

Utilization of Sewage Sludge for Production of Electricity using Mediated Salt Bridge Based Dual Chamber Microbial Fuel Cell

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Abstract

For developing a feasible world we need to reduce the utilization of fossil fuels and also the pollutant production. These two aims can be fulfilled by treating the waste like sewage sludge. Sewage sludge is a perfect substrate for power generation as they rich in organic substance. This study consolidated bio-cathode with in a dual chamber MFC to generate voltage from sewage sludge (2 L) at a maximum voltage generated of 2.5 V. The use of bio cathode generates an internal resistance of 36-46 ohm, hence yielding maximum voltage generation (2.5 V) from MFC. *Saccharomyces cerevisiae* sp. was used as biocatalyst. Methylene blue (10 ml) was used a mediator and potassium ferricyanide (350 ml) was used as an oxidizing agent for the conversion of sewage sludge into voltage generation. In this MFC, anode solution was in batch and cathode was in continuous mode of operation under optimum conditions of the operating parameters like pH, oxygen flow rate and substrate concentration.

Keywords: Electricity; Sewage sludge; Microbial fuel cell; Biocathode

Introduction

Today the world is facing many problems of energy crises and global warming, there are also new technologies available in the world to overcome the problems of energy demand and global warming's. The major world energy source is the fossil fuel mostly use now a days. It is predicated that these resources will be depleted in 40-50 years. In addition, it is anticipated that it will damage the environment and cause catastrophic on global environment [1]. These emissions from fossil fuel have alarmed the world community. Microbial Fuel Cell (MFC) is probably the less complicated and one of the most advantage ways of utilizing biomass for replacement of fossil fuels for stationary energy generation. MFC has many advantages regarding environmental pollution and also suitable for power generation. Pakistan has advantages regarding biomass available in large amount. Different researchers also work on different biomass, their blends to decreases the amount of pollution and also decrease the energy crises. When we utilize the biomass it gives good option for decreasing the amount of CO₂ and also different types of emissions. In Pakistan agriculture and other waste are increasing, so there is need to be utilize MFCs to reduce it. MFC gives the opportunity to utilize biomass waste with for power generation and to reduce the emissions. The electrochemically active microbes that responsible for substrate oxidation and electron transfer are the key component of MFC, which makes it different from traditional chemical fuel cells in the past decade. The earliest current generation by microorganism was demonstrated by Potter in 1910. However, this finding was not well appreciated until the mid-18th century, when it was discovered that microorganisms could transport the electrons gained from cellular metabolism to insoluble minerals (e.g., manganese) in a process termed extracellular electron transfer. During 1990s, researchers have developed various MFC reactors using domestic or industrial wastewater as substrate which greatly accelerated the progress of technology [2,3]. In the last decade, numerous research papers on biological wastewater treatment with MFCs have been published. The first generation of MFC is driven by electron mediators. Although mediators can enhance the electron transfer for some microbes, most of the mediators are toxicity and instable, which limit the applications of mediator-assisting MFCs. Comparing traditional bioenergy technologies, the MFC technology has following advantages: (1) broad fuel availability. Nearly all kind of

organic matters such as wastewater, sludge and biomass can be utilized as fuel in MFC for electricity production; (2) clean production process and products. A MFC has no substantial intermediary processes, it can convert substrate to electricity directly, which is kind of energy ready for use. There is no second pollution and pollutant production. The off gas is CO₂, which can be discharged without further treatment; (3) less sludge production, due to the electricity production. The bacteria growth yield is considerably low compared to that of anaerobic processes; (4) mild operation condition. Unlike anaerobic digestion and other fermentation processes, MFC can be applied in mild condition such as low temperature and low strength wastewaters; (5) no need of aeration. The air cathode MFC could use oxygen directly from air, thus lower the aeration cost; (6) low cost of catalyst. With the development of bio-anode and bio-cathode, microorganisms could sever as efficient catalyst instead of expensive metals; (7) broad applications. MFC was initially designed for wastewater treatment, but with some modifications, MFC could be easily converted to other kind of technologies for special applications such as pollutant removal, hydrogen production and bio production etc. Though promising and has nearly 100 years history, the systematic development of MFC has started only decade ago, MFC is still "young" and has some limitations, such as the performance of the system are far from optimized, the power generation is still low compared with traditional fuel cells; the construction and materials cost are still expensive. The advances in bio cathode research have greatly expanded the application scope of MFCs. It is reasonably expected that with the development of engineering and science, the MFC and its based technologies have the potential to be more promising renewable energy sources for future. MFC is not only

