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Generation of Bio Electricity by Active Sludge Process

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ABSTRACT

The aim of the paper is to understand and implement the energy conversion process using microbial fuel cell. This microbial fuel cell technology is a new form of renewable energy. This technology uses bacterium present in wastes such as waste water, sewage and farm wastes as catalysts to generate electricity. Microbial fuel cells allow the bacteria to move from anode which contains of chamber with sewage to cathode which contains of chamber with normal water via proton exchange membrane and they create the flow of electron. In this paper energy conversion is done using microbial fuel cell in real time. The results are presented.

Keywords: Microbial fuel cell (MFC), Chemical Oxygen Demand (COD), Carboxy Methyl Cellulose (CMC), Proton Exchange Membrane (PEM)

INTRODUCTION

The power generated from fossil fuels in the world causes environmental pollution and global energy crisis. This creates the need for power from renewable source of energy which is an environmental friendly. Nowadays bio electricity is a developing area where electricity can be generated from organic or inorganic compounds. In this paper, a bioreactor is used to convert chemical energy in the organic or inorganic compound substances to electrical energy with the help of catalytic reactions of microorganisms which is named as Microbial fuel cell (MFC). Carbohydrates, proteins, volatile acids, cellulose, wastewaters are the main substrate and it is used as feed in MFC for the generation of electricity. MFC has a wide range of applications such as: in household electrical generators and powering items such as small portable electronic devices, boats, automobiles, electronics in space and self-feeding robots. In this paper, the MFC energy conversion process is studied and implemented in real time.

SELECTION OF MATERIALS

Waste Water

The main benefit of using waste water as substrate is purification of waste water and producing electricity at less cost. In 2004, Liu *et al* demonstrated MFC which has the ability to treat wastewater with low energy consumption and additional energy production [1].The authors used single-chamber MFCs, in which oxygen aeration into the cathode chamber is not required. In addition to that Chemical Oxygen Demand (COD) for removing the rate of domestic wastewater was improved to 80%. As a result, 96% of the organic matter in wastewater was converted to electricity by a tubular, single-chamber MFC with a COD removal efficiency over 90%.

Micro Organism

The selection of microorganism is a major task which depends on the functioning and efficiency of the MFC. The substrates which produce electricity from waste water are simple or complex organic or inorganic compounds which are present in the waste waters. Rismani -Yazidi used cellulose from rumen of cattle for bioelectricity generation using microorganisms [2]. A dual-chambered MFC for electricity generation using a binary culture of cellulose-degrading bacteria named clostridium cellulolyticum and electrochemically active bacteria called geobacter sulphur reduces in fed-batch mode is employed which produce maximum 143mW/m^2 with 1g/L carboxymethyl cellulose (CMC).

Electrodes

The electrodes selected for the process plays a vital role as it decides the electron transfer and electrochemical efficiency of the whole system. The power production depends on the nature of electrode that is whether it is porous or not. Carbon paper, carbon felt, carbon fibre, carbon nanotube based composites are the commonly used electrode materials. The efficient MFC technology will be having less lavish materials with high power densities and a good cathode with oxygen reduction properties. In general, the output of MFC depends on the surface area of electrodes [3-5].

The Ohmic losses are directly proportional to the resistance of the electrode. The easiest way to decrease the resistance is to increase the effective surface area while keeping the volume the same. Furthermore, a high surface area provides more sites for reactions, enhancing electrode kinetics [6]. However, porosity will decrease the electrical conductivity of the material. Electrons released from microbes have to travel along an external circuit after passing through an anode. The high electrical conductivity of the electrode material makes the electron flow with less resistance. At the same time, the interfacial impedance should be low to facilitate the electron transfer. At the cathode, the ionic conductivity is required for boundary reaction, stability and durability.

