

Effect of Different Substrate on the Performance of Microbial Fuel Cell Using Nafion as Membrane

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Abstract: The present study investigated the performance of microbial fuel cell (MFC) in terms of electricity production and chemical oxygen demand (COD) removal rate using different substrates. A double-chambered MFC was constructed with Nafion as separator and carbon cloth as an electrode. Glucose, municipal waste water, and sugar industry waste water were taken as a substrate for MFC. Maximum Open Circuit Voltage (OCV) of 0.34 V, 0.58 V, 0.67 V were obtained for sewage wastewater, glucose and sugar industry waste respectively with a current density 0.2730 micro A/c.c, 0.4183 micro A/c.c, 0.4211 micro A/c. The COD removal rate was found to be 53%, 65%, 78%, for sewage wastewater, glucose, sugar industry wastewater. OCV and current density were obtained in the following order: sugar industry wastewater > glucose > municipal wastewater. Carbon balance was done to determine the organic carbon removal and to check the efficacy of the system. SEM and microscopy analyses demonstrated a biofilm with a mixed population of gram-negative species.

Keywords: Microbial fuel cell (MFC); Nafion; Carbon balance.

Highlights

- (a) For the first time glucose, sugar industry waste and sewage waste water were compared for electricity production in microbial fuel cell.
- (b) Carbon mass balances were done for the first time for microbial fuel cell.
- (c) SEM results support the growth of biofilm layer on carbon cloth.

1. Introduction

The worldwide increase in economic development and population overgrowth has led to the increased demand for fossil fuel for energy production. The current consumption of energy resources is much faster than its availability. If the energy consumption continues at such rate, the world will face an energy crisis. To overcome the energy crisis, there is a need to develop alternative, cost-effective technology^{1,2}. Microbial fuel cell (MFC) has proved its suitability in this direction that utilizes energy from waste (organic or inorganic) to produce a renewable energy source³. MFC provides an interesting replacement of many wastewater treatment technologies along with electricity production^{4,6}.

A microbial fuel cell is a type of cell which is used for the production of electricity using microorganism through the catalytic activity of electrochemically active bacteria⁷. Electron produced by Microbes at anodes is transferred to the cathode through the circuit where they get combined with protons and an electron acceptor (such as oxygen) to form water⁸. Several types of MFCs with different electrode arrangements and membrane have been developed, including two-chamber and single-chamber reactors⁸. Based on the mode of transportation of electrons MFC have been characterized as mediator and mediatorless⁴. MFC Performance of MFC is affected by many parameters such as the type of electrode material, design, proton exchange membrane, type of bacterial community and type of substrate^{4,9}.

Different electrode material such as aluminum mesh, graphite rods, carbon cloth, carbon paper coated with a platinum catalyst, etc have been reported by the researcher¹⁰. The proton exchange membrane (PEM) play an important role in MFC performance by providing transport to H^+ ion. A wide variety of membrane have been used such as Nafion, glass fiber mats, agar membrane, etc and they have proved their efficiency in the transport of H^+ ions². In mediator-less MFC exoelectrogens such as *Geobacter* sp., *Shewanella* sp., *Pseudomonas* sp., *Burkholderia* sp., *Escherichia coli*, *Ochrobactrum anthropi*, *Rhodospirillum rubrum*, *Citrobacter* sp. and *Clostridium sticklandii* were used for the production of electricity¹¹. For electrochemically inactive MFC, electron transfer from microbial cells to the electrode is provided by the mediators such as thionine, methyl blue, humic acid, and so on⁴. A great variety of organic(natural) substrates have been also used by researchers such as glucose, acetate, brewing wastewater, rice mill wastewater, and landfill leachate, etc. for electricity

production. Most of MFC technology has proved that they have the potential of biodegradation of waste with the successful production of electricity¹²⁻¹⁴.

Although many researchers have investigated electricity production with glucose, sugar industry waste and sewage wastewater independently. To date, there is no comparative study of all these three substrates along with carbon mass balance. To fulfill the gap in the literature in the area of carbon mass balance with electricity production, the present study was focused on using three different substrates namely glucose, sewage wastewater, and synthetic sugar industry wastewater for the production of electricity along with biodegradation and on their carbon balance.

