

Bioelectricity Generation in Locally Available Construction Microbial Fuel Cells using an Algae-assisted Cathode

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ABSTRACT

The present work was designed to design low cost locally available double chamber Microbial Fuel Cells (MFCs) with photosynthetic algae as cathode; inorganic carbon source algae, carbon dioxide, and sunlight to produce oxygen through photosynthesis. Microalgae grow fast; some can double in size within 7 days so that we can easily obtain large biomass within a few times. This process combines the production of biomass with efficient conversion to electrical energy. Three separate algae species were used to achieve the highest voltage levels of Chlorella sp, Scenedesmus sp, Chroococcus sp. Initially the anodic section was inoculated by activated sludge from the wastewater treatment plant and the cathodic section was inoculated by the cultures of Chlorella sp, Scenedesmus sp, Chroococcus sp as pure culture and then mixed with each other. Pure culture of each algae sample generated electricity for 7 d in a single chamber of the MFC. But mixed cultures produced more stable and more powerful than pure cultures.

Keywords: Microbial fuel cell, Bio Cathode, Algae, voltage

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1. INTRODUCTION

There are more than 7 billion people on the planet, and apart from the general increase in energy demand, a specific and even faster increase in electricity demand over the last decades is expected to continue and may even be faster than before. This is mainly due to the rapid development of some previously underdeveloped regions in Asia and Africa, with global electricity generation still largely dependent on fossil resources. Over 67% of the electricity produced comes from coal, oil or natural gas. Increasing the use of fossil fuels brings with it a number of serious issues, such as the global energy crisis, environmental pollution, and global warming.

The development of alternative energy generation technologies has become a major interest in the research community (Kouroussis, D and Karimi, S. 2006).

The microbial fuel cell is not only an attractive alternative energy source; it can also be used as a tool for the production of hydrogen, bioremediation, and biosensors. Power can be generated from biodegradable biomass (Rahimnejada M. et al., 2015). Microbial fuel cells (MFCs) are a device used to convert organic compounds to energy (electricity or hydrogen) using microorganisms as catalysts.

Bacteria are generally used in MFCs to generate electricity while anaerobic decomposition organic matter or waste. Figure (1) shows a schematic diagram of our MFC for the generation of electricity. It consists of anodic and cathodic chambers partitioned by a separator or a proton exchange membrane (PEM) (Liu, H. et al. (2008) and Potter, M. C. (1911)). The anode shell is normally held under anoxic circumstances, while the cathode may be suspended or exposed to air in aerobic solutions. There is an additional electrical connection between the anode and the cathode that usually contains a resistor, a charged battery or another electrical unit. Microbial substrate in the anodic chamber of the MFC oxidize the supplements and in this process emit electrons and protons. The protons enter a cathode chamber after passing the PEM or salt bridge where they bind oxygen to form water.

Microbes in the anodic chamber extract electrons and protons in the dissimilar process of oxidizing organic substrates [Cheng X, et al., (2004)]. During the last decade, special attention has been paid to the microbial fuel cell (MFC) technology because it could generate electrical energy and at the same time degrade multiple compounds.

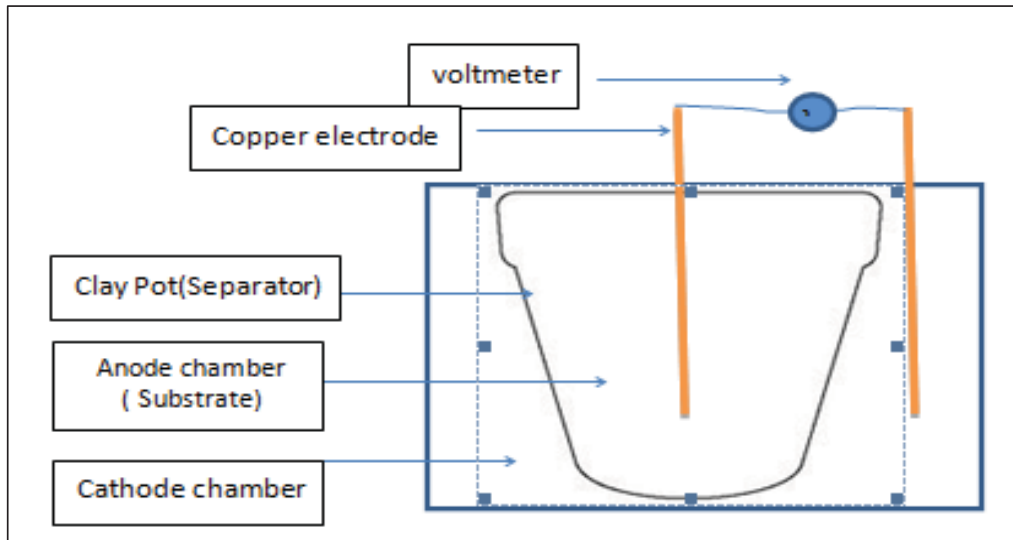
MFC technology could use a variety of materials as fuels, including glucose [Li, J et al., 2010]. Power output would be improved by an increased organic loading rate [Juang, D.F., et al., (2011)]. However, the energy generation that relies heavily on the input of the substrate would not make the system cost-effective.

