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Comparative Analysis of Carbon Cloth and Aluminum Electrodes Using Agar Salt-Bridge Based Microbial Fuel Cell for Bioelectricity Generation from Effluent Derived Wastewater

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ABSTRACT

Renewable and clean forms of energy are one of society's most crucial needs. In the meantime, two billion individuals on the planet lack satisfactory sanitation and the monetary intends to breathe cost of it. In this work, we have attempted to address both of these human needs. Every year huge amount of expenses are carried out by industries to incorporate chemicals and electricity consumption for running water plants. Given the wealth disparity in India, present work explores a microbial fuel cell for production of bioelectricity. It contains two chambers, which are connected with a salt bridge (H-shaped) structure. At the same time, it brings down the BOD and COD level of the wastewater and decrease the toxicity. These devices use bacteria as the catalyst to oxidize the organic and inorganic matter and generate electricity. Electrons are produced by the bacteria and transferred to the anode (negative terminal) and flow to the cathode (positive terminal) with the help of conducting appendages. Two setups have been tried to check the different possible results with carbon cloth and aluminum mesh as electrodes. Carbon cloth arrangement shows peak open circuit voltage recorded as 540 mV and Al mesh shows peak open circuit voltage recorded as 400 mV. Carbon cloth gives consistent generation of electricity, whereas aluminum mesh gives some fluctuations in electricity generation. H-shaped systems are shown to be acceptable for the basic parameters of research, such as examining power production using new materials.

INTRODUCTION

We tend to think of energy crisis in world because today the main problem faced by the society is fuel crisis and the water infrastructure. Energy crisis is the main and broad topic because we have limited primary resources like coal, petrol an diesel, and one day these sources will reach critical point as demand rises and it takes thousands of years to replenish these sources (Bose et al. 2017). Governments are working to make use of renewable sources i.e., solar energy, wind energy and biofuels. Renewable sources of energy play an important role to address the energy crisis (Sen & Ganguly 2017). Microbial fuel cell is a form of renewable energy that can be a part of this system to support our water infrastructure.

Microbial fuel cell (MFC) is a device that converts chemical energy into electrical energy by using the microbial metabolism in wastewater (Logan et al. 2006). Microbial fuel cell technology is one of the better ways of wastewater treatment which is effective as a process of harnessing energy from the bacteria in the form of bioelectricity. Developing scalable forms of such technology would first require treatment of different types of wastewaters, which come from different places like domestic, industrial and other sources (Xu et al. 2007). The energy captured from the wastewater might not be sufficient to power an entire city, but it is sufficient enough to power less energy intensive devices, making it a parameter of energy sustainability for the water infrastructure (Bose & Bose 2017).

Microbial fuel cells are electrochemical devices which contain wastewater in the anode and a conductive salt solution in the cathode (Fig. 1). With the help of bacteria in the wastewater, as they consume the effluent, they produce electrons which are transferred from anode to cathode via an external circuit and electricity is produced. Microbial fuel cell has capacity to produce electricity by reducing the chemical oxygen demand (COD) of wastewater (Ismail et al. 2017).

In this work, food wastewater was collected from the cafeteria of the University Campus. Initial characterization of the wastewater showed chemical oxygen demand (COD) of 640 mg/L, biochemical oxygen demand (BOD) of 168 mg/L, and total soluble solids (TSS) of 250 mg/L. And they were charged into a two chambered salt bridge MFC to see power performance of the mixed bacterial culture in the wastewater.

CONSTRUCTION OF MICROBIAL FUEL CELL

Cathode: Carbon cloth and aluminum (Al) mesh were used as electrodes in this study. Different materials can be used in the cathode chamber, like $K_3[Fe(CN)_6]$ (ferricyanide); it has a very good advantage because of low overpotential, but the re-oxidation is not properly done by oxygen, due to this replacement needs to be done on time to time (Kaushik et al. 2017). Oxygen has high reduction potential and it is easily available, due to this oxygen is considered an appropriate electron acceptor (Guo et al. 2016).

Anode: Carbon is the commonly used material as an electrode because it is chemically stable and biocompatible (Li et al. 2016). Carbon cloth is used as an electrode. This study proposed using Al mesh because it has non-reactive and non-corrosive properties. For better performance of the system, different chemical mediators are used in the anodic chamber to scavenge the oxygen. If oxygen is in bulk in the anodic side, the efficiency of the system decreases, and due to this oxygen must be removed from the anode.