Therefore, the material for electrodes should be durable as well as stable in an acidic and a basic environment. The cost of the electrode material influences the capital cost of the MFC to a large extent. To commercialize the MFC, the material should be low cost, sustainable and easily available. Some metals like platinum are highly expensive, non-durable and no sustainable as well. Non-precious metal materials such as composites might be an alternative to substitute precious metals in electrodes in the future [7-8]. In addition, materials used for the anode must have biocompatible properties. A superior biocompatible material will increase the bacterial adhesion and hence the life of the MFC anode material.

Electrodes Technical Specification

Cloth type electrodes have been selected for building MFC in the present work. Anode and cathode uses microfibre-carbon cloths as the electrodes since it fulfils the essential requirements of electrode as discussed earlier. The carbon cloth electrode is shown in figure 1 and the electrode technical specification is shown in table 1.

Power Collecting Conductor

The power collecting conductor has the following properties:

- Copper conductor resistance at **30^0C is 0.01 ohms.**
- Temperatures withstand **-40^0c to 105^0c.**
- Cross sectional Area of the conductor is **2.58 mm^2.**
- Length of the conductor is **1m.**
- Insulation type is **PVC (FLRY-A).**

Proton Exchange Membrane

A Proton Exchange Membrane (PEM) was chosen for the prototype design. Based upon the design criteria, membranes were chosen and compared in a decision matrix. Nafion and Ultrex are competing brands of proton exchange membranes (PEMs) used typically in the electroplating industry and fuel cell industry [9]. Drawbacks of these PEMs are that they are relatively expensive and tend to fail in the presence of chlorine. Cellophane was indicated as an appropriate membrane in some of the literature. As cellophane scored low internal resistance overall and was subsequently not considered for use as a PEM. Salt bridges are simple to construct, and are quite inexpensive but has a high internal electrical resistance as well as poor reliability. However, because of the effective performance, Nafion bridges were used in the experimental prototypes [10]. The measurement of internal resistance of membrane is shown in figure 2.

Table -1 Electrodes Technical Specification

Technical speciation	Anode electrode(carbon)	Cathode electrode(carbon)
Carbon coating	0.35mg/cm^2	0.35mg/cm^2
Length of the electrode	100mm	100mm
Breadth of the electrode	50mm	50mm
thickness of electrode	0.1mm	0.1mm
Surface area of the electrode	$5*10^{-3}m^2$	$5*10^{-3}m^2$
Internal resistance	2 ohm at 30^0C	2 ohm at 30^0C
Number of electrode	2 No’s	2 No’s

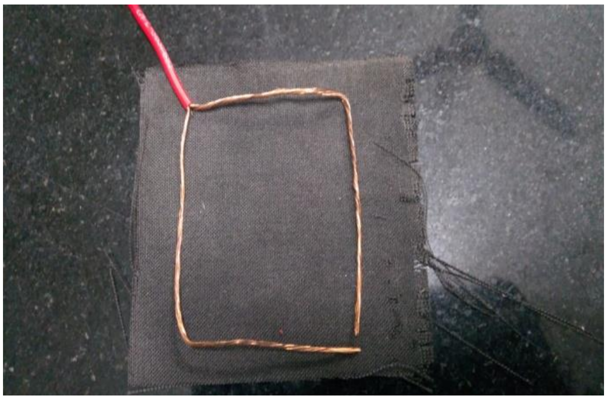

Fig. 1 Electrode (Carbon Cloth)

