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ANODE-CATHODE ARRANGEMENT AND ITS EFFECT ON MICROBIAL FUEL CELL PERFORMANCE USING DATE PASTE AS A SUBSTRATE

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Abstract

Waste water containing 4 g/l of date paste (molasses) was used as a substrate in microbial fuel cell system composed of anode and cathode electrodes made of carbon cloth using two arrangements; in the first the anode is in parallel to cathode horizontally while the other one the cathode was above the anode vertically. The benefit of such system is by using the generated power as a source for treatment of waste water as well as other energy usages. The results showed that the second arrangement gave better values of power of about 122 μW during 20 hours of operation compared to 115 μW power harvested from the first arrangements for the same period of time. While a reduction of about 67% in COD from its initial value after an elapsed of 100 hours of operation using the second arrangement was captured, after that the system was falling down quickly due to depletion of molasses and due to film formation, limitation of mass transfer and others.

Keywords: Microbial fuel cell, Molasses, Carbon cloth, Power, COD.

1. Introduction

Microbial fuel cells (MFCs) are devices which use bacteria as the catalyst to oxidize organic and inorganic matter and generate current by electrochemical reactions (oxidation-reduction reactions). As a result of the electrodes reactions, a potential difference develops between the anode and the cathode and current flows in the external circuit [1-3]. Several parameters affect the performance of MFC, namely microbial inoculums, chemical substrates, mass transfer area, absence or existence of exchange materials, mechanism of electron transfer to the anode surface, cell internal and external resistance, solution ionic strength, electrode materials and the electrode spacing, substrate concentration, bacterial

Nomenclatures

COD	Chemical oxygen demand, mg/l
GDL	Gas diffusion layer, mm
OCP	Open circuit potential, V
O.P	Operating potential, V
R	External resistance, Ω
Abbreviations	
MFC	Microbial Fuel Cell

substrate oxidation rate, presence of alternative electron acceptors, microbial growth and others [4-6].

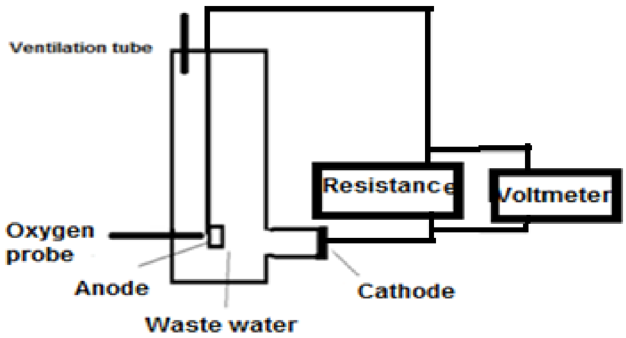
The application of MFCs for wastewater treatment or bioenergy production requires the use of inexpensive electrode materials that are electrochemically and biologically stable, and that have a high specific surface area and electrical conductivity [7-8]. In addition, the type of substrates also plays a vital role in improving the cell performance. Cheng et al. [9] through their study worked on increasing power by increasing the number of diffusion layers subjected to the air while the other side was catalyzed with platinum. The variation of power output regardless of materials of electrode depends also on the type of substrate [10], for example a value of 261 mW/m^2 was obtained using swine waste water while a 205 mW/m^2 was obtained by brewery waste water [11]. Mokhtarian et al. [12] by using Palm oil mill effluent (POME) and anaerobic sludge found that a value of 55.25 mW/m^2 was given. Ghoreysh et al. [13] compared two substrates; glucose with date syrup and they found that the power gained was better for the later than the former one. Rakesh et al. [14] found that increasing substrate concentration leads to increase in the voltage of the cell till a specified limit, beyond this limit any the environment turns unfavorable for microbes. Other valuable study about MFC can be found elsewhere [15].