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the foundation but also shares common limitations with other MFC-based technologies, thus a better understanding of MFC technology is important and helpful for optimizing all MFC-based technologies. A typical two chamber salt bridge based MFC has two chambers one is cathodic chamber and another anodic chamber and these separated by membrane like salt bridge. In the MFC microbes acting as a biocatalyst, that utilize organic matters and release electrons. In addition, ferricyanide is generally used as electron acceptor, which can enhance power density by 1.5 to 1.8 times. However, toxicity and nonrenewable property of ferricyanide limit its application. There are many specific contaminants (such as nitrate) that can serve as electron acceptors in natural environment. The aim of this research is to generate electricity from sewage sludge using dual chamber MFC in relation to operational parameters like pH, oxygen flow rate, substrate concentration etc. [4-6].

Materials and Methods

Substrate collection-sewage sludge

Sewage sludge (1000 ml), which served as the substrate of the MFC was collected from the hostel of MUET Jamshoro, Pakistan (Table 1).

Fabrication and operation of double chamber MFC

Salt Bridge-Immersed-Air Cathode MFC consisted of a plastic container of capacity 2 liters which served as the anodic chamber (Figure 1). The anodic compartment contained the substrate and the copper electrodes (6" each). The salt bridge served as an electrolyte in transfer of protons. The cathode was immersed in the salt bridge when it was in molten stage to ensure complete surface contact. The 50% cathode surface was exposed to atmospheric air.

Salt bridge

Salt bridge employed here was made with 5M NaCl and 10% Agar. The salt bridge was cast in a PVC pipe (12 cm × 2 cm). Proper precautions were taken to ensure complete sealing of anodic chamber by means of applying epoxy and wax to ensure anaerobic conditions [7,8].

Cathodic and anodic chamber

This chamber of the MFC was made up of plastic bottles. Two plastic bottles each of 1000 ml were used for this purpose. The bottle was washed with distilled water and then medium was filled in it [9]. Methylene blue (10 ml), sewage sludge (2 L) as a sample and *Saccharomyces cerevisiae* sp. (44 g) added to it. The sewage sludge was collected from the Hostel from MUET Jamshoro and was stored at room temperature (25 ± 3°C).

MFC operation

Substrate (sewage sludge), was added in anaerobic chamber (anodic chamber) and then it is sealed completely for the creation of anaerobic conditions. In the cathode chamber 2000 ml (H₂O 650 ml and C₆N₆FeK₃) was prepared and put in aerobic chamber (cathodic chamber). Electrodes (copper rods) were inserted in both chambers. Biocatalyst (*Saccharomyces cerevisiae*) is used in anaerobic chamber (anodic chamber). That digest organic matters present in sewage sludge and release electrons and protons were generated and moved to the cathode from the anodic chamber through salt bridge and by this way voltage was generated. A batch configuration was employed and readings were taken for a period of 20 days. The readings were taken on a daily basis [10-12].

Electrical parameters and measurements

Digital multimeter (T-33) was used to measure the voltage, which was generated during the experiments. After 20 minutes, readings were recorded for a maximum of 200 minutes.

Results and Discussion

In the experiment conducted by employing NaCl and agar based salt bridge, the maximum voltage generated was 2.5 V. All the experiments were performed in salt bridge based MFC. The generated voltage was affected and controlled by the number of factors. For the voltage generation two liters of sewage sludge was utilized in the salt bridge based dual chamber MFC, which generated a maximum voltage of 2.5 V after 200 minutes (Table 2). After 140 minutes of operation, maximum voltage generated was 2.5 V, and then it shows gradual decrease during the next 60 minutes of operation [13,14]. The voltage generation decrease after 140 minutes of operation probably takes place due to the limitation of substrate concentration. It shows that voltage generation was related with the substrate concentration's amount in anodic chamber of MFC. This study also suggested that the utilization if biocatalyst was able to convert the organic materials present in the sewage sludge at their optimum efficiency resulting in the transfer of maximum number of electrons leading to concomitant voltage generation (Figure 2) [13-17].

