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Comparative Study on Two Different Up Scale Locally Available Construction Microbial Fuel Cells

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Abstract: The present work deals with the up-scale double chamber microbial fuel cell (MFC) to generate electricity from wastewater. The experiment was performed to improve generation electricity from wastewater as the substrate using the MFC. There are two strategies for making large-scale MFCs for electricity generation and wastewater treatment: enlarging the size of an individual reactor and combining small MFC units as a stack cells. Present cells were constructed from locally available materials of clay pot. The performance of MFC was evaluated by characterizing the generated voltage, current, power and power density. Large size MFC has given maximum voltage by 717 mV and COD removal 66.3%, while stack MFCs has given maximum voltage by 1185 mV and COD removal 75.5 %. Thus, this study has demonstrated that the MFC can be used for electrical energy generation and COD removal from wastewater with more efficiency and less cost.

Keywords: Renewable source, stack MFC, Microbes, clay pot.

1 Introduction

There are over 7 billion people on the planet and the exploitation of the energy stored in fossil fuels has supported global industrialization and economic growth during the past one hundred and fifty years but it is obvious that this practice cannot be sustained. Oil will not actually run out for at least another 100 years or more but demand for oil is expected to exceed production capabilities from known and anticipated oil reserves within the 2015 to 2025-time frame and this triggers a global energy crisis [1].

Apart from the general increase in energy demand, a specific and even faster increase in electricity demand can be seen over the last decades, it is expected that this increase in electricity demand will continue and might even go faster than before. This is mainly due to fast development of some previously underdeveloped regions in Asia and Africa, Worldwide electricity generation is still mainly dependent on fossil resources. Over 67% of the electricity produced is originating from coal, oil or natural gas. Other sources are nuclear (13.4%), hydropower (16.2%) and others including Wind, solar biofuels and waste (3.3%). [2] Renewable bioenergy is viewed as one of the ways to alleviate the current global warming crisis. Major efforts are devoted to developing alternative electricity production methods. New electricity production from renewable resources without a net carbon dioxide emission is much desired [3]

In this context, microbial fuel cells (MFCs) have emerged as a promising yet challenging technology.

Microbial fuel cells (MFCs) are devices which convert organic matter to energy (electricity or hydrogen) using microorganisms as catalysts. Generally, bacteria are used in MFCs to generate electricity while accomplishing the biodegradation of organic matters or wastes. Figure (1) shows a schematic diagram of our MFC for producing electricity.

It consists of anodic and cathodic chambers partitioned by a separator or proton exchange membrane (PEM) [4]. The anode compartment is typically maintained under anoxic conditions, whereas the cathode can be suspended in aerobic solutions or exposed to air. Electrons flow from the anode to the cathode through an external electrical connection that typically includes a resistor, a battery to be charged or some other electrical device. Microbes in the anodic chamber of an MFC oxidize added substrates and generate electrons and protons in the process. Carbon dioxide is produced as an oxidation product. However, there is no net carbon emission because the carbon dioxide in the renewable biomass originally comes from the atmosphere in the photosynthesis process. Unlike in a direct combustion process, the electrons are absorbed by the anode and are transported to the cathode through an

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external circuit. After crossing a PEM or a salt bridge, the protons enter the cathode chamber where they combine with oxygen to form water. Microbes in the anodic chamber extract electrons and protons in the dissimilative process of oxidizing organic substrates [5].