Air is used as the source for cheap reactant agent; oxygen reaction or cathodic reaction -reaction 1- and at the same time molasses and its biodegradables constituents- form the anodic reaction –reaction 2-. Since there is a type of bacteria called anaerobic, therefore, when this type of bacteria is exposed to oxygen it is vanished and can’t be survived. Accordingly, in the early stages of the MFC developments the anode compartment was separated from the cathode one by a membrane [16] but due to losses of potential on membrane as well as the high cost of this material accordingly it was omitted to render the MFC working as a single chamber. In a single chamber MFC, when the cathode is subjected to air through its diffusion layer some of excess oxygen or air which is not reacted at the boundary is leaked to the solution side hence comes into contact with anaerobic bacteria especially when the anode is located to the opposite direction of the cathode a horizontally which is applied extensively [6].

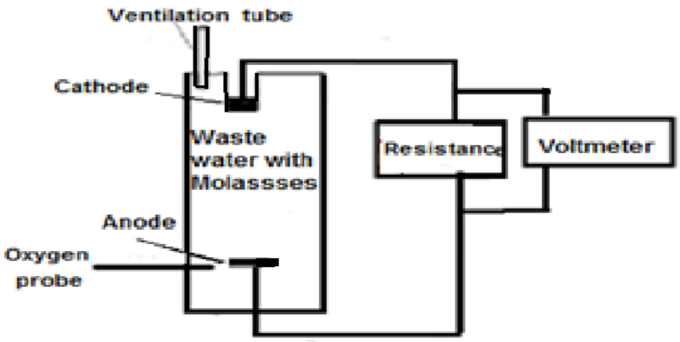
Some studies focused on the effect of the air on the behavior of MFC such as that in Oh S.E. et al [17] where they found that pumping air to the anode reduces the cell power. From the other point and according to cathodic reaction in reaction 1, it is obvious that increasing oxygen concentration leads to increasing cathodic half-cell which eventually gives high cell potential. Quan et al. [18] found that oxygen has no such effect on the anode performance in the MFC.

In this study focusing on date paste or molasses as natural, cheap (in our country) and has no hazard effects which contains a good quantity of sugars [19] such as sucrose ($C_{12}H_{22}O_{11}$), glucose ($C_6H_{12}O_6$) and fructose ($C_6H_{12}O_6$) to be used as a biodegradable substrate with high value of electrochemical potential.

Also in this study comparing the outputs of two arrangements of the MFC arrangements was studied, the first one is the familiar one and has a wide application [6] where the anode is in parallel to the cathode as in Fig. 1(a) while the other is shown in Fig. 1(b) in which the cathode is above the anode vertically. The second arrangement was suggested by the author and according to our knowledge it was not applied previously [20]. The purpose of such arrangements is to check the concentration reduction effect (if it exists) of dissolved oxygen on the MFC performance. Another aim of this paper is to get knowledge of the performance of date paste (molasses) as a substrate with carbon cloth as electrodes in MFC through measuring the output parameters such as current, potential and power and the related COD reduction.



(a) Arrangement in which anode is in parallel to cathode.



(b) Aarrangement in which cathode is above the anode vertically.

Fig. 1. The MFC assembly.

2. Experimental Procedures

A single chamber microbial fuel cell (MFC) as shown in Fig. 1 is used throughout this study. It consists of glass cylinder containing the anode and cathode having equal area of 1 cm^2. The electrodes are fixed about 5 cm from each other for the two arrangements and they are made of carbon cloth (Fuel cell earth). The cathode external face; the gas diffusion layer GDL is exposed to the air while the internal face of the cathode is facing the solution which has a volume of 500 cm3. The substrates used in this work is the raw waste water containing bacteria as inoculum with addition of 4 g/l of molasses (native manufacturing) as a feed and as biodegradable material with the composition indicated in the literature [19]- approximately sugars represent 75% of the date. The operating conditions are 30°C and pH is about 7. The electrodes were connected by copper wires to the external resistance. Open circuit potential OCP was calculated for an interval of ten hours and at each reading it was stabilized within a time of 5-10 minutes. The cell polarization was done starting from the OCP till the maximum current and from these data the output parameters were calculated. The whole duration depends on the cell performance. To measure the COD a Reactor Digestion Method was used for this with standards vials of 1500 range. A Fluke voltmeter was used to check the voltage across the leads of an external resistance R which was 1000 Ω and by using Ohm's law current was calculated, hence the power output (V^2/R) where V is the operating potential (O.P). A Hanna dissolved oxygen probe was fixed near the anode at the two cases to measure dissolved oxygen as required.

