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Electricity generation from wastewater using a microbial fuel cell by using mixed bacterial culture

Harshal D. Kawale*, Anil C. Ranveer, Abhijit R. Chavan

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Abstract

A microbial fuel cell (MFC) is a device that uses microorganisms as biocatalysts to transform chemical energy into electricity. This study demonstrated the electricity generation from the synthetic wastewater in a two chambered microbial fuel cell (MFC) inoculated with a mixed culture of cellulose degrading bacteria (CDB). With an initial addition of a nutrient broth having concentration of 13 g/l the power density reached 469.48 W/m^2; while the maximum voltage reached is 1.0 V. The maximum power for this two chambered MFC was 1.0 W (at current of 1.0 Amp). These results demonstrated that electricity can be produced from the synthetic wastewater by exploiting CDB as the biocatalyst. In this case, the synthetic wastewater consists of cellulosic material and hence the most suitable mixed culture of bacteria is cellulose degrading bacteria. The research study of this kind was done first time and provided satisfactory good results. This method suggests that, if the constituents of the wastewater are known then we can use a bacterial culture as per the constituting elements which can give us the maximum output for bioenergy production.

Keywords: Microbial Fuel Cell, Sustainable Energy, Bioelectricity generation, Wastewater treatment.

Introduction

It is well recognized that alternative sources of energy are urgently required. Current reliance on fossil fuels is unsustainable due to pollution and finite supplies. While much research is being conducted into a wide range of energy solutions, it does not appear that any one solution alone will be able to replace fossil fuels in its entirety. As such it is likely that a number of different alternatives will be required, providing energy for a specific task in specialized ways in various situations. It was discovered that, bacteria can be used to produce electricity from waste and renewable biomass has gained much attention. Therefore, there is great interest in exploring alternative energy sources to maintain the sustainable growth of society (Zhu et al, 2006). Microbial fuel cells (MFCs) convert the energy available in biodegradable substrates such as glucose, sucrose, and starch; low molecular weight organic acids such as acetate, oxalate, and fumarate; and amino acids directly into electricity through the catalytic activity of electrochemically active bacteria attached to the electrode (Bond DR and Lovely DR, 2003, Kim MS and Lee YJ, 2010, Min et al 2005, Jung S and Regan JM, 2007, Logan BE and Regan JM, 2006, Karra et al 2013). These bacteria can oxidize organic compounds to carbon dioxide and transfer electrons to the anode; then, electrons pass through an external circuit to the cathode to produce current (Min et al 2005, Logan BE and Regan JM, 2006, Liu et al 2013). Protons migrate to the cathode to and combine with O_2 and with electrons which released from anode to from water (Bond DR and Lovely DR, 2003, Logan BE and Regan JM, 2006). Electron transfer can occur either through membrane associated components (Min et al 2005, Logan et al 2005), soluble electrons shuttles generated by specific bacteria (Bond DR and Lovely DR, 2003). Microorganisms that have been used in MFCs include pure cultures of obligatory and facultative anaerobic bacteria (Bond DR and Lovely DR, 2003) and mixed bacterial cultures (Min et al 2005, Logan et al, 2005, Bond et al, 2002) and municipal and industrial wastewater (Min et al 2005, Kim et al 2004, Min B. and Logan BE, 2004).

The maximum current in the MFC depends on (a) the MFC design, which determines the electrochemical losses (such as internal resistance); (b) activation losses, which can be lowered by the microbial production of an electron shuttle; (c) the type of substrate and its concentration; and (d) the genus and the activity of the microorganisms; (e) presence and types of membrane, electrode surface area and conductivity; (f) ionic strength and pH (Borole et al 2011). However, electricity production from a single MFC is quite limited due to the low power generation of the unit, which largely depends on the redox potential between the respiratory enzymes of anodophilic bacteria and the cathodic reactant (Ortega-Marti'nez et al 2013). The use of stacked MFCs in series or parallel is essential to increase the voltages and currents produced by MFCs. (Aelterman et al 2006) Aelterman et al increased the voltage and current by stacking six individual continuous MFC units. Each MFC unit was composed of two chambers (anode and cathode chamber). In addition, Oh and

Harshal D. Kawale*, Anil C. Ranveer, Abhijit R. Chavan

Department of Chemical Engineering, Dr. Babasaheb Ambedkar Technological University, Lonere, Raigad - 402103, Maharshtra., India

*Tel: 0091 8655592246; *E-mail: harshalkawale12@gmail.com

Logan (Oh SE and Logan BE, 2007) used stacked MFCs to increase the voltage output; they found that open circuit voltage for serial connection was 1.3 V, but voltage reversal still occurred.