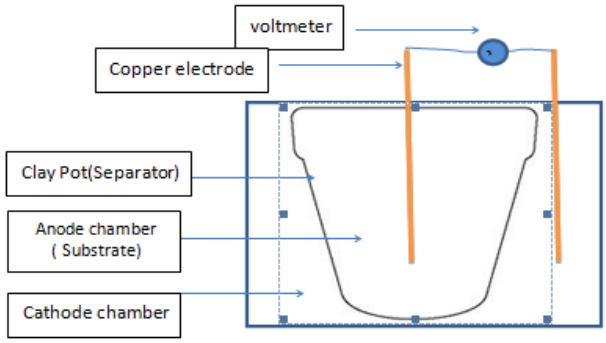

Figure (1) a schematic diagram of a our MFC

MFCs will have to compete with more mature renewable-energy technologies, such as wind and solar power. The operating costs needed for electricity production with MFCs will probably be too great if the substrate for the MFC is grown as a crop in a manner similar to that for ethanol production from corn. An MFC would be used in a wastewater treatment system as a replacement for the existing energy-demanding bioreactor (such as an activated sludge system), resulting in a net energy-producing system [6]. However, we do not yet know how to economically scale up an MFC or what the costs would be to replace a conventional system with an MFC based design. Scale-up and materials issues are the greatest challenges in the application of MFCs for wastewater treatment.

There are two strategies for making large-scale MFCs for wastewater treatment: enlarging the size of an individual reactor and combining MFC units as a stack.

A variety of challenges exist in the scaling up of individual MFCs, which may prevent the reactor size being as large as the existing treatment systems. An alternative, which may be a more feasible option for MFC scaling-up, is to construct stacks of moderately-scaled MFC units. In order to practically apply MFCs as an energy source, one can connect MFC units in parallel to produce a higher current or in series for a higher voltage [7].

When the MFC is scaled up to several liters or more, the volumetric power density can be 2–4 orders of magnitude lower than that of laboratory-scale MFCs [8,9,10,11]. Previous scaling up efforts provide us valuable information for understanding the reasons for this low power output from large-scale MFCs, which should be considered in for future reactor design. It has been proposed that one of the main reasons for power loss upon scaling up of MFCs is the increase in internal resistance [12].

May be a more feasible option for MFC scaling-up, is to construct stacks of moderately-scaled MFC units. In order to practically apply MFCs as an energy source, one can connect MFC units in parallel to produce a higher current or in series for a higher voltage. Aelterman et al. [13] connected six MFCs in parallel, which resulted in a current equal to the sum of the individual MFCs, while the voltage was similar to the average of the individual MFCs. Furthermore, the maximum power density of parallel-connected MFCs can be several times greater than that of the single MFC unit [14,15]. Another critical problem hindering the large-scale application of MFC is its high capital cost, which mainly arises from the expensive construction materials. Reducing the capital cost can be achieved by using highly efficient, scalable and less-expensive anode, cathode and separator materials. Electrodes that contain current collectors are now considered a suitable configuration, due to their simple structure and effective current collection.

The aim of this research paper is to compare between two upscale MFC for power generation and examines clay pot as an ion exchange partition or membrane less system , Also the efficiency of these MFCs were investigated for utilizing wastewater as a substrate and electron donor in MFC for electricity generation and cost for each type was also investigated.

2 Experimental Section

2.1 Sample collection

The sample (wastewater), was obtained from Sohag Governorate lifting sewage plant El-Shahid 3, Sohage, Egypt, Samples were taken in sterilized polyethylene bottles and stored at 4 ^{o}C until examination, according to the standard method for examination of water and wastewater.

2.2 MFC construction

For enlarge MFC we designed one large custom-made cylinders clay pot with wall thickness (5.0 mm) as anode chamber and ion exchange partition putted inside a plastic box in middle of the air-tight food grade rectangular plastic box 2.0 L capacity as a cathode chamber. Two small holes were made in the caps of the bottles to insert copper electrodes with is diameters 0.13 cm and length 25.0 cm, other two ends of wires were attached to digital multimeter, The wastewater was added in the anode chamber as 1L which act as a substrate and inoculum. The microorganism present in wastewater act as consortium endemic, while the cathode chamber was filled with 1 L plain water,

In stack MFC we connected four small MFCs units in series for a higher voltage. Four MFCs connecting successively each cell contain dual chambered was constructed using air-tight food grade rectangular plastic containers of 1.0-liter volume was prepared as a cathode chamber and a 0.5 L capacity custom made clay pot as anode chamber inside cathode chamber. Two small holes were made in the caps of the box to insert wire through it. Wire using aluminum clips were attached to copper electrodes; and each of them filled up by 250 ml wastewater as substrate.