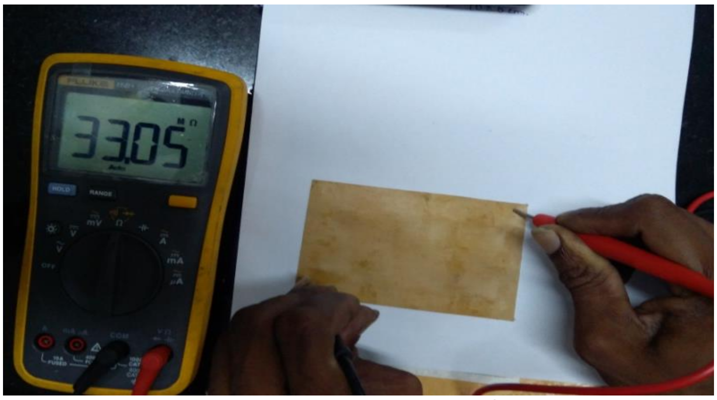

Fig. 2 Internal resistance of membrane

Proton Exchange Membrane Specifications

- Membrane type is Nafion proton exchange membrane.
- Length of the membrane is **100mm.**
- Breadth of the membrane is **50mm.**
- Area of the membrane is **$5*10^{-3}m^2$**
- Internal resistant of membrane is **33.05 MΩ.**

CHAMBERS

The prototype casing material was selected on the basis of several key design factors such as – Availability, Cost, Opaque nature, Durability and Workability etc. Based on these criteria, materials were investigated for possible use. Acrylic sheet is widely available and it is selected for the present work [11]. Acrylic sheet is also being inexpensive, however, when comparing to others, acrylic sheet is significantly less expensive. The chamber specifications are mentioned in table 2.

Media Storage Chamber

The media storage chamber is where fresh media is stored for later use within the cell [12]. The volume of the media storage chamber is adequate to provide full media replacement of the anode chamber and under the suggested operating procedures, can last up to two months**.**

Anode Chamber

The anode chamber is completely sealed with the exception of a service port to drain and/or fill the chamber initially. The Anode Chamber is filled completely with the nutrient media and contains the microorganisms as well as the electrodes upon which the organisms grow.

Cathode Chamber

The cathode chamber is open to the atmosphere under normal operating conditions, although a threaded cap is provided to prevent leakage during transportation of the cell. The electrodes are submerged in an aqueous buffer solution, providing ideal conditions for the reduction reaction to occur with oxygen, completing the electrical circuit.

Media Injector

The media injector is a primer bulb that takes media stored in the media storage chamber and pumps it through the pre-injection Filter and into the sealed anode chamber.

Media Outlet

The media outlet is connected to the anode chamber using a one-way valve. When the pressure in the anode chamber is increased by the injection of new media, spent media is ejected through tubing to the media outlet located on the end cap.

Proton Exchange Membrane

The proton exchange membrane is made from Nafion (PMI-7000 proton exchange membrane) and separates the anode chamber from the cathode chamber. The membrane is the key to the functionality of the cell since it is the membrane that forces the electrons to run through external wiring (load) in order to get to the cathode chamber.

