrodes are more efficient and superior in power production due to higher catalytic activity with oxygen than other electrodes, they are not cost effective Alternate catalysts for platinum include ferric iron, manganese oxides, iron and cobalt based compounds. Ferricyanide (K3(Fe(CN)6) is frequently used as an electron acceptor in the microbial fuel cells due to its good performance and low over potential Biocathodes increases the power by decreasing the over potential.

E. Air Pump

An air pump is a device which is used for pumping air. Here it is used for the supply of oxygen in the cathodic chamber i.e. in the distilled water chamber for the better acceptance of hydrogen ion generated in the anodic chamber.

F. Salt Bridge

A salt bridge, in electrochemistry, is a laboratory device used to connect the oxidation and reduction half cells of a galvanic cell (voltaic cell), a type of electrochemical cells. It maintains electrical neutrality within the internal circuit, preventing the cell from rapidly running its reaction to equilibrium. If no salt bridge were present, the solution in one half cell would accumulate negative charge and the solution in the other half cell would accumulate positive charge as the reaction proceeded, quickly preventing further reaction, and hence production of electricity.

IV. ANALYSIS OF MICROBIAL FUEL CELLS

A. Fundamentals of Voltage Generation in MFCs

Thermodynamics and the Electromotive Force. Electricity is generated in an MFC only if the overall reaction is thermodynamically favorable. The reaction can be evaluated in terms of Gibbs free energy expressed in units of Joules (J), which is a measure of the maximal work that can be derived from the reaction , calculated as

$$\Delta G_r = \Delta G_r^{\circ} + \mathrm{RTln}(\Pi) \text{ ---------- (1)}$$

where ΔGr (J) is the Gibbs free energy for the specific conditions, ΔGr° (J) is the Gibbs free energy under standard conditions usually defined as 298.15 K, 1 bar pressure, and 1 M concentration for all species, *R* (8.31447 J mol^{-1} K^{-1}) is the universal gas constant, *T* (K) is the absolute temperature, and Π (unit less) is the reaction quotient calculated as the activities of the products divided by those of the reactants. The standard reaction Gibbs free energy is calculated from tabulated energies of formation for organic compounds in water, available from many sources .

For MFC calculations, it is more convenient to evaluate the reaction in terms of the overall cell electromotive force (emf), *E*emf (V), defined as the potential difference between the cathode and anode. This is related to the work, *W* (J), produced by the cell, or

$$W = E_{emf} Q = -\Delta G_r \text{ ----------(2)}$$

Where (Q) nF is the charge transferred in the reaction, expressed in Coulomb (C), which is determined by the number of electrons exchanged in the reaction, n is the number of electrons per reaction mol, and F is Faraday's

constant (9.64853 × 10^4 C/mol). Combining these two equations, we have

$$E_{emf} = -\frac{\Delta G_r}{nF} \text{ ---------- (3)}$$

If all reactions are evaluated at standard conditions, Π = 1, then

$$E^{\circ}_{emf} = -\frac{\Delta G^{\circ}_r}{nF} \text{ ----------(4)}$$

where E_{emf} (V) is the standard cell electromotive force. We can therefore use the above equations to express the overall reaction in terms of the potentials as

$$E_{emf} = E^{\circ}_{emf} - \frac{RT\ln(\Pi)}{nF} \text{ ----------(5)}$$

The advantage of eq (5) is that it is positive for a favorable reaction, and directly produces value of the emf for the reaction. This calculated emf provides an upper limit for the cell voltage; the actual potential derived from the MFC will be lower due to various potential losses.