Recent studies have demonstrated that cellulosic biomass can be partially degraded for electricity generation (Rezai et al 2007, Ren et al 2008, Rismani - Yazdi et al 2007, Hassan et al 2012) using exoelectrogenic bacteria (Min et al 2005, Logan BE, and Regan JM, 2006). For electricity production from a cellulosic biomass in an MFC, the biocatalyst (bacteria) should be able to utilize synthetic wastewater (nutrients) under anaerobic conditions and be electrochemically active. Also, the bacteria should not require any electron shuttles for electron transfer to the electrode surface. Mixed bacterial cultures contain both anaerobic and facultative anaerobes, which capable to hydrolyze cellulosic biomasses. This study demonstrates that a mixed culture of cellulose degrading bacteria (CDB) can be used as a biocatalyst to produce electricity from synthetic wastewater consisting nutrient mineral buffer (NMB) solution.

Materials and Methods

Microorganisms

A mixed culture of CDB was used in this study as inocula in the MFCs. The mixed culture consists of *Pseudomonas Aurogenosa (NCIM 2036)* and *Pseudomonas Fluresence (NCIM 2653)*. This mixed culture is then transferring to modified Dubos' salt medium amended with carboxymethyl cellulose (CMC) as the carbon source. The CMC amended Dubos' salt consisted of 10 g/l CMC, 0.5 g/l $NaNO_3$, 1.0 g/l K_2HPO_4, 0.5 g/l $MgSO_4.7H_2O$, 0.5 g/l KCl, and 0.001 g/l $FeSO_4.7H_2O$. The CDB culture was incubated at 30 °C for two weeks; then, it was used as the inoculum in the MFC.

Medium

Nutrient mineral buffer (NMB) was used as the medium in the anode chamber of the MFC. It consisted of 3.13 g/l $NaHCO_3$, 0.31 g/l NH_4Cl, and 0.75 g/l NaH_2PO_4, trace metal and vitamin solutions whereas nutrient mineral broth was used as the electron donor and as the carbon source in this study.

Wastewater Sample

It consists of wastewater from the exit of dyes industry mixed with tap water, 6.5 g of nutrient mineral broth and distilled water sum up to make 500 ml of sample for anaerobic chamber and the mixing is done using shaker.

Salt bridge

It was made by using 5% of KCl, 2.5% Agar, Agar Type I, 92.5 % distilled water. After mixing these constituents, the mixture was heated till boiling, and then quickly poured the mixture into the plastic tubing and then cooled it to room temperature.

MFC construction and operation

The H-type MFC consisted of two chambers, an anaerobic anodic chamber and an aerated cathode chamber. The two MFC chambers were constructed by joining two media bottles which are fitted on the top with plastic tubing i.e. with salt bridge totally dipped into the bottles. Two electrodes (one anode and one cathode, both 21.3 cm^2) are nothing but the carbon rods dipped into the solutions. Those two electrodes are separately joined with the copper wires which are clamped on the crocodile clips. The schematic diagram of H-Type microbial fuel cell is shown in Figure 1.

All MFC tests were operated at a fixed external resistance of 1 ohm. The anode chamber is filled with 500 ml of synthetic wastewater whereas; the cathode chamber is filled with 500 ml of saline water (4.25 g of NaCl in 500 ml of distilled water). The anode compartment was inoculated with a mixed culture of CDB (*Pseudomonas Aurogenosa* and *Pseudomonas Fluresence*) 2 ml. The clamped clips of copper wire are connected to a digital multimeter to show the generating electricity in volts. Once the MFC demonstrated a repeatable cycle of power generation, the anode compartment was refilled with fresh synthetic wastewater solution and then repeats the procedure.

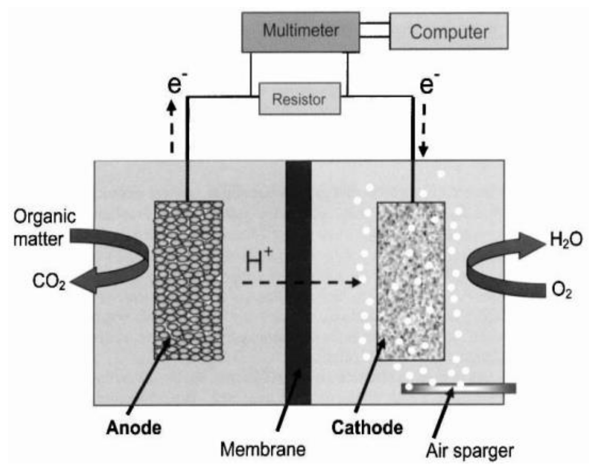

Figure 1: Schematic diagram of H-Type Microbial fuel cell.