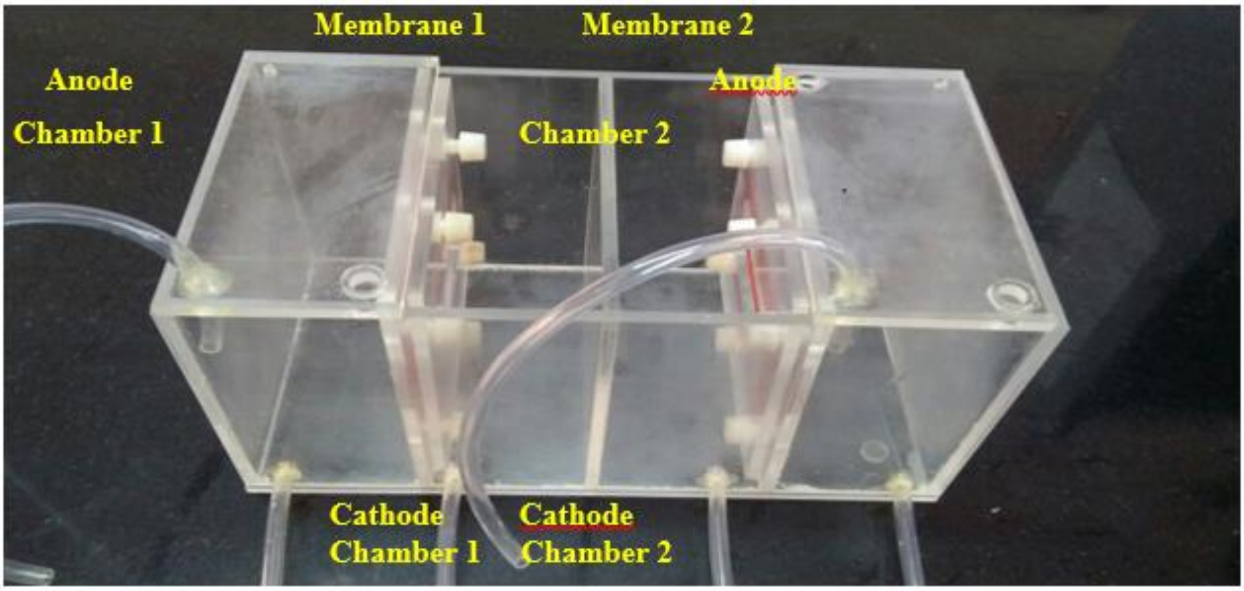

Fig. 3 Double chamber proto type microbial fuel cell

Table -2 Chamber Specification

Chamber specification	Anode chamber	Cathode chamber
Length	75mm	75mm
Breadth	150mm	150mm
Height	150mm	150mm
Volume of the chamber	$1687*10^{-6}m^3$	$1687*10^{-6}m^3$
Thickness	6mm	6mm
Number of chamber	2	2

Anode Electrodes

Electrodes composed of carbon cloths are wired in parallel to a single terminal in the anode chamber. The microorganisms form a bio film upon the electrodes, providing the electrons needed to produce electricity.

Cathode Electrodes

There are cathode electrodes composed of carbon cloths that are wired in parallel and connected to a single cathode terminal. The reduction of oxygen occurs on the surface of these electrodes, completing the electrical circuit between the anode and cathode chambers.

OPERATION OF MFC

The double anode and double cathode chamber type MFC is selected in this project to obtain the increased current density. Both two anode chambers have been filled by the sewage of 1.25 litres and salt water has been fed to the cathode chamber approximately about 2.25 litres. Both anode chambers sealed to avoid entering of the air since it is an anaerobic which helps to grow the bacteria. The cathode chamber is aerated by oxygen to improve the recombination of the proton and electrons. Bacteria present in the anode chamber separate the electrons and protons from the sucrose during their growth. The double anode and cathode chamber proto type fuel cell is shown in figure 4.

The carbon which acts as an electrode in anode chamber collects the electron and the electrons get flowed from chamber to load through electrode and power collecting conductor. The protons only allowed to flow from anode chamber to cathode chamber through proton exchange membrane. Hence the anode chamber loses the electron and it is called electron donor chamber. The cathode chamber accepts the electron and proton by aeration hence it is called electron acceptor chamber [13].The microorganisms have the ability to produce electrochemically active substances that may be either metabolic intermediaries or final products of anaerobic respiration. When microorganisms consume a substrate such as sugar in aerobic conditions they produce carbon dioxide and water. However, when oxygen is not present, they produce carbon dioxide, protons and electrons.

The Power Density of MFC

The power density of MFC normalized by surface area is calculated by using - $\mathbf{P = E^2/ [A \times R]}$. Here, **E** is measured voltage across the load (Volts), **A** is surface area of both sides of anodic electrode (m^2) and **R** is the load (Ohms).

RESULTS AND DISCUSSION

The performance of the MFC was monitored by observing the voltage as a function of time. The results are displayed in the figures 5 and 6. As seen in this figure 5, a semi-steady output was attained after two weeks of operation.