3. Results and Discussion

1-arrangment as in Fig. 1(a): A 4 g/l of molasses was selected between other values. This choice is due to the best results obtained-not shown-such as (OCP and operating potential) while the electrode used was carbon cloth only. Figure 2 shows the potential versus time, from this figure it is clearly seen that the potential at time equal zero has a good value and as the time starts it began to fluctuate till the 60 hours of exposure suggesting several trends; the fluctuation is the unsteady behavior of the electrode between the oxygen reduction reaction 1 and the biodegradation of the molasses components reaction 2 due to the formation of the biofilm and electrode capacitance as well as some transfer aspects. The 400 mV at t=0 suggests that the molasses is a good biodegradable substrate –since this value represents the difference between reaction 1 and 2 at equilbrium. After 60 hours, the OCP fallen down steeply and this is due to consumption of the molasses as well as reduction of oxygen concentration in the solution. Approximately 100 hour represent the end point of the system performance. The cell reactions are [21]:

Cathode reaction:

$$O_2 + 4H^+ + 4e = 2H_2O \quad (1)$$

Anode reaction:

$$C_x\, H_yO_z + (2x - z)H_2O = xCO_2 + (4x + y - 2z)H^+ + (4x + y - 2z)e \quad (2)$$

The operating potential values are less than the open circuit one due to some losses [6].

From Fig. 3 it is seen the current has the same trend of the operating potential due to applicability of Ohm's law. Also the fluctuation is due to the same reasons mentioned above. Figure 4 shows the power gained from the cell after 20 hours of operation, approximately a 115 μWatt was harvested after the elapsed of 20 hours. This figure when analyzed, it can be seen that the maximum power of the system is at about 0.1 mA but this value is the case gained when the current takes a time of 10 hours from the starting point. This value of current represents a good value by noting that the external resistance was 1000 Ω which represents a high value compared to other studies [22]. To be remembered also that only carbon cloth without any artificial catalysts was used throughout study.

2- arrangement as in Fig. 1(b): again, by using 4 g/l of molasses in the 500-ml waste water, the following potential, current values were recorded in Figs. 5 and 6. By comparing Figs. 2 and 3 with Figs. 5 and 6 it is seen that the current value is increased in case of the second arrangement, Fig. 1(b).

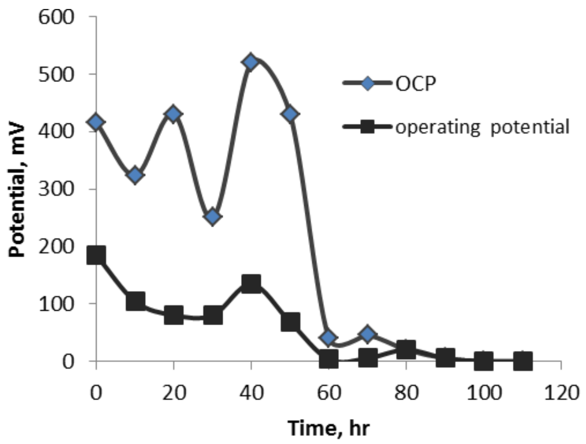


Fig. 2. OCP and operating potential of the MFC.