2.3 MFC operation

MFC was sterilized by immersed in 5% hypochlorite bleaching solution then washed by 70% ethyl alcohol before adding the substrate solution. The MFC operated at room temperature (30 +/- 5C). The MFC was kept at static condition. All the components of MFC are connected via clay pot internally and externally with wires to the digital multimeter. The generated voltage and current were recorded from the digital multimeter for 7 days. cell connect to 100 Ω as external resistance.

2.4 Polarization curve

Polarization curve which represents a powerful tool for the analysis and characterization of fuel cells was plot as the function of current density against potential. A power curve that describes the power as the function of the current is calculated from the polarization curve show the useful power produced by the system, which considered as the main goal of MFCs production. Polarization curves were recorded after steady state of open circuit voltage (OCV). The polarization and power density curves were obtained by operating the MFCs at different external circuit resistances (100 –10000 Ω) after a steady state of operation. Potential differences were measured using voltmeter and the current were calculated using I = V/R. Current density and power density were calculated and normalized by the anode electrode surface area. Internal resistance calculated from the polarization curve from the slope line from the plot of voltage versus current. The lower of the internal resistance the higher in power density as the high internal resistance consumes the amount of power output inside MFCs and low electrochemical activity causing decrease of power generation.

2.5 COD Removal Efficiency

According to this equation we can detect the efficiency of MFC to remove chemical oxygen demand COD for large MFC.

$$\text{COD removal efficiency} = \frac{\text{COD inlet - COD outlet} \times 100}{\text{COD inlet}}$$

COD inlet represents the initial COD concentration (mg/l) in the feed and COD outlet denotes COD concentration (mg/ l) in the reactor outlet.

2.6 The Columbic efficiency CE

The Columbic efficiency, defined as the ratio of total charge actually transferred to the anode from the substrate to the maximum charge if all the substrate removal produced current, i.e. the fraction recovery of electrons recovered as current versus the starting of organic matter if all the substrate oxidized produces current. Columbic efficiency (CE) was determined by:

$$CE = 8 \int_0^{tb} idt / FV_{an} \Delta COD$$

Where, 8 is a constant used for COD, based on MO2= 32 gram/mole, 4 electrons exchanged per mole of oxygen, F is the Faraday's constant (96485 C/mole–electrons), Van is the volume of wastewater chamber, and ΔCOD is the difference between inlet and outlet COD of wastewater and tb is time duration for the cycle.

2.7 Power to cost ratio (PCR)

According to Patra [16] power to cost ratio (PCR) metric was used to compare the low-cost MFCs to more costly MFCs that produce higher amounts of power. The results reported must indicate that power was a function of the electrode surface area, the term PCR electrode surface was used for this comparison as follows:

Power (mW) = voltage (V) × current (mA)

Assuming power output is proportional to anode surface area, then:

Surface power density (mW/m^2) = Power (mW) ×10 000 / surface area

Power to cost ratio (PCR) = surface power density (mW/m^2) × Cost ($)

3. Results and Discussion

Characterization of the wastewater was carried out and shown in Table 1.

Table 1. wastewater parameters.

parameters	values
pH	6.9
COD mg/l	980
TOC mg/l	1314.6
Total N mg/l	58

increasing the surface area of the anode increasing the power generation –the large size- of MFC could significantly increase the power density compared to smaller fuel cell ,for example the larger MFCs doubling two time the size of the anode increased voltage output by only 12% According to Logan et al [14]. An alternative, which may be a more feasible option for MFC scaling-up, is to construct stacks of moderately-scaled MFC units. In order to practically apply MFCs as an energy source, one can connect MFC units in parallel to produce a higher

current or in series for a higher voltage.

However, MFCs may experience cell voltage reversal and ionic short circuits, making the series stack efficiency low, Voltage reversal can be prevented by using air cathodes of high parallelism in performance, maintaining similar homogeneity of substrate distribution in different unit cells But, in present study as shown in Figure 2 where Large Size MFC has given maximum voltage by 717 mV at day 6 ,While Stack MFCs has given maximum voltage by 1185 mV at day 4 where the single small MFC has given maximum voltage by 471mV.