B. Standard Electrode Potential

The reactions occurring in the MFC can be analyzed in terms of the halfcell reactions, or the separate reactions occurring at the anode and the cathode. According to the IUPAC convention, standard potentials (at 298 K, 1 bar, 1 M) are reported as a reduction potential, i.e., the reaction is written as consuming electrons. For example, if acetate is oxidized by bacteria at the anode we write the reaction as

$$2HCO_3^- + 9H^+ + 8e^- \text{ ----►} CH_3COO^- + 4H_2O \text{ --- (6)}$$

The standard potentials are reported relative to the normal hydrogen electrode (NHE), which has a potential of zero at standard conditions (298 K, pH 2) 1 bar, [H^+]) 1 M). To obtain the theoretical anode potential, E_{An}, under specific conditions, we use eq (5), with the activities of the different species assumed to be equal to their concentrations. For acetate oxidation, we therefore have

$$E_{An} = E^{\circ}_{An} - \frac{RT}{8F}\ln\left(\frac{[CH_3COO^-]}{[HCO_3^-]^2\,[H^+]^9}\right) \text{ ---------- (7)}$$

For the theoretical cathode potential, *E*cat, if we consider the case where oxygen is used as the electron acceptor for the reaction, we can write

$$O_2 + 4H^+ + 4e^- \text{ ----------►} 2H_2O \text{ ---------- (8)}$$

$$E_{cat} = E^{\circ}_{cat} - \frac{RT}{4F}\ln\left(\frac{1}{pO_2[H^+]^4}\right) \text{ ---------- (9)}$$

The cell emf is calculated as

$$E_{emf} = E_{cat} - E_{An} \text{ ---------- (10)}$$

Bio-wastes	Day 1	Day 2	Day 3	Day 4	Day 5
cow dung (250 gm)	147	139	128	116	103
drain water (400 ml)	141	135	125	113	101
rice washing water (400 ml)	137	129	118	104	98
cow dung (250 gm) and slurry (5 gm)	189	172	153	138	117
drain water (400 ml) and slurry (5 gm)	185	171	150	134	120
rice washing water (400 ml) and slurry (5 gm)	190	179	161	145	123
cow dung (250 gm) and vermicompost (2 gm)	159	145	136	123	111
drain water (400 ml), slurry (5 gm) and vermicompost (2 gm)	147	138	126	117	109
rice washing water (400 ml), slurry (5 gm) and vermicompost (2 gm)	151	143	136	122	107
slurry (250 gm)	197	181	169	145	133
slurry (250 gm) and vermicompost (2 gm)	192	174	152	143	129

Table 1: Total voltage generation with differents feed

V. RESULTS AND DISCUSSION

A. Results and Discussion

The single and double chambered MFC were run parallel. The whole study was conducted under ambient environmental conditions. Different feed concentrations were given for single and double chambered MFC. The increase in feed concentration showed a positive effect on the current and voltage. Five feed concentrations from 2.1 g COD/L to 6.1 g COD/L with an increment of 1g COD/L were given. The study is under progress for higher feed concentrations.

B. COD removal efficiency

At every increment in feed concentration, the improvement in COD removal efficiency was observed. Distillery wastewater showed its potential for COD removal indicating the function of microbes, present in wastewaters in metabolizing the carbon source as electron donors. It is evident from experimental data that current generation and COD removal showed relative compatibility. Continuous COD removal was observed in both the MFCs.