Calculations and Chemical analysis

Cell voltages (V) were measured across an external circuit resister (1 Ω) after a certain period of time. The area of electrodes is 21.3 cm^2 each. Whereas the current generated (I) was calculated using Ohm's law i.e. V = I.R. Then the power (P) was calculated according to, P = I.V. After this, calculations were done for current density and power density. Current density is nothing but the produced current per total area and the power density is the division of square of volts generated to the multiplication of total area with the resistance. Now the Columbic efficiency for a MFC evaluated over a period of time t is calculated as,

$$\mathbf{CE} = \frac{M \int_0^t I dt}{F b V a n \, \Delta COD}$$

where, M is the molecular weight of oxygen, F is Faraday's constant, b = 4 indicates the number of electrons exchanged per mole of oxygen, Van is the volume of the liquid in the anode compartment, and ∆COD is the change in chemical oxygen demand (COD) over time 't'. COD was measured according to standard methods after centrifugation using Eppendorf centrifuge and the supernatant was filtered using 0.2 mm pore-diameter filter.

Results and discussion

Table 1: Electricity generation from wastewater using MFC

Time, Hr	Voltage, V	Current, Amp	Current Density, (Amp/m^2)	Power Density, (W/m^2)	Power, (W)
0	0	0	0	0	0
2	1	1	469.48	469.48	1
17	0.9	0.9	422.53	380.28	0.81
21	0.6	0.6	281.69	169.01	0.36
36	0.5	0.5	234.741	117.37	0.25
60	0.4	0.4	187.79	112.67	0.16
110	0.4	0.4	187.79	112.67	0.16
132	0	0	0	0	0

The CDB culture was incubated for 360 hrs. Then the synthetic wastewater was inoculated with CDB culture which consist *Pseudomonas Aurogenosa* and *Pseudomonas Fluresence*. Up to 2 hrs after transferring there was rapid increase in cell voltage reaching an initial maximum voltage of 1.0 V, having power density of 469.48 W/m^2. Over a period of time i.e. after 16 hrs there is slight voltage drop which is recorded as 0.9 V. From here onwards the voltage drop can be seen up to 60 hrs where the recorded voltage was 0.6 V and from the 60^{th} hr to 110^{th} hr the voltage was recorded as 0.4 V which is nothing but a stationary phase. After 110 hrs voltages drops towards minimum i.e. at 132^{th} hr the reading was recorded 0.0 V. Hence the run was stopped here. The COD of the samples which were taken out after the certain period of time was maxima at the start of run which was calculated 2500 mg/lit. After the completion of run it was obtained 100 mg/lit.

The obtained and calculated results are shown in Table 1. From the Table 1, it is clear that obtained values are showing very good results which actually mean that, using synthetic wastewater in MFC and adding known mixed bacterial culture for the first time proves that, the two chambered MFC system can give the maximum output by knowing the constituents of the wastewater sample and accordingly adding the mixed bacterial culture.

For the first time, this study demonstrates that, the work performed in such manner will be very helpful for the purpose of research work in the field of electricity generation using microbes which provides the scope for the bigger and better work. It is also the gateway for the systems to be used in wastewater treatment plant where at very low cost we can get the effective results and the very reach resource of Bioenergy or Bioelectricity.

The obtained results in Table 1 specify their effectiveness in following polarization graphs.

Polarization characteristics

Polarization properties of the MFC are shown in following figures. Figure 2 shows the plot of Voltage Vs Time from where we can see that maximum voltage obtained in this process is 1V. As we compare these results with some litrature using the system in wastewater sample it is perfectly clear that going with this system gives very good result in accordance with voltage production.

The polarization curves of Voltage and Power Vs Current from Figure 3 shows the maximum power reached was 1.0 Watts whereas; the maximum current was 1.0 Amp. The following curves shows us that the generating current is analogues to the voltage generated by the system and the behavior of power Vs current shows that, as current increasing the power is also increasing.