Open Circuit Characteristics

The MFC voltage produced at no load is increased steadily from the first day up to a maximum voltage of 1.120 Volts on the sixth day before it started decreasing and it is shown in figure 6. This was due to increased bacteria activity at the anode. The bacteria form a bio film at the anode and as the bacteria food decreases, some of the bacteria die leading to the decrease in the voltage produced [14-15].After inoculation, the voltage increases steadily depending on the type of resistor connected across the terminal. The voltage reached the peak on the sixth day and started decreasing steadily but at a slower rate. The trend is explained by the increase in number of the bacteria and by the fact that the bacteria took some time to form the anodic bio film. The rate of production of electrons decreased. This was due to death of some bacteria and the reduction in the substrate concentration which necessitated supply of additional food to the bacteria through inoculation.

In the open circuit characteristics, no load voltage is taken in Y axis and time in hours taken in X axis. After the 40 hours of process the open circuit voltage is reached to 1.12 V maximum for this double chamber type MFC. After two days the voltage gets gradually reducing to reach the steady state value.

Load Characteristics

On connecting a load resistor in MFC, the power delivered to the external load (i.e. the resistor) would be V_{max} times I_{min}. Voltage can be measured across the load. Load characteristic is drawn and it is shown in figure 6. The circuit voltage is taken along Y axis and load current is taken along X axis. After connecting the 1kΩ resister the voltage rapidly decreased to 0.3 V at 6 mA. The load characteristic of MFC is shown in figure 7.