Salt bridge: In H-shaped MFC design, the anode and cathode are separated by a proton exchange membrane (PEM); in this case it is a salt bridge. These are used to transfer the cations from anode to cathode. In this work, agar powder is used for a salt bridge (Fig. 2). Separation can also be done by membranes like nafion (Dupont Co. USA), but these membranes are costly, whereas salt bridge systems are more economic, but are plagued by high internal resistance.

METHODOLOGY

A two chambered MFC reactor was inoculated with wastewater from the University cafeteria and supplied with a defined medium containing glucose as a carbon source to maintain the effluent concentration. Agar powder was used to create a salt bridge by mixing with a saturated potassium salt followed by the heat treatment of around 85-95°C. On solidifying, it was inserted in the system where this acts as a PEM between the anode and cathode.

Chemically, agar consists of a mixture of agarose and agaropectin. The former is a linear polysaccharide made up of the repeating monomeric units of agarobiose, a disaccharide made up of D-galactose and 3,6-anhydro-L-galactopyranose. The latter is a heterogeneous mixture of smaller molecules that occur in lesser amounts. Their structures are similar, but slightly branched and sulphated (Samiey & Ashoori 2012). Namely, agar is a potent carbon source made up of sugars, mainly galactose.

In this study, two electrodes were used, carbon cloth and aluminium mesh for two identical reactors. Size of the electrodes in both the setups was kept similar (10 × 10 cm). Capacity of the anode and cathode containers is 1.7 L and both are connected through the salt bridge. Epoxy glue was used to seal the salt bridge to the containers to avoid leakage. After the epoxy coating, layering of duct tape is done as an added protection from leakage and contribute to stability of the system.

Electrodes, which are present in anodic and cathodic chamber are connected with titanium wires and a multimeter is connected with this to complete the circuit.

The anode was filled with wastewater and cathode with a conductive salt water solution of the sodium salt. The level of fluid in both the containers was kept same, otherwise due to the pressure difference diffusion can occur through the salt bridge which is undesirable. An air pump was connected to the cathodic chamber to provide sufficient amount of atmospheric air to increase the rate of reaction (7.8 litre/minute).

Inoculation was done on the anode side, 10 g of glucose was inoculated with small amount of wastewater. For the conductive cathode solution, 10 g of sodium chloride was added to the normal water.

RESULTS AND DISCUSSION

Carbon cloth as an electrode: The voltage characteristics were measured using a fully calibrated multimeter on 24-hour basis as previously discussed (Bose et al. 2018). It generates constant voltage within the range of 60-550 mV (millivolts) over one week of operation. The highest value of open circuit voltage was 570 mV.

Initially, it gives around 500 mV and shows constant behaviour after a period of time. It starts decreasing later as the food is not available to microorganisms, after this 10 g of glucose is added to the wastewater, due to which voltage generation is further increased and goes up to the level of 500 mV again (Fig. 3).

Now, a graph between the voltage vs total dissolved solute (TDS) is drawn. TDS is continuously measured by a TDS meter (Magideal, RC-51003142). It shows that the TDS follows the generation of voltage; as the voltage generation decreases with the time, TDS also decreases. When TDS is increased voltage also increases, but as usual both decrease again with time (Fig. 4). When the voltage level goes below 150 mV, the system was discontinued for further study.

Aluminium mesh as an electrode: In this system, the pattern between the voltage generated and time is quite different. In this system, the generated voltage was fluctuating in nature with time as shown in Fig. 5. For the fluctuation in voltage, the chemical composition of the aluminum mesh is an important factor. The highest open circuit voltage meas-

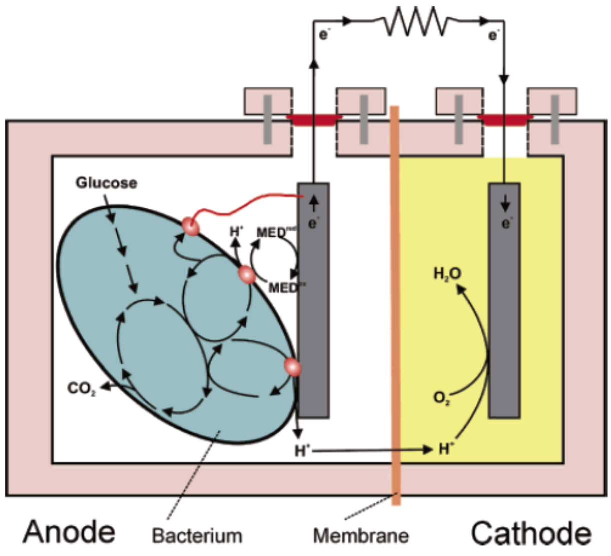

Fig. 1: In MFCs bacteria grows on one electrode, break down organic matter and release electrons in the process, similar to energy utilization via respiration in humans (Rabaey et al. 2005).