2. Materials and Methods

2.1 Microbial fuel cell setup design and culture maintenance: A double-chambered rectangular ($11.5 \times 13 \text{ cm}^2$) microbial fuel cell (Fig. 1) was constructed using Perspex material. Carbon cloth (Area 50.24 cm^2) as electrodes and Nafion as proton exchange membrane was procured from Sainergy fuel cell, Chennai, India. In MFC, a circular (4 cm inner diameter) provision for electrodes and proton exchange membrane were made for attachment of carbon cloth and nation. Compartment used for anode was sealed properly with parafilm to make it anaerobic and had provision for outlet CO_2 gas outside reservoir containing 1 molar KOH solution continuously from day first to end of the experiment for carbon balance. Cathode compartment was filled with 200 ml distilled water with Continues aeration. A resistance box (1000 ohm) was connected with MFCs to measure the voltage drop across the cell.

The Anaerobic chamber was inoculated with a mixed culture of bacteria waste (5% v/v) collected from primary clarifier of the wastewater treatment plant, Bhagwanpur, Varanasi, India. *Geobacter* specific growth media were used for culture maintenance¹⁵. For carbon source glucose (1 gm/lt), wastewater and synthetic sugar industry wastewater (sucrose 2 g /lt) were taken. The composition of synthetic sugar industry waste was given by Nimje¹⁶.

2.2 Analysis: MFC was operated for a period of 22 days in batch mode and experiments were performed in triplicates and averages of the data were taken. Samples were collected regularly at a 24-hour time interval from fuel cell for analysis. Samples were centrifuged (5000 rpm) for 10 min. Supernatant from the centrifuged sample was collected for further analysis

(COD, glucose concentration, sucrose concentration. Pellets obtained from centrifuge were re-suspended in *Geobacter* medium for measuring bacterial optical density. COD measurements and pH were carried using COD analyzer (UNIPHOS) and (EuTech 510 pH meter) respectively. CO₂ concentration was determined weakly by collecting gas in the gas chamber by titration method¹⁷. Scanning electron microscopy (FEI ESEM Quanta 200) was performed to determine biofilm formed on the surface of carbon cloth. *Geobacter* species confirmatory tests were done with the microscope (DEW/038 Dewinter technology). Sucrose concentration was determined by a modified anthrone method (Finley and Fellers, 1973) and glucose concentration was determined from DNS method¹⁸ using UV-visible spectrophotometer (Elico SL-159). Electrical measurement (potential drop and current) across the cell were carried out using a digital multi-meter (MASTECH ms8340B) which is connected to the computer for data recording.

3. Results and Discussions

3.1 Electrical result : During MFC startup, before inoculation, the blank run was performed for two days with distilled water in both the chambers to check the error produced by the system. Open circuit voltage was recorded at the time of blank run and was found to be 0.001 V. After this, MFC setup was seeded with 5 % v/v wastewater taken from primary clarifier along with other nutrient medium and carbon source (glucose 1 %). Continuous rise of voltage were recorded and maximum OCV was found to be in case of glucose 0.58 V and after that voltage decreases and reaches a minimum of 0.24 V. Same experiment was performed for sewage wastewater and sugar industry wastewater was taken from primary clarifier (both used as nutrient media and carbon source) for growth of microorganism. A maximum OCV of 0.34 V and 0.6738 V were obtained respectively for sewage and sugar industry wastewater (fig. 2). Rise and fall of the profile are attributed to the fact that as the growth of bacteria increases, OCV increases with time but with the increase of growth, consumption of substrate (carbon source) also increases which leads unavailability of substrate for the microorganism. And ultimately death of bacteria occurs which leads to decreases of OCV with time. The OCV obtained is high as compared to the result obtained by²⁰ and comparable with the result obtained with^{7,8, 21}.

The current was recorded with another multimeter connected with the circuit in series at the resistance of 1000 ohm. Current density profiles were

shown in fig. 3 in which with the increase of voltage current density and power density continuously increases. A maximum current density of 0.2730 A/m^3 , 0.4183 A/m^3 , 0.4211 A/m^3 were obtained for wastewater, glucose, and sugar industry wastewater respectively. Power density profile was shown in fig. 3 with a maximum of 0.0149 W/m^3 , 0.0349 W/m^3 , 0.0354 W/m^3 for wastewater, glucose, and sugar industry wastewater respectively. Above result is similar to the results obtained by various researches^{3, 11, 22, 23}.

3.2 Chemical oxygen demand: COD is another important parameter which is used to determine the efficiency of MFC in terms of removal of waste. Since here waste material has been taken for the production of electricity; COD determination has been taken into account. % COD removal was calculated taken into account first day sample (fig. 4). So first day COD removal efficiency was 0 % and with time it increased and reached to a maximum value of 53%, 65%, 78%, for sewage wastewater, glucose, sugar industry wastewater respectively. This removal efficiency is quite good when considered along with electricity production. The result obtained is consistent with other result reported in the literature²²⁻²⁴.