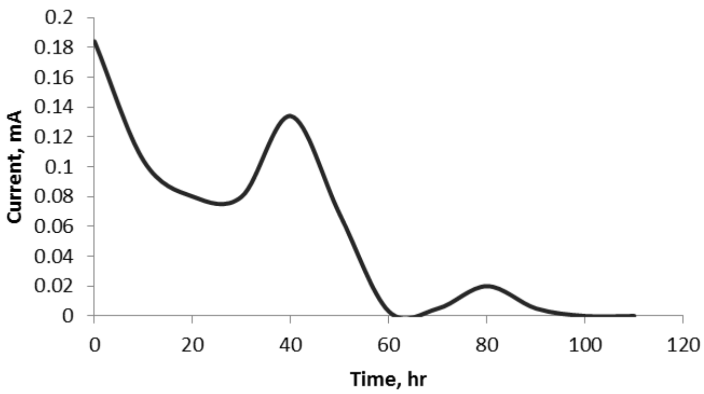


Fig. 3. The operating current of the MFC with 4 g/l of molasses.

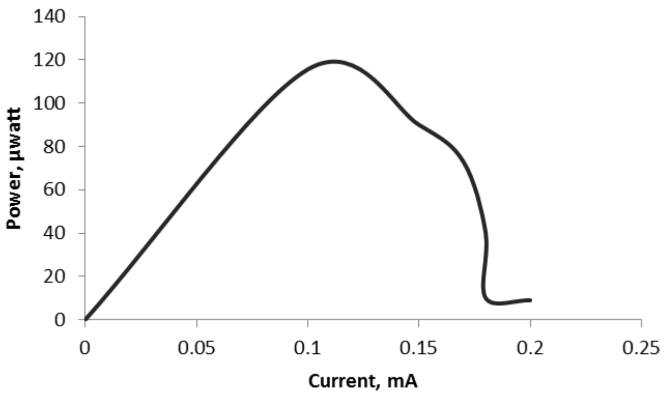


Fig. 4. The power-current for MFC with 4 g/l of molasses after 20 hours of operation.

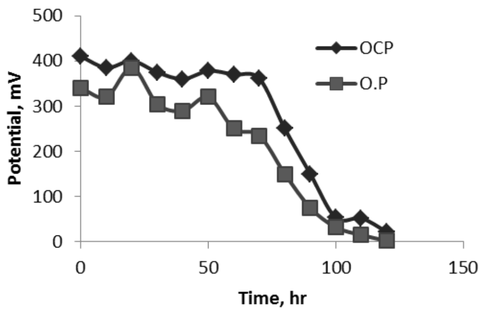


Fig. 5. OCP and O.P of the MFC.

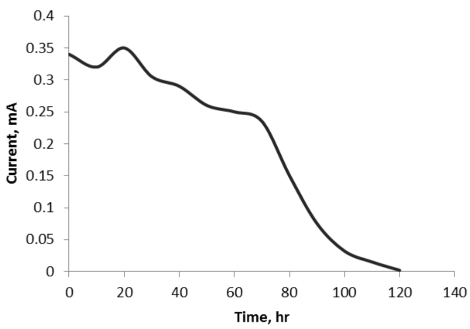


Fig. 6. The operating current of the MFC with 4 g/l of molasses.

The reason behind this lies-according to author analyzing-in that the dissolved oxygen is reduced in the vicinity of the anode region since the diffusion from the cathode vertically to the anode is minimized or limited by the buoyancy of oxygen where at t=0 the dissolved oxygen concentration was 0.43 mg/l for both figures and at t=60 hour the dissolved oxygen was 0.2 for Fig. 1(a) and 0.1 mg/l for Fig. 1(b) which ascertain the above conclusion.