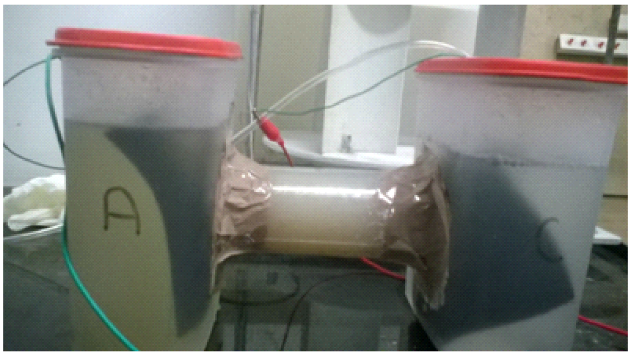

Fig. 2: H-shaped wastewater MFC connected with agar salt bridge and carbon cloth used as an electrode.

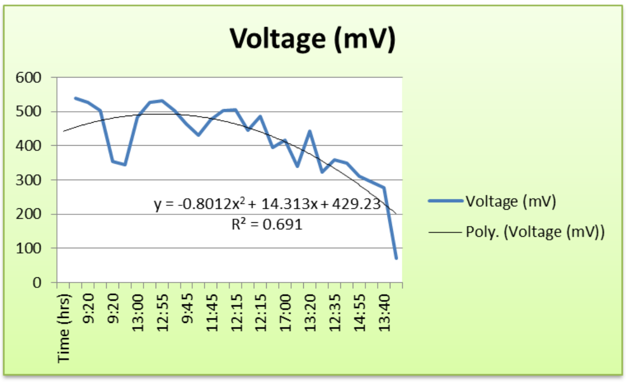

Fig. 3: Graph between time (hrs) and voltage (mV) for carbon cloth as an electrode.

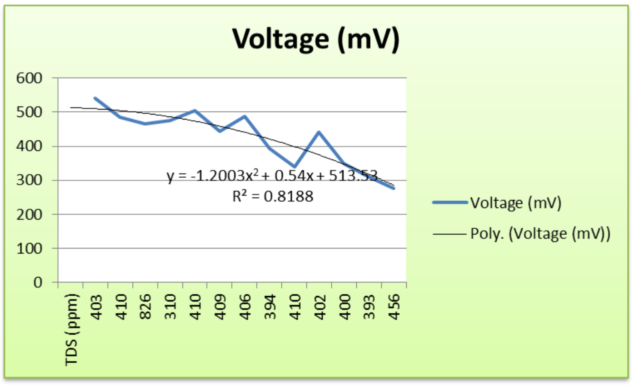

Fig. 4: Graph between TDS (ppm) and open circuit voltage (mV) for carbon cloth as an electrode.

Fig. 5: Multimeter shows the reading of MFC with carbon cloth as an electrode (reading is 578mV).

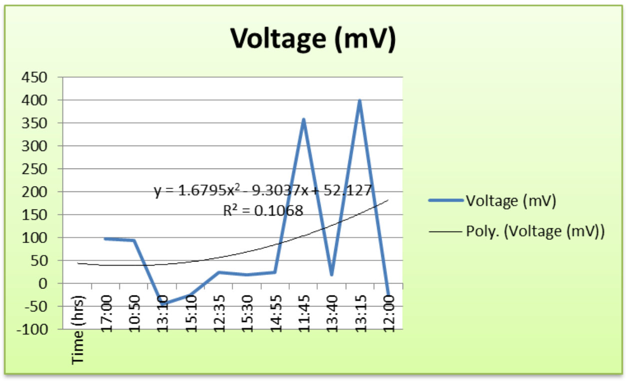

Fig. 6: Graph between voltage (mV) and time (hrs) for aluminium mesh as an electrode.