Factors affecting electricity generation

Impact of oxygen flow rate on voltage generation: Impact of oxygen flow rate on voltage generation during working of MFC was examined at different oxygen flow rates from 15 to 60 psi yielding in voltage generation between 0.729 V and 1.00 V respectively (Figure 3) [18]. These results show that voltage generation enhance as the oxygen flow rate was increased and reached at the maximum of around 2.5 V at oxygen flow rate of 45 psi before showing decline afterwards. This indicates that at the higher air flow rate, power generation capacity decrease due to the higher rate of oxygen flow rate in air diffused

S. No.	Characteristics	Unit	Sewage sludge
1.	pH	-	6.7
2.	Color	-	Greyish
3.	Total Solids	(mg/L)	1140
4.	Total Dissolved Solids		980
5.	Suspended Solids		160
6.	BOD		290
7.	COD		945
8.	Chlorides		262

Table 1: Characteristics of sewage sludge.

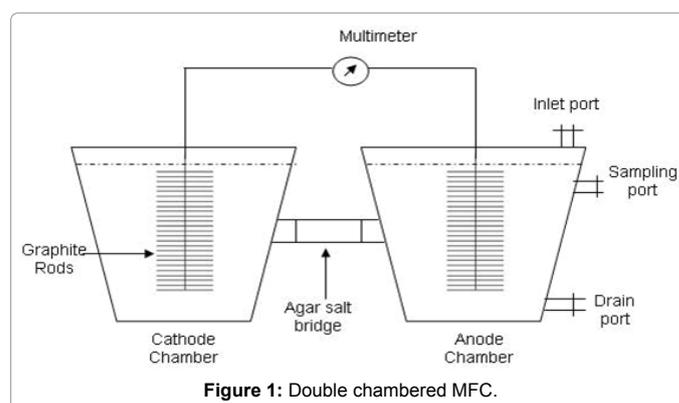


Figure 1: Double chambered MFC.

Time (mins)	Volts (V)
20	0.729
40	0.768
60	0.846
80	0.968
100	1.03
120	2.00
140	2.50
160	2.10
180	1.70
200	1.00

Table 2: Voltage generated from sewage sludge.

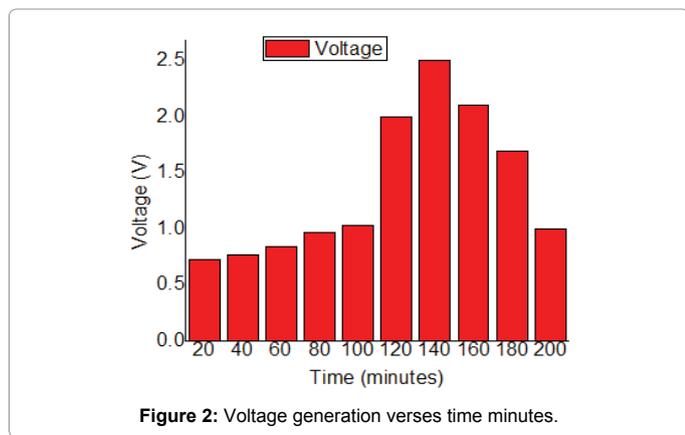


Figure 2: Voltage generation versus time minutes.

down to the vicinity of anode, which probably disturbed the anaerobic microbes living on the anodic surface (Table 3) [19].

Impact of pH on voltage generation

pH is a significant factor that affecting the activity of microbes. Growth and development of microbe's maximum at optimum pH. Figure 4 shows the maximum output of voltage was recorded at pH 8.5. The experiments show that at pH 6 and below, activities of microbes minimum when compared with the result recorded at higher pH. This is by the neutralization of proteins or active sites under acidity. These results demonstrate that there is also impact of pH on voltage generation using sewage sludge in MFC (Table 4) [20,21].