3.3 Carbon balance: Very less work has been reported which correlate the work of MFC with carbon balance. Carbon balance analysis is found to be effective for the determination of organic carbon removal²⁵. Fig. 5 shows the variation of carbon dioxide with time. As time increases gas production increases and reaches to a maximum value and again production decreases. This variation of gas is attributed to the viability and activity of bacteria as viability increase gas production increases and as viability decreases, gas decreases (fig. 6) Since we have obtained, high OCV in case of synthetic sugar industry waste, therefore carbon balance analysis was performed only with high OCV producing waste (sugar industry). Assuming synthetic sugar industry wastewater (mainly sucrose 2gm/lit) as the sole source of carbon for microorganism, the carbon present in theses substrate get converted into²⁶ mainly into CO_2 , biomass, and some portion may remain unconverted. Samples were taken at the end of the experiment and the results were shown in table 1. About 22.03 % of biomass fractions were obtained which supports biodegradation of substrate. Carbon remains unconverted was found to be 45.92 %.

3.4 Morphological examination of electrodes: At the end of the experiment, 1 cm of carbon cloth was cut and the attached biofilm was fixed with glutaraldehyde and examined under SEM. Fig. 7 shows the SEM image of a carbon cloth electrode, showing uniform coverage of *Geobacter* biofilm

at a scale bar of 20 μm . Another microscopic observation was carried out to confirm the presence of *Geobacter* species. Gram staining was done and pictures were obtained in fig. 8 confirms the presence of gram-negative bacteria. This result is consistent with the result obtained with other researchers²⁷.



