Energy recovery efficiency of Low Cost Microbial Fuel Cell using Domestic Wastewater

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Abstract. Microbial fuel cell is one of the emerging technologies which utilize wastewater to generate electricity with the help of action of microorganisms. The real interest in microbial fuel cells has tremendously grown in recent years. It converts chemical reaction into electrical energy and helps in the recovery of energy from wastewater. The main objective of this study was to enhance the electricity production and simultaneously treat the wastewater. The lab scale model consists of double chamber microbial fuel cell, i.e., two separate chambers one with salt water and the other with wastewater representing anode and cathode, a salt bridge acting as proton exchange membrane; electrodes from batteries are used for this study. In this, the proton exchange and electron transfer occurs after the redox reaction. The microbes in the sludge or wastewater are responsible for the release of electrons. These electrons tend to move through the external circuit producing electricity. For maintaining electrical neutrality salt bridge is used. The dual chamber microbial fuel cell used in this experiment produced an average voltage of 0.37mv for a wastewater volume of one liter. This set up is done on small scale, but with further and more detailed study it can be installed in industries that produce Microbial Waste water as a by-product to generate electricity and reuse the waste water for other processes after treatment.

Key words: Microbial fuel cell, salt bridge, electrons, voltage, wastewater treatment.

1. Introduction

Waste management and energy recovery became the limelight of the world due to the increase in the production of waste and decrease in the available resources. To meet this problem researchers have taken immense efforts and came up with different solutions. Microbial fuel cells is one of the emerging technologies to meet the waste water management [1]. Microbial fuel cell can be differentiated into two groups: mediated and unmediated. Early 20th century the first microbial fuel cells were developed and used as mediators. In the 1970s Unmediated MFCs were developed [2]. The cell is set up with anode and cathode that converts chemical energy into electrical energy by transferring electrons directly to the anode with the help of electrochemically active redox protein (cytochromes) present in the outer membrane of bacteria [2] [3]. The microorganisms interact with electrodes, which are present in the electrical circuit [4]. The huge obstacle in microbial fuel cells is high conductivity and active surface area [5]. To increase the voltage and the current in the Microbial fuel cell they are joined into two connections, one is in series and other in parallel circuit modes. The parallel connection gained high output power and some energy losses than the series stack [6]. They are the most significant bio-electro chemical systems through the metabolic activity of microorganisms that helps in converting biomass immediately into electric current. It is the most favorable and environmentally friendly method that can meet the enlarging energy needs particularly utilize wastewater while substrate will simultaneously produce electric current as well as accomplish wastewater treatment hence it also reduces the costs of treating wastewater [7]. This fuel cell consists of an anodic and cathodic chamber separated by a proton exchange membrane. Inside the proton exchange and electron transfer occurs after the redox reaction. The microbes in the sludge or waste water are responsible for the release of electrons. These electrons tend to move through the external circuit producing electricity [8]. The electrodes are made using Activated carbon charcoal produced from sawdust and were used as electrodes. Ultra-microspores (0.65–0.85 nm) were most efficient, they helped in increasing the rate performance of electrodes.
Therefore, activated carbon charcoal can be used as electrode since the pore diameter and pore length could be easily managed. However, the higher cost of microbial fuel cells is an obstacle to the market place. It is advisable to look for low-cost carbon sources [9] [10] [11]. Low cost carbon electrodes from unused batteries or cells can be used for Microbial fuel cells.

2. Material

2.1. Chambers
Both the anode and cathode chambers were taken as two glass aspirator bottles. One chamber is filled with tap water (salt water) and was left open to the atmosphere to maintain aerobic condition; the other chamber was filled with waste water and was completely closed for anaerobic condition. Each chamber has a volume of 1000 ml water. Two chambers with side opening were joined by polyvinyl chloride pipes which contains 15 ml of salt bridge. The joints were covered by Teflon tape to prevent the leakage.

2.2. Electrode
In microbial fuel cells electrodes play an important role to increase its efficiency. To increase the power production various carbon based materials like carbon paper, carbon fibre, carbon felt and carbon nanotubes composites are being used. In order to utilise microbial fuel cell technology the cost of the material used in making it has to be less and the power production has to be more. For oxygen reduction to take place the material used as cathode should have catalytic properties. Majority of the studies focus on the production of material used for electrodes to enhance the performance of Microbial Fuel Cells. The microbial fuel cells when used in large scale application results in low efficiency and less generation of electricity which is due to the limited surface area of the electrode. The important properties which the cathode has to possess are surface area, porosity, stability, electrical conductivity, durability, accessibility and it should be economical. Factors affecting the performance of electrodes are thickness and length. If energy is provided in the form of heat or radiation the electron density of the metal has to be more but since the microorganisms act as the source of the electron the thickness of the electrode does not affect the conductivity of the metal. The length in which the electron travels is directly proportional to the resistance. Therefore the wires are placed at different locations in order to reduce the distance through which the electron travels as well as reduce the resistivity of the metal \( R = \text{constant}.L/A \). Electrode materials may accelerate the reaction and reduce the resistance for transfer of electrons. Increase in the total surface area may increase the performance of electrodes. Electrodes made up of carbon are mostly used in microbial fuel cells as it improves the performance and thereby increase the surface area for conduction. In this study electrodes from unused batteries were used as electrodes. The electrodes used has a diameter of 5mm and a length of 304mm.

2.3. Wastewater
In microbial fuel cells wastewater is used to generate energy and also the treatment of wastewater is done by using anaerobic digestion. This method will be useful in reducing the disease causing microorganisms. It requires an extra process to convert the biogas into electricity and the temperature required is above 30 degree Celsius. The anodic chamber contains wastewater which was collected from the sewage treatment plant and various tests such as pH, Total Dissolved solids, Hardness etc., were performed to know its physical chemical parameters before treatment. The parameters are shown in table 1.

2.4. Salt water
The catholic chamber contains the tap water
2.5. Salt bridge
Agar is made up of various sub units of galactose and species of red algae that makes them into a polymer. Agar plays a major role in microbiology in culturing different types of microorganisms. It is also used in the fields of dentistry and culinary. In a microbial fuel cell, the anode part where the oxidation takes place and the cathode where reduction takes place are connected by a compartment made of agar which is known to be the salt bridge. In the microbial fuel cell waste water is utilized to produce hydrogen peroxide by some microbial actions and this when passes through the proton exchange membrane produces electricity. The proton exchange membrane now separates hydrogen peroxide and allows only hydrogen to pass through it. The free electrons that passes through the anode produces minimal amount of electricity.

2.6. Electrical measurements
The cell voltage recorded by digital multi-meter. Voltage is recorded every 5 minutes and the graph is plotted. “I” represents the current generated and “R” represents the external resistance.

3. Construction and working of MICROBIAL FUEL CELL
The microbial fuel cells consists of two different chambers connected together by a bridge consisting of potassium salt bridge