So, from our results we did at 4 MFCs series which had given high voltage but low power due to with connection in series where the voltage increases by 248% and power density by 199%, it would be ideal that the output voltage equals the sum of the voltages of the individual MFCs, and the current would be at the average of the individual reactors.

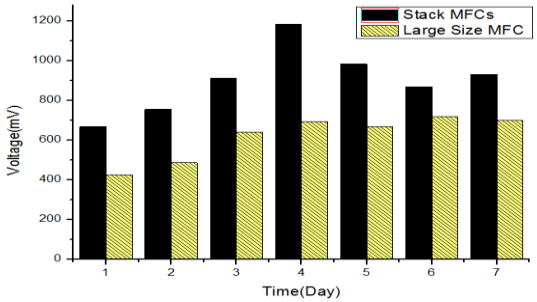

Figure 2. Effect of different up Scale MFC designs on production of electricity.

Polarization curve which represent a powerful tool for the analysis and characterization of fuel cells was plotted with the function of current density against potential presented in Fig.(3-4) show the useful power produced by the system, which considered as the main goal of MFCs production .

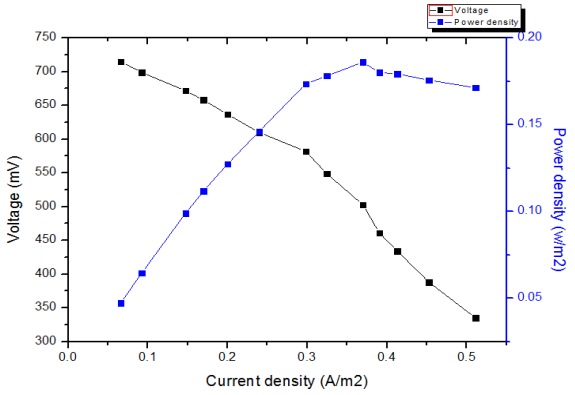

Figure.3 large MFC polarization power curve

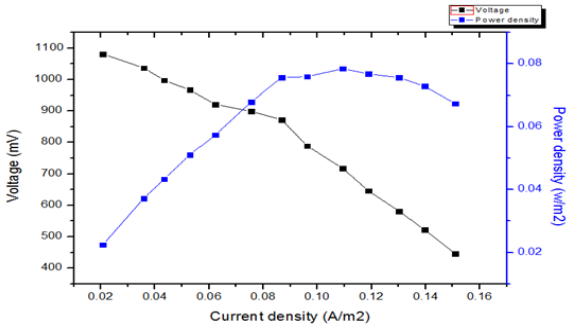

Figure.4 Stack MFCs polarization power curve

For large scale MFCs, the initial COD value recorded before the MFC process was 980 mg/l, and the final COD after the MFC process was 330 mg/l .Based on the COD removal after the MFC process, the carbon removal efficiency had a value of 66.3%.While, for stack Type III MFCs ,the initial COD value was 980 mg/l, and the final COD after the MFC process was 240 mg/l Based on the COD removal after the MFC process, the carbon removal efficiency had a value of 75.5 %.

For large MFC, the maximum power density is 0. 186 W/m^2 normalized with anodic operating surface area and it occurs at a current density of 0.1094A /m^2 so, CE was 20.89 %.

For Stack MFCs the maximum power density is 0.0784W/m^2 normalized with anodic operating surface area and it occurs at a current density of 0.056 A/m^2. so, CE was 3.66 %.

Final power to cost ratio of our large size MFC by $ was 8.12 mW/$ and, Final power to cost ratio of our stack MFCs by was 8.6 mW/$. While, Ashutosh Patra design MFC had PCR 0.42 mW/$.

The main goal was efficient upscale MFCs by cheap, locally available materials for constructing.

.4 Conclusions

the scaling up of individual MFCs was the main target of our works so upon the last information of part one we tested two methods of scaling up MFC the first method was enlarging individual MFC while the second method was stack 4 small MFCs. And each method has benefits. Some analysis did on large MFC like polarization curve and COD removal efficiency. Finally, we used a tool to evaluate our works from economical view so we used power to cost ratio (PCR) method which indicated that our MFC was near to 15 times as cost efficient than other MFC.

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