Impact of substrate concentration on electricity generation

Power production was observed to increase by enhance in the concentration of substrate (Figure 5) [22]. Starting from about 10% substrate concentration, generated voltage at 10% concentration was 0.725 V. At 70% substrate concentration, voltage was increased up to 2.5 V and then voltage was decline by decrease in substrate concentration of 100%, the generated voltage at 100% substrate concentration was 1 V. This is due to the decline in the activity of the microbes owing to various factors such as pH. This was probably due to the reduction in the activity of the enzymes owing to various factors such as pH. This also indicates that higher concentration of the substrate could actually affect the anode performance significantly resulting in simultaneous lesser power production (Table 5) [23,24].

Impact of agar concentration

In this experiment, maximum voltage generated increased with increase in agar concentration (Figure 6). A maximum of 2.5 V was obtained with 20% agar concentration (Table 6). The movement of O₂

from higher to lower concentration takes place in cathode was reduced by increased the agar concentration and hence the increase in voltage

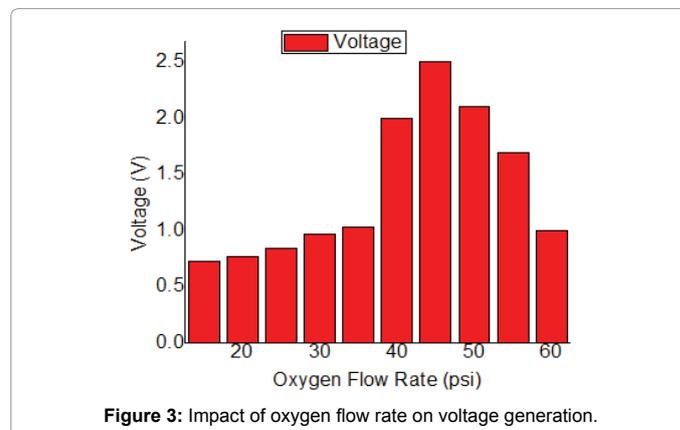


Figure 3: Impact of oxygen flow rate on voltage generation.

Oxygen Flow Rate (psi)	Volts (V)
15	0.729
20	0.768
25	0.846
30	0.968
35	1.03
40	2.00
45	2.50
50	2.10
55	1.70
60	1.00

Table 3: Impact of oxygen flow rate on voltage generation

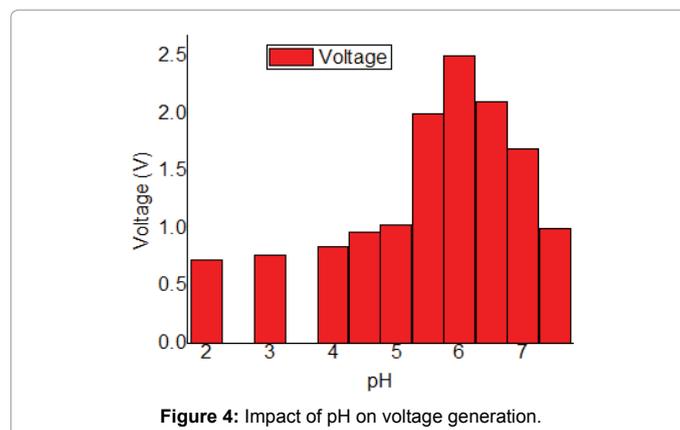


Figure 4: Impact of pH on voltage generation.

pH	Volts (V)
02	0.729
03	0.768
04	0.846
4.5	0.968
05	1.03
5.5	2.00
06	2.50
6.5	2.10
07	1.70
7.5	1.00

Table 4: Impact of pH on voltage generation.