From Fig. 7 the maximum power approximately is 122 μWatt and it is higher than that gained of 115 μWatt from Fig. 4 after 20 hours of operation for both noting that the current – time curve trend (Fig. 6) gave higher values in the second arrangement which implies that the molasses concentration should be reduced faster than the first arrangement due to its consumption by evolution of current along this period, nevertheless the system performance lasted till slightly longer than that of first arrangement, therefore, some other reasons play a vital role such as the biomass film formation on both of electrodes and mass transfer limitation, reduction in oxygen reduction-which could reduce the destruction of some microbes- and others. Figure 8 shows the state of the resistance obtained from the linear branch of the polarization curve of the cell obtained for the second arrangement. During the 120 hours, it is clearly shown that at the beginning of the experiment the film increases which lead to a decrease in the output current then it fluctuates till stabilization approximately around 120 hours. The resistance value comprises all the above components.

From Fig. 9 the COD reduction from about 1800 to 600 (about 67% reduction) took approximately the whole duration. This value represents a good indication for treatment by auto action without sludge formation and without any cost of adding chemicals for treatments.

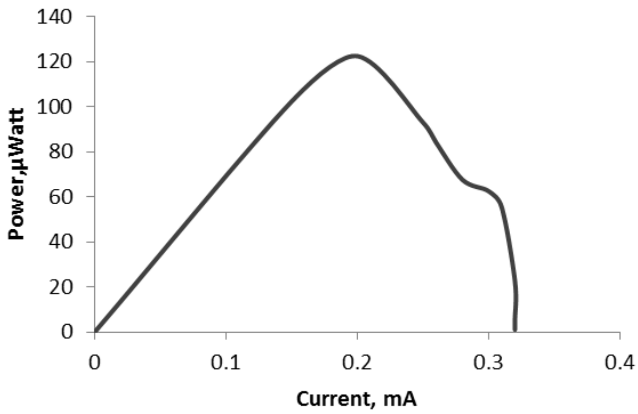


Fig. 7. Power vs current after 20 hours.

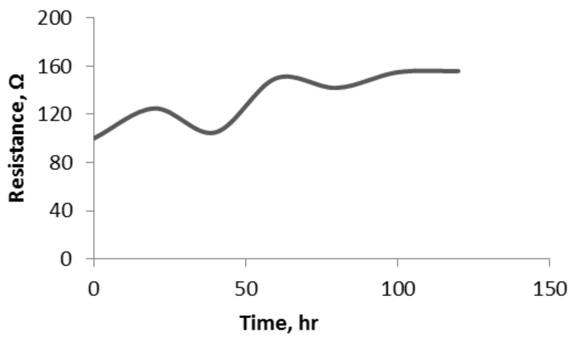


Fig. 8. The resistance evolution of the MFC for Fig. 1(b).

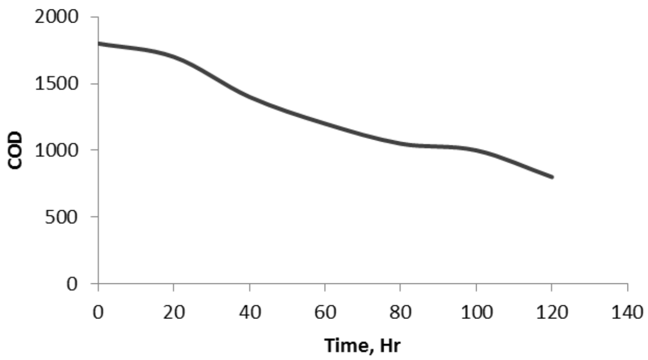


Fig. 9. COD-time value for the treatment of waste water plus 4g/l of molasses.

4. Conclusions

Waste water containing 4g/l of molasses as a substrate with alteration the position of electrodes- the cathode and anode were made of carbon cloth-in a microbial fuel cell gave a good result regarding power generation and waste treatment or COD reduction (about 67%) especially when the anode is located under the cathode. The advantage of this work is by using simple, safe substrate in handling and even has no hazard as an effluent which eliminates the need to use other chemicals that in themselves need treatment when they are disposed to sewages. This system carbon cloth electrodes plus 4g/l molasses- sustained good values of power and COD reduction for a period of about 100 hours of operation.

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