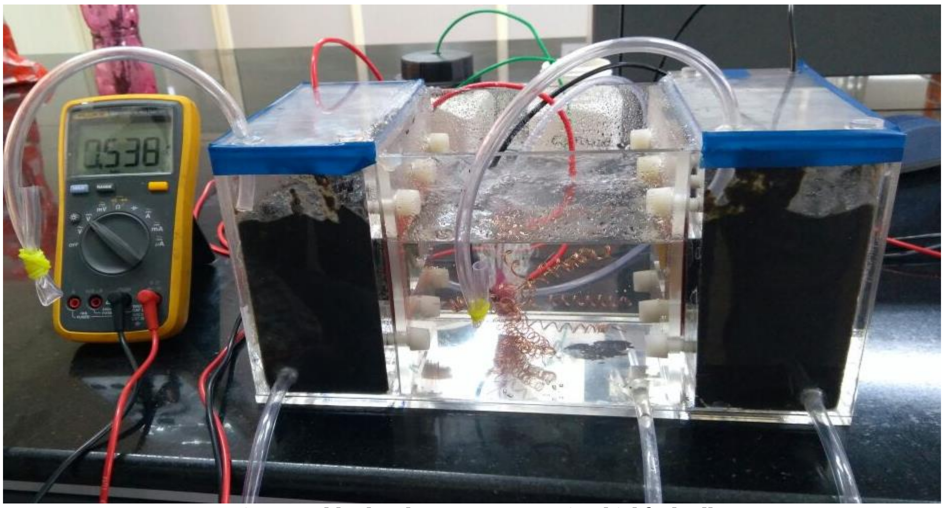

Fig. 4 Double chambers proto type microbial fuel cell

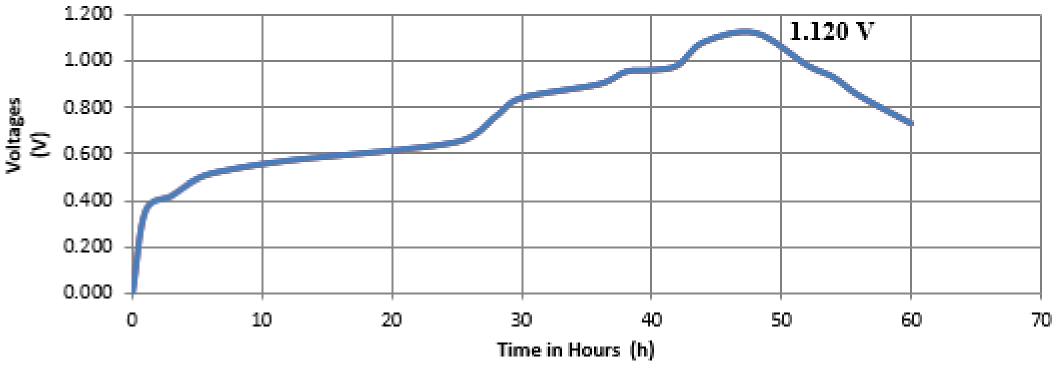

Fig. 5 Open circuit characteristics of MFC

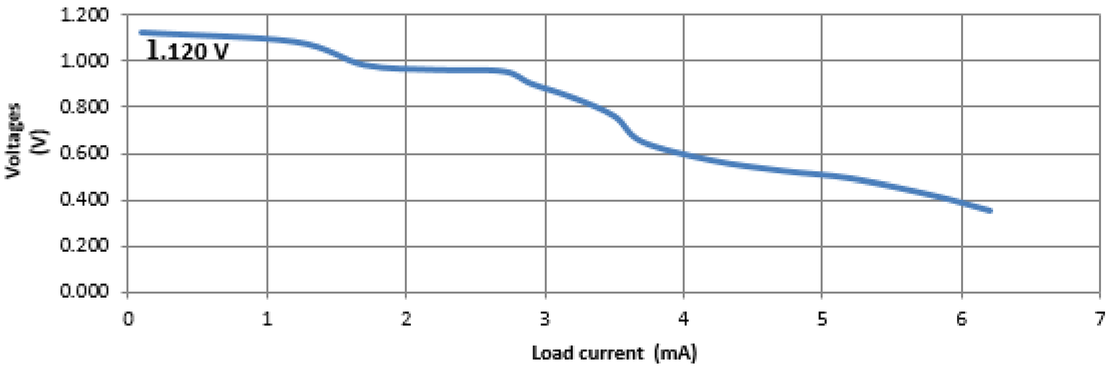

Fig. 6 Load Characteristics

PARAMETERS DEFINING THE PERFORMANCE OF MFC

To commercialize the MFC, power that can be generated is dependent on both biological and electrochemical processes. These are explained below:

The Substrate Conversion Rate

This depends on the amount of bacterial cells, the mixing and mass transfer phenomena in the reactor, the bacterial kinetics (m max, the maximum specific growth rate of the bacteria, and Ks, the bacterial affinity constant for the substrate), the biomass organic loading rate (g substrate per g biomass present per day), the efficiency of the proton exchange membrane for transporting protons and the potential over the MFC.

Over Potential at the Anode

Generally, when the open circuit potential (OCP) of MFCs is measured, this OCP is in the order of between 750 mV to a maximum of 798 mV. Parameters influencing the over potentials are the electrode surface, the electrochemical characteristics of the electrode, the electrode potential, the kinetics together with the mechanism of the electron transfer and the current of the MFC.

Over Potential at the Cathode

Similar to the losses observed at the anode, the cathode exhibits significant potential losses. To remediate this, several researchers have used hexacyano ferrate solutions. However, hexacyano ferrate is not completely re-oxidized by oxygen in the air, and should be considered as an electron acceptor rather than a mediator sustainable.

The Proton Exchange Membrane Performance

Membranes are sensitive to (bio) fouling by ammonium, for example. The best result was obtained using an Ultrix action exchange membrane. Liu *et al* [1] omitted the membrane, using pressed carbon paper as the separator. However, although this omission significantly decreased the MFC internal resistance, this type of separation provoked growth at the cathode based on acolyte.

Internal Resistance of the MFC

Internal resistance is dependent on both the resistance of the electrolyte between the electrodes and the membrane resistance. For optimal operation, anode and cathode need to be as close together as possible. Also proton migration significantly influences resistance-related losses; adequate mixing could minimize these losses.

CONCLUSION

This paper demonstrated the working of MFC and its performance under no-load and load conditions. Further, this study reveals the significant challenges of applying MFCs into an aeration tank as well as how to treat high-solid wastes. On the other hand, the results also show the capable application of MFCs for treating low-strength wastewater such as domestic wastewater. These findings will be helpful for further development in MFC.