Scientists tried to use the wastewater as a substrate, but the wastewater system was not clean and the power output was low [Franks, A.E. and Nevin, K.P.]. (2010)]. The MFC also uses energy much more efficiently than the standard combustion cells. Theoretically, MFC efficiency is more than 50 percent [Gregor, H, (2002)].

Any organic material can be a source of nutrition for MFCs. Micro-organisms generate electrical flow by oxidizing the organic material and do not require any pressure in MFCs like other Fuel cells, which is the most important [Yia, H. And, Nevina, K.P 2009, Bond, D. And that's D.R. Lovley, in 2005]. There is a lot of types of MFC's.

In conventional MFCs, the anode is biological and the cathode is abiotic. The high cost of materials used in MFCs, such as the Nafion membrane commonly used in laboratories as a proton permeable membrane, would also limit applications that led to Developing a variety of alternative low-cost components, for example. clay-ware membrane. [Rajesh, P.P Noori et al., 2014], Ceramic membrane [Walter, X.A et al., 2015], natural rubber membrane [Winfield, J. et al., 2014]. Efficient cathode needs a high concentration of oxygen available at all times, and low oxygen solubility in catholyte can be a problem.

Also, the slow rate of oxygen reduction in cathode electrodes was also a major limiting factor for power generation, which significantly contributed to the low level of power generation required for industrial applications in the MFC laboratory for the time being, with only a few low-power applications



successfully deployed. In order to overcome these obstacles, microorganisms are used in the cathode, the so-called bio-cathode.

On the other hand, when sunlight is transformed into electricity within the metabolic reaction scheme of the MFC, this system is described as a photosynthetic MFC [Rosenbaum, M., He Z. and Angenent L. T. 2010].

Figure (1): a schematic diagram of our MFC

One solution is to add photosynthetic cultures to the cathode chamber, where the catholyte is oxygenated under illumination. Algae have been explored for some time to provide an alternative source of energy. In the present study, an attempt was made to produce bioelectricity from different algae samples in order to evaluate electricity using pure and mixed species under illumination.

2. MATERIALS AND METHODS

In this work, a photosynthetic microbial fuel cell with two compartments was used as a custom-made clay pot cylinder with a wall thickness (5.0 mm) as an anode chamber and an ion exchange partition positioned inside a plastic box in the middle of the air-tight food grade rectangular plastic box. Electrodes with an active area of 5.1 cm² of copper electrodes with a diameter of 0.13 cm and a length of 25.0 cm. The electrodes were sterilized in 100% ethanol for 30 min. The anodized compartment was initially inoculated with 250 ml of activated sludge from the biological reactor of the Sohag Governorate wastewater treatment plant El-Shahid 3, Sohag, Egypt.

The cathodic compartment was initially inoculated with 250 ml of the culture of *Chlorella* sp, *Scenedesmus* sp, *Chroococcus* sp due, the most isolated species from the wastewater treatment plant found in Sohag, Egypt. Isolation of some algae by streaking-plate method. The cultures are grown in solid or liquid Bold Basel Medium and incubated at 25°C with an irradiance of approximately $24 \mu\text{mol m}^{-2} \text{s}^{-1}$ (Stanier et al., 1971) until single species of Chlorophyta was isolated and then each species was grown under the same previous condition. Both electrodes were connected by an external resistance of 100 Ω which was used after serial potentiostat studies. Digital Multimeter was connected to the system to monitor cell potential daily, and hemocytometers were also used daily for 7 days of the experiment. The temperature in both compartments was 26 ± 1 °C. In this experiment, 6 trials were performed as a table:

Trial	Anode	Cathode	Light (hr)
Trial A	wastewater	Dist. Water	12
Trial B	wastewater	<i>Chlorella</i> sp	12
Trial C	wastewater	<i>Chroococcus</i> sp	12
Trial D	wastewater	<i>Scenedesmus</i> sp	
Trial E	wastewater	<i>Chlorella</i> sp <i>Scenedesmus</i> sp	12
Trial F	wastewater	<i>Chlorella</i> sp <i>Scenedesmus</i> sp	24

Table (1): all trial that is used in the cathodic compartment.