Figure 1. MFC with arrangement for CO₂ trapping

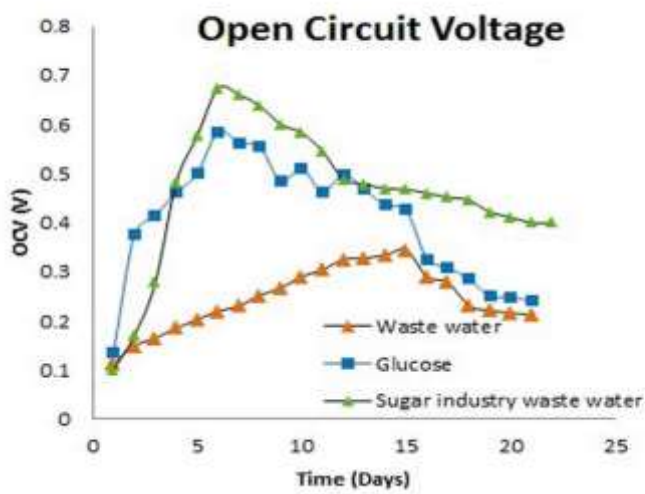


Figure 2. variation of OCV with time for three different substrates

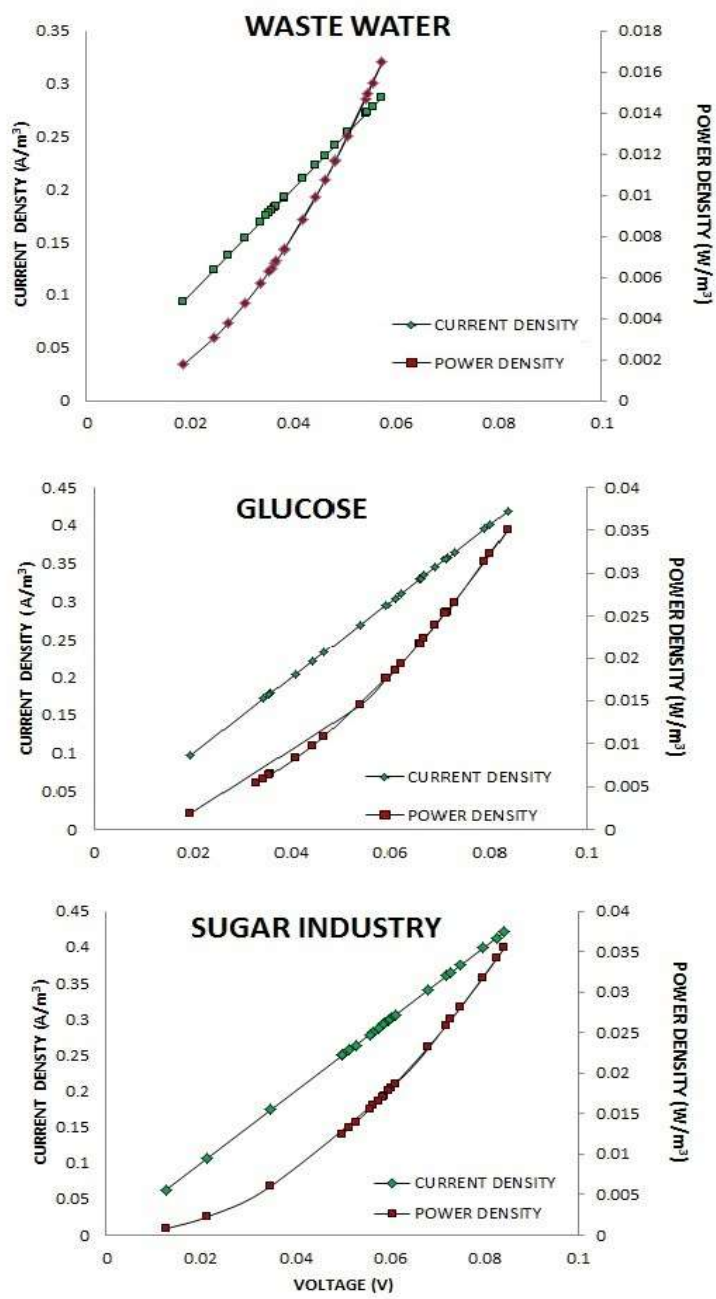


Figure 3. current density and power density profile for three different substrates