REFERENCES

[1] Hong Liu and Bruce E Logan, Electricity Generation Using an Air-Cathode Single Chamber Microbial Fuel Cell in the Presence and Absence of a Proton Exchange Membrane, *Environmental Science & Technology*, **2004**, 38 (14), 4040-4046.

[2] H Rismani-Yazidi, AD Christy, BA Dehority, M Morrison, Z Yu and OH Tuovinen, Electricity Generation from Cellulose by Rumen Microorganisms in Microbial Fuel Cells, *BiotechnologyBioengineering*, **2007**, 97(6), 1398–1407.

[3] Meehan, H Gao and Z Lewandowski, Energy Harvesting with Microbial Fuel Cell and Power Management System, *IEEE Transactions on Power Electronics*, **2011,** 26(1), 176–181.

[4] L Tender, S Gray, E Groveman, D Lowy, P Kauffma, R Melhado, R Tyce, D Flynn, R Petrecca and J Dobarro, The First Demonstration of a Microbial Fuel Cell as a Viable Power Supply, *Journal of Power Sources*, **2008**,179, 571–575.

[5] J Cha, S Choi, H Yu, H Kim and C Kim, Directly Applicable Microbial Fuel Cells in Aeration Tank for Wastewater Treatment, *Bio Electrochemistry*, **2010,** 78(1), 72-79.

[6] PranabK Barua and D Deka, Electricity Generation from Bio Waste Based Microbial Fuel Cells, *International Journal of Energy, Information and Communications,* **2010**, 1(1), 77-92.

[7] Rati Ranjan Sabat, Manoj Kumar Swain, Jiban Jyoti Garnaik and Sudhadhara Sarangi, Utilization of Waste Water and Production of Electricity using Non Mediated Microbial Fuel Cell, *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*,**2013,** 4(2), 47-51.

[8] AnandParkash, Microbial Fuel Cells: A Source of Bio Energy, *Journal of Microbial & Biochemical Technology*, **2016**, 8(3), 247-255.

[9] SS Uddin, KS Roni and AHMD Shatil, Double Compartment Microbial Fuel Cell Design using Salt Bridge as a Membrane with Sucrose and Starch as a Substrate, 2nd*International Conference on Electrical, Computer & Telecommunication Engineering (ICECTE)*, Rajshahi, Bangladesh, **2016,** 1-4.

[10] S Ayyaru and S Dharmalingam, Development of MFC using Sulphonated Polyether Ether Ketone (SPEEK) Membrane for Electricity Generation from Waste Water, *Bioresource Technology*, **2011,** 102(24), 11167–11171.

[11] DJ Juang, Application of Microbial Fuel Cell in Wastewater Treatment System by using Algae as the Oxygen Supplier in Cathodic Chamber, *IEEE International Conference on Power System Technology*, Auckland, **2012**, 1-4.

[12] V Vineetha and K Shibu, Electricity production coupled with wastewater treatment using microbial fuel cell, *International Conference on Energy Efficient Technologies for Sustainability*, Nagercoil, **2013**, 821-826.

[13] PMD Serra, A Espírito-Santo and A Albuquerque, An Experimental Setup for Energy Efficiency Evaluation of Microbial Fuel Cells, *IEEE Institute Telecommunicates, University of Beira, Portugal,* **2015,** 902-907.

[14] A Pietrelli, V Ferrara, F Khaled, B Allard, F Buret and F Costantini, Electrical characterization of MFC for low power applications, *IEEE 16thInternational Conference on Environment and Electrical Engg*., Florence, **2016**, 1-5.

[15] Ajith Madhavan, Vishnu Nandakumar, Sindhu Shetty K and Bipin Nair Optimization of Microbial Fuel Cell (MFC) Operated with Waste Water as Substrate, *International Conference on Electrical, Electronics and Optimization Techniques*, **2016,** 4403-4406.