Little work has been done to date on finding cheap, locally available materials for the construction of efficient MFCs. Most of the research focuses on increasing energy production rather than lowering costs. Most MFCs use expensive materials such as Nafion® for membranes and platinum for cathodes. Traditionally, the efficiency of MFC is expressed in terms of "energy/MFC unit." This research has shown that the Ashutosh Patra (2008) method power to cost ratio (PCR) metric was used to compare low-cost MFCs with more expensive MFCs that produce higher amounts of power.

3. RESULTS

In this study, three different factors improve the efficiency of MFC experiments to investigate the role of MFCs in the MFC system.

- 1-Addition of algal species
- 2-The type of algal species
- 3-The role of illumination

In order to determine whether the addition of algae to the cathodic solution would make a positive contribution to the production of electricity, we compared the addition of different algae species (Pure-Mixed) with no additional algae species.

The current algal species output voltage of MFCs has a different power generation potential. As shown in Figure (2), there is a significant correlation between the growth of *Chlorella* sp. And *Scenedesmus* sp, *Chroococcus* sp.

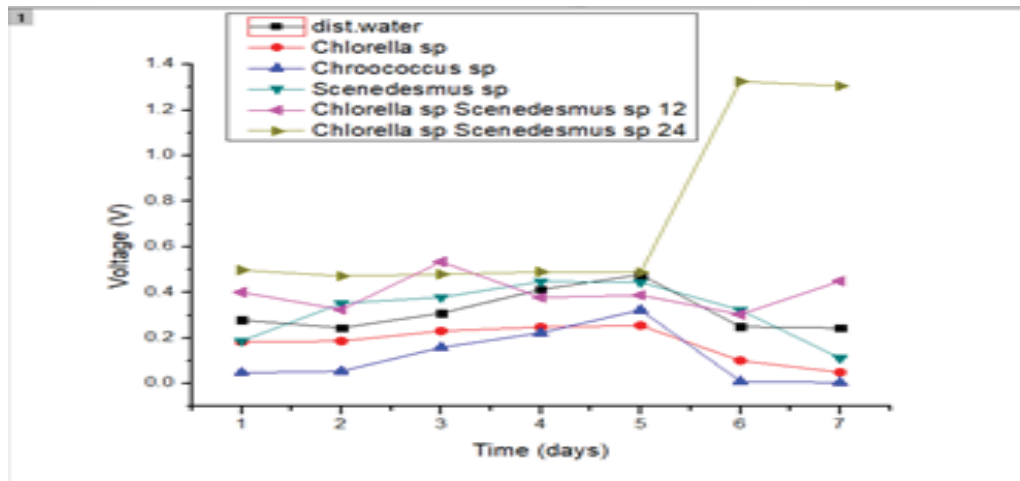


Figure (2): Relation between algal species and the output voltage

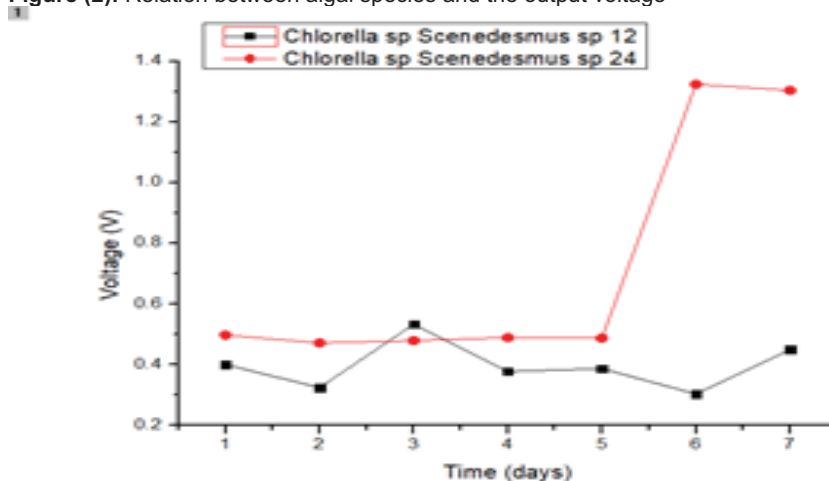


Figure (3): Effect of period of illumination on the output voltage

Extension of the light exposure of the algae in the cathode to promote the production of added-value pigments in the cells and with the agreement of this parameter as shown in Figure (3) 24h of illumination (1.3 V) led to a duplication of the voltage compared to 12h of illumination (0.4V).