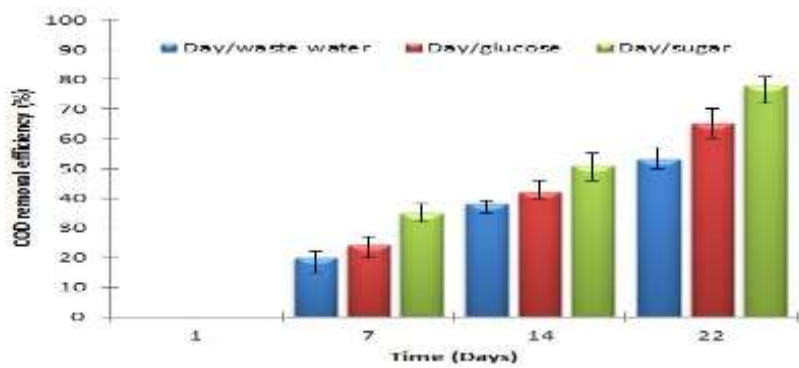


Figure 4. COD removal efficiency

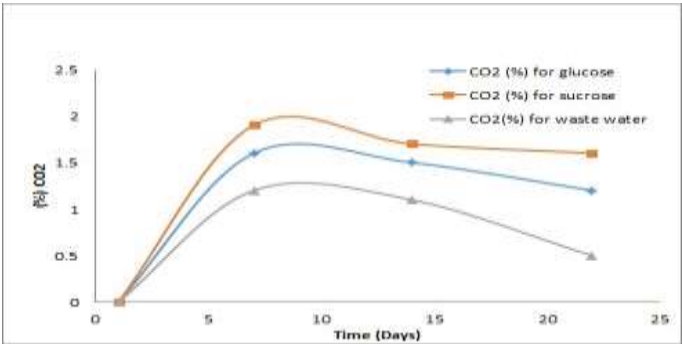


Figure 5. variation of carbon di oxide with time

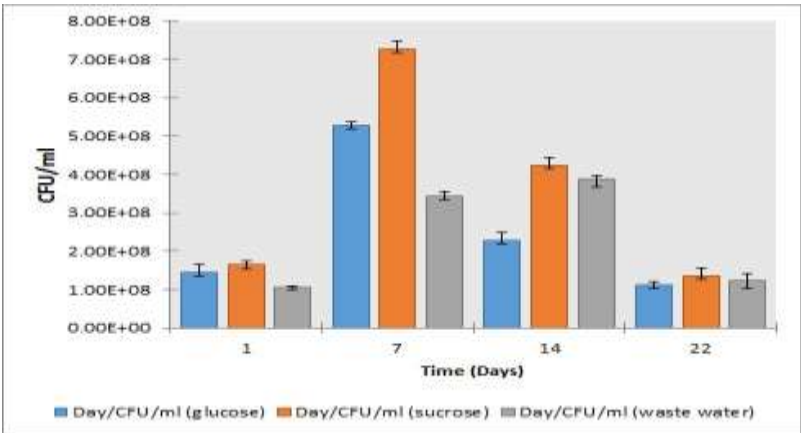


Figure 6. variation of viability of cell with time

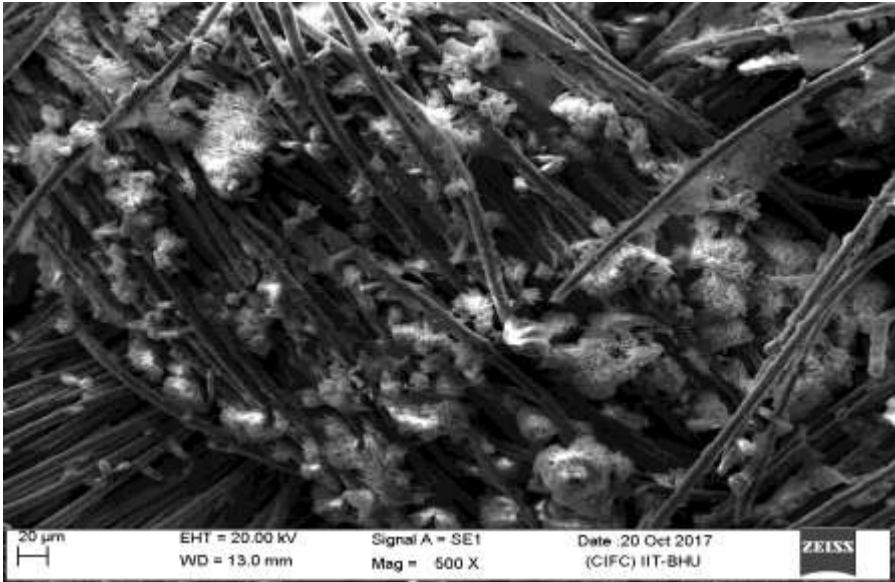


Figure 7. SEM image of carbon electrode at the end of the experiment, showing uniform coverage of *Geobacter* biofilm. Scale bar is 20 μm.

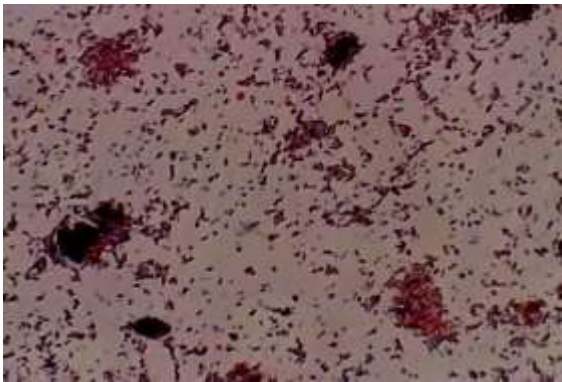


Figure 8. gram staining of sample taken from MFC

Table 1 Carbon mass balance

Carbon present	Amount of carbon (mol/l)	Percentage (%)
Inlet sucrose	0.0699	100
CO ₂	0.0224	32.04
Unconverted sucrose	0.0321	45.99
Biomass fraction	0.0154	22.03

Table 2 Summary of result obtained by MFC operation

Summary of result for Different Substrate						
Sample	Waste Water		Glucose		Sugar industry waste water	
Parameters	Initial	Final	Initial	Final	Initial	Final
pH	6.83	6.96	8.14	8.72	9.14	9.32
COD	192 mg/l	115.44 mg/l	1060 mg/l	632.45 mg/l	2240 mg/l	1259 mg/l
%COD Removal	39.87		40.33		43.79	
OCV (max)	0.34 V		0.58 V		0.6738 V	
Voltage (max) at 1000Ω	0.0546 V		0.0836 V		0.08423 V	
Current density (max)	0.2730 micro A/c.c		0.4183 micro A/c.c		0.4211 micro A/c.c	
Power density (max)	0.0149 micro W/c.c		0.0349 micro W/c..c		0.0354 micro W/c.c	

4. Conclusions

The present study successfully demonstrated the use of double-chambered MFC for the production of electricity along with the biodegradation of waste. MFC has the potential of converting different waste (substrate glucose, sewage wastewater, and sugar industry wastewater) into electrical energy. Maximum OCV was obtained with the sugar industry wastewater because of its high sucrose content. SEM analysis indicated the presence of a biofilm layer on the surface of the electrode and optical microscopy also confirms the presence of gram-negative bacteria. COD removal efficiency ranges in between 39 - 44 % (table 2) which was good enough if electricity production was taken into account. Carbon balance also indicated that only 22 % of inlet carbon was converted into biomass fraction.

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