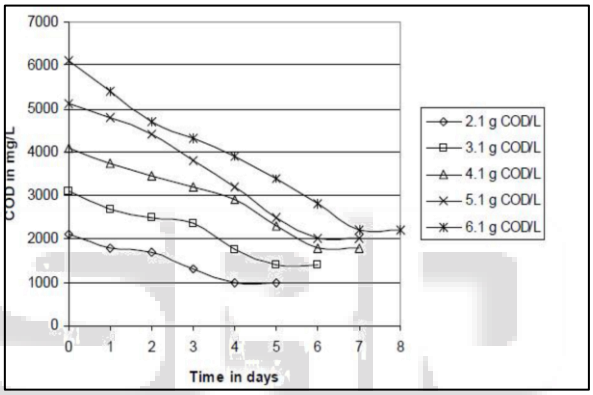

Fig. 1: COD reduction in double chambered MFCs

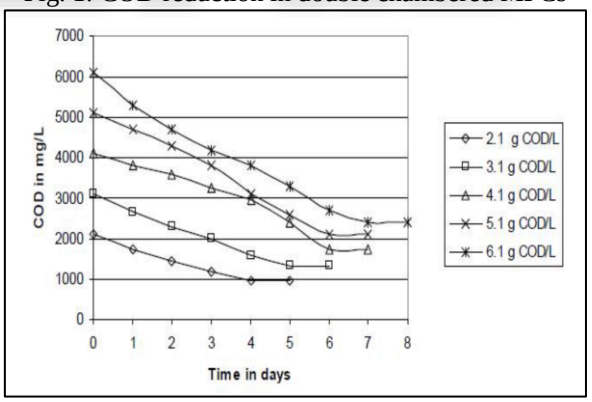

Fig. 2: COD reduction in single chambered MFCs

The COD removal efficiency was almost similar in single and double chambered MFC but single chamber MFC showed more consistent COD removal than double chambered MFCs.

VI. ADVANTAGES AND DISADVANTAGES OF MFCS

A. Advantages of Microbial fuel cells

- Microbial fuel cells eliminate pollution caused by burning fossil fuels; the only by product is water.
- If the hydrogen used comes from the electrolysis of water, then using microbial fuel cells eliminates greenhouse gases

B. Disadvantages of Microbial fuel Cells

- Fuelling microbial fuel cells is still a major problem since the production, transportation, distribution and storage of hydrogen is difficult.
- Reforming hydrocarbons via reformer to produced hydrogen is technically challenging and not clearly environmentally friendly

VII. APPLICATION

- Applications
- Electricity generation
- Biohydrogen
- Wastewater treatment
- Biosensor

VIII. CONCLUSION

This research work showed good association in terms of electricity generation and wastewater treatment. However, practical implementation of this technology remains limited because of low power and energy conversion efficiency due to over-potential losses, and high material costs. There may be several possible factors which affect the MFC performance including substrate nature, biomass type and concentration, ionic strength, pH, temperature and reactor configuration. Least is known about the ecology of microbial communities that metabolise the waste or catalyse the reactions on biocathodes. A good understanding of the acclimatization of the communities in MFC and their response to environmental perturbations would reduce the perceived risks and accelerate the adoption of MFC. The new sequencing technologies combined with proteomics and metagenomics could give a clearer picture of the changes in microbial community, composition and metabolic pathways that occur in response to different operating conditions.

Further improvements can be made to MFC configurations to improve the energy recovery or to increase voltages by linking MFC in series. Towards MFC commercialization different scale-up studies were performed and these studies indicate that scaling-up MFCs is feasible, but it is important to improve power output with cost-effective materials and new designs that can be used in large scale applications.

REFERENCES

[1] Aelterman, P., Rabaey, K., Pham, H.T., Boon, N., and Verstraete, W. (2006). Continuous Electricity Generation at High Voltages and Currents Using Stacked Microbial Fuel Cells. Environmental Science & Technology *40*, 3388-3394.
[2] Balat, M. (2009). Microbial Fuel Cells as an Alternative Energy Option. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects *32*, 26-35.
[3] Caspermeyer, J. (2011). Fuel Cell Uses Bacteria to Generate Electricity. Chae, K.-J., Choi, M.-J., Lee, J.-W., Kim, K.-Y., and Kim, I.S. (2009). Effect of different substrates on the performance, bacterial diversity, and bacterial viability in microbial fuel cells. Bioresource Technology *100*, 3518-3525.
[4] Chaudhuri, S.K., and Lovley, D.R. (2003). Electricity generation by direct oxidation of glucose in mediator less microbial fuel cells. Nature biotechnology *21*, 1229-1232.
[5] Chen, G.-W., Choi, S.-J., Lee, T.-H., Lee, G.-Y., Cha, J.-H., and Kim, C.-W. (2008). Application of biocathode in microbial fuel cells: cell performance and microbial community. Applied Microbiology and Biotechnology *79*, 379-388.