ured was 400 mV, and the lowest 25 mV (Fig. 6). There was formation of bio-film above the surface of the water in the anode as shown in Fig. 8, which might be because of the conductivity of the Al mesh. A significant correlation be-

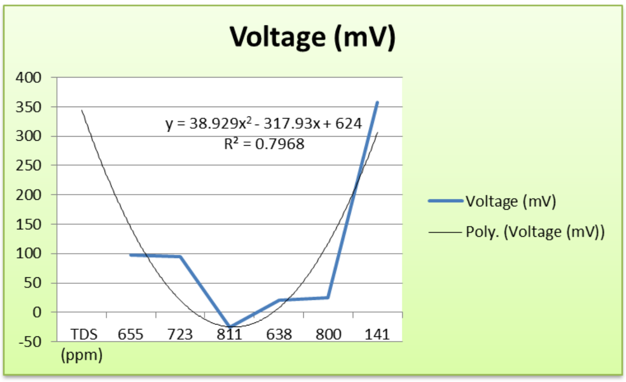

Fig. 7: Graph between voltage (mV) and TDS (ppm) for aluminium mesh as an electrode.

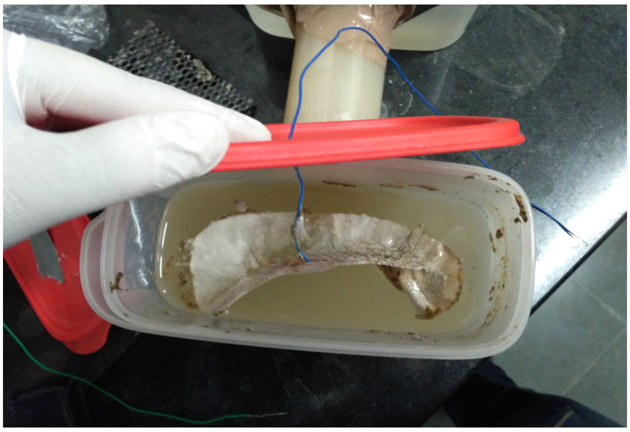

Fig. 8: Formation of biofilm over the surface of the wastewater in the anode chamber of MFC with Al mesh as an Electrode.

tween material composition and conductivity of the electrode will be an interesting avenue to explore.

Now, the curve is plotted between the voltage and TDS. There is a change in behaviour of the TDS vs voltage with time. TDS and voltage both decrease over time, and when voltage goes down to a level of 100 mV, the system was discontinued for further study (Fig. 7).

Factors affecting the voltage generation: In this study, oxygen diffusion was observed from cathode to anode through salt bridge, affecting the water level and it limits the generation of voltage.

Diffusion of dissolved oxygen into the anodic chamber varies as a function of bacteria and the capacity of the bacteria to scavenge the dissolved oxygen. If oxygen is present more in the anodic chamber, it limits or reduces the rate of reaction which is happening in the anode chamber. Different methods exist to minimize the effect of oxygen e.g., use of of different compounds like L-cysteine and pyrogallol (Holmes et al. 2007). L-cysteine and pyrogallol work as a oxygen scavenger in the anode, however they were not considered in this study (Logan et al. 2005).

Variation in COD consumption leads to electricity generation: COD (chemical oxygen demand) is a measure of the amount of oxygen which is consumed by microorganisms to degrade organic matter in waters. The COD of wastewater is dependent upon the source of the water. The COD value of the industrial wastewater is often more than the domestic wastewater (Badawy et al. 2006).

When we used wastewater in MFC (microbial fuel cell) for the electricity generation, the COD decreases with time due to microorganisms continuously metabolizing and releasing electrons. Decreased COD shows a proportional correlation between COD consumption and voltage generation.

CONCLUSION

According to this study, carbon cloth shows better result than aluminium mesh. Carbon cloth provides more active surface area to microbes to accumulate, as compared to Al mesh. Wastewater MFC reactor system is still in research phase as it needs more refined systems. Performance would be enhanced by having increased BOD and COD level. The diversity of MFC operations offer several advantages over parameters such as COD loading, temperature change, and stability of performance. Also, it can function over thermophilic, mesophilic and psychrophilic temperature ranges. Such systems can be used with anaerobic digestion (AD) process functioning as a complimentary process, with MFC used for dilute wastewater treatment and ADs for the sludge treatment. The separation of processes may change over time as MFCs are improved and applied over a wide range of conditions, making it sustainable.

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