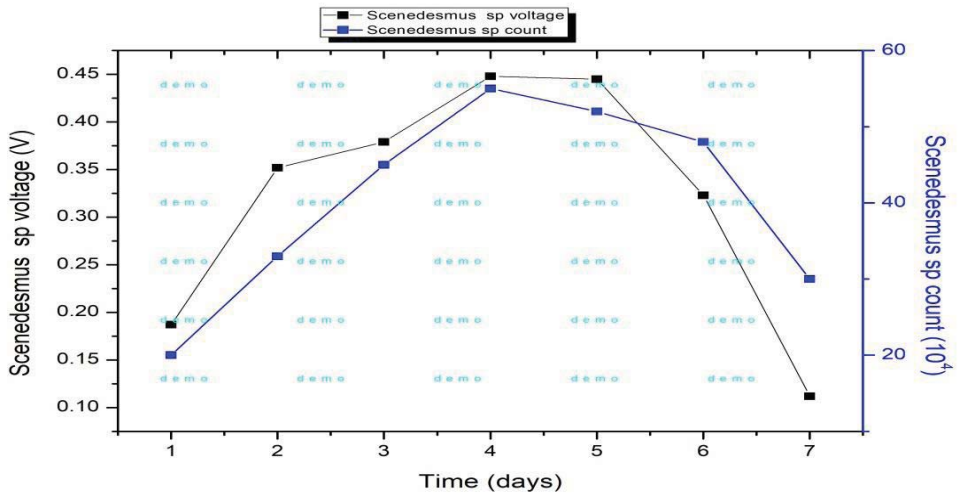


Figure (4): Relation between algal count and output voltage

The concentration of microorganisms in the cathodic compartment was changed during the experiment. As shown, an increase in the concentration of algae was observed on day 4. Electricity has begun to increase at this time. After that, the concentration of algae in suspension decreased from $55 \times 10^4 \text{ cell/ml}$ to $30 \times 10^4 \text{ cell/ml}$ on day 7 when electricity production reached a stable state.

Therefore, the decrement of the algae concentration indicated that the algae in suspension could form a biofilm on a cathodic electrode decreasing the concentration in suspension which had a significant effect on the output voltage of the MFC, which had given a maximum voltage of 0.45 V at a high algal species count of 55×10^4 cells.

3.2 Power to cost ratio (PCR) for Our MFC

For Design, wastewater at anode – mixed algae at cathode

Voltage = 1.32 V

Current = 0.024 mA

Electrode surface area = 5.3 cm²

Therefore, $P = 1.32 \times 0.024 = 0.0317 \text{ mW}$

The assumption that power is proportional to the area of the anode is, then:

$P/m^2 = 0.0317 \text{ mW} \times 10,000 \text{ cm}^2 / 5.3 \text{ cm}^2 = 59.77 \text{ mW/m}^2$

Cost = 5.0 \$ /m²

Final power to cost ratio of our MFC by \$ = $59.77 \text{ mW} / 5.0 \$ = 11.95 \text{ mW}/\$$

While Ashutosh Patra design MFC had PCR 0.42 mW/\$ Ashutosh, P. (2008).

4. DISCUSSION AND CONCLUSION

The prime purpose achieved was to use low cost locally available double chamber construction Microbial Fuel Cells and to improve the electricity yield of the algal species added to the MFC through algae and illumination to improve the electron acceptance of the MFC cathode and to make a positive contribution to the production of electricity, and the various algae species (Pure-Mixed) showed that the mixed culture produced stable among these powerful pure cultures, *Scenedesmus* sp. More electricity can be generated than *Chlorella* sp. and *Chroococcus* sp. Participates in photosynthesis at a higher rate and thus rapidly increasing and converting maximum amounts of energy.

An approach to improving the economic viability of such an MFC system was presented by Gouveia et al.[19], which increased the light exposure of the algae in the cathode in order to promote the production of added-value pigments in the cells and, in agreement with this parameter, the 24h illumination resulted in a duplicate of the voltage compared to 12h of illumination.

The concentration of microorganisms in the cathodic compartment changed during the experiment. Increased concentration of algae has been observed as electricity has begun to and the concentration of algae in suspension decreased when electricity production was exhausted.

Therefore, the decrement of the concentration of algae indicated that the algae in suspension could form a biofilm on a cathodic electrode that decreased the concentration in suspension which had a major influence on the output voltage of the MFC, which had given a maximum of high algae species, as a result of which we could conclude that the drawback of this approach was a drop in the concentration of oxygen in the dark.

Efficiency of the MFC can be evaluated with the new parameter "Power to Cost Ratio" (PCR) Increase. Oxygen cultures with microbial fuel cells the cathodic solution would improve the production of electricity, and mixed algal culture would produce more power than pure culture. The output voltage of the MFC was positively related to the count of algal species and verses. Experiments have shown the ability to construct low-cost, effective MFCs. For example, Design Type III was 28 times as cost-effective (\$/mW) as the typical Ashutosh Patra MFC design.

Finally, the extension of the illumination should provide MFCs with the maximum yield for a period of time, but the feed batch of the new algal culture will produce stable and high electricity.

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