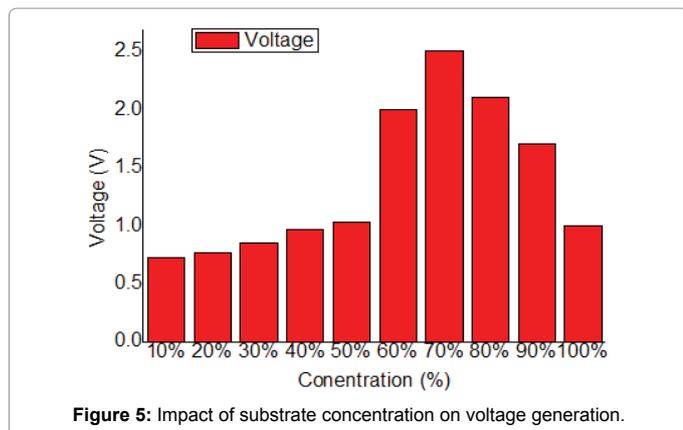


Figure 5: Impact of substrate concentration on voltage generation.

Concentration (%)	Volts (V)
10	0.729
20	0.768
30	0.846
40	0.968
50	1.03
60	2.00
70	2.50
80	2.10
90	1.70
100	1.00

Table 5: Impact of substrate concentration on voltage generation.

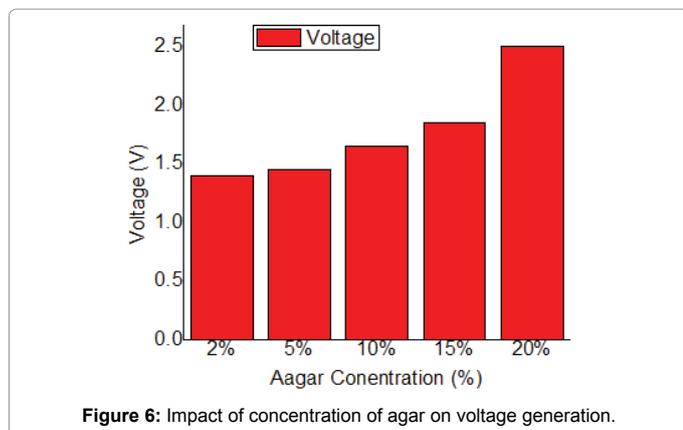


Figure 6: Impact of concentration of agar on voltage generation.

Agar concentration of salt bridge	Maximum Voltage (V)
2%	1.40
5%	1.45
10%	1.65
15%	1.85
20%	2.5

Table 6: Impact of concentration of agar on voltage generation.

generation [25].

Conclusion

MFC was tested with in the laboratory employing a fixed resistance, which might be thought about to be connected serial with the external resistor. Rescale can only be conservative if volumetrically loading rate can be expanded while not decrease in columbic efficiency. Generation

of electricity is controlled by factors with proficiency of electron change with in the electrode chamber. Thus, it's clear from the given studies that increasing production of power in MFCs needs innovative flow patterns and conductor orientation that minimizes internal resistance and findings strategies for improved cathode potential. The price of materials utilized for development of MFC is a key issue for application of the technology at the massive scale. Hence, developing a value effective procedure that is environmentally sound and property owing to due utilizing of biodegradable sludge as substrate within the MFCs. In this study double chambered MFC utilizing *Saccharomyces cerevisiae* was tried for its performance. Different salt bridges were tested. 2.5 volts was maximum voltages, generated by the dual chamber MFC. It was run for 20 days and readings were noted at regular intervals.

Recommendations

The voltage generated was still low and coupled with a high internal resistance lowered the power generated by the cells. The following are the possible studies and changes that should be established to enhance an MFC's power rating:

1. The electrical conductivity of the MFC fuel solution should be enhanced to levels that do not affect the microbial community in the sewage/waste as well as to levels that lower the cell's internal resistance to acceptable levels.
2. Studies on voltage and resistance changes should also be carried out at an hourly or half-hour basis to get a better view of the variation of voltage with time.
3. Studies should be carried out to establish the most appropriate C/N ratio that gives off the highest electrical voltage. Further studies can also be made through digestion of several biodegradable materials to establish which materials will give the highest voltage from the cell.
4. Applying of genetic engineering in the development of strains of bacteria that will be highly adaptive, efficient in the breakdown of the bio material as well as have a high affinity for a variety of bio material.
5. Up scaling of the MFC to larger treatment volumes like septic tanks and industrial food processing waste ponds and with further development, designs should be made that incorporate MFC into waste water treatment plants.

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