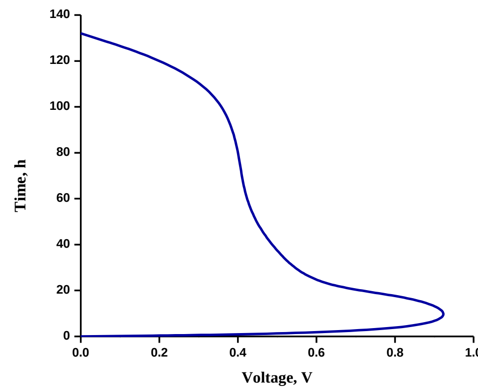

Figure 2: Voltage generation from synthetic wastewater by mixed culture of cellulose degrading bacteria using microbial fuel cell.

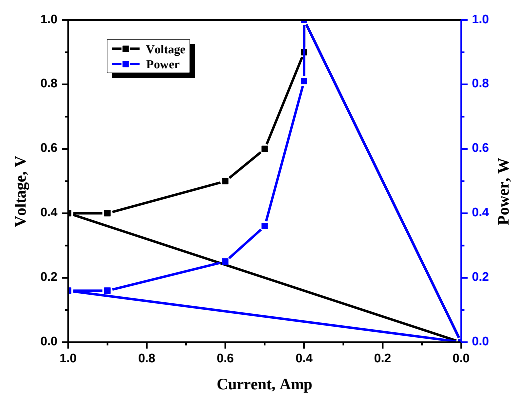

Figure 3: The maximum voltage, current and power profile.

Figure 4 shows the Voltage Vs Current plot which is linear means that, as voltage increases current increases and as voltage decreases current also decreases. It is similar to that of most of the results found by other studies.

The maximum power density was determined from the polarization curves shown in Figure 5. It is cleared that the maximum power density and maximum current density are same i.e. 469.48 W/m^2 and 469.48 Amp/m^2 respectively. But as per time passes the graph showing diminishing nature which means that the results are affected by the operating condition and the other values than the values which are maximum are also different at each and every step. This level of power and current generation is similar to the other studies (Liu *et al* 2013, Ren *et al* 2008, Hassan *et al* 2012).

These polarization characteristics are showing the significant differences between the systems after comparing with the studies of (Liu *et al* 2013, Ren *et al* 2008, Hassan *et al* 2012). other researches. Thus going with stated system in the study of MFC will encourage the new aspects of the research work. And hence will also give a scope beyond our hope.

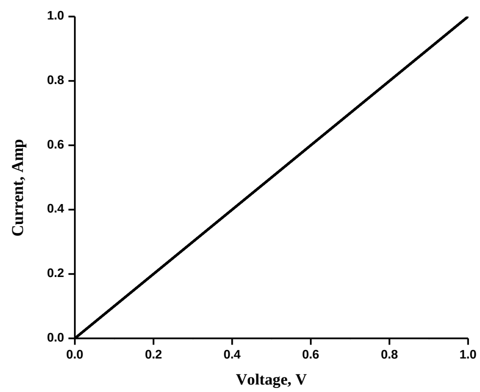

Figure 4: Voltage Vs Current showing Straight line.

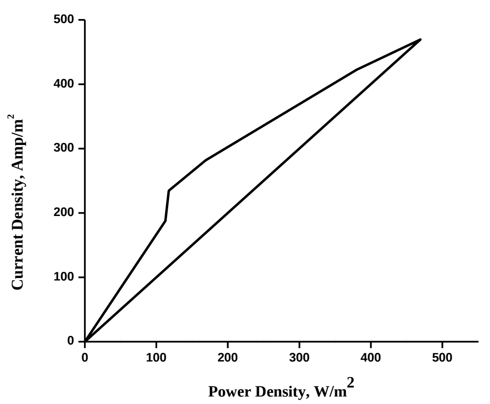

Figure 5: Power Density Vs Current Density

Conclusions

For the first time this study was done and also demonstrates that a mixed culture of CDB is capable of directly using known nutrients as substrate i.e. synthetic wastewater for electricity generation and transferring electrons to a MFC electrode without external electron shuttles. In addition, this study corroborates with previously reported studies that a mixed culture of CDB is able to produce electricity in MFCs. From the results it was cleared that if we know the constituting elements of wastewater then accordingly we can use the mixed culture of bacteria which can give the maximum results required. Therefore, this system should be very helpful for studying microbial communities and improving our understanding of how CDB degrade synthetic wastewater and transfer electrons to solid electron acceptors. And the work performed in such manner will be very helpful for the purpose of research work in the field of electricity generation using microorganisms which obliviously gives the scope for the better work in the field of wastewater treatment. It is sure that the further works can be done using same system for producing maximum electricity at very low cost at the commercial wastewater treatment plants on large scale by designing the project and understanding the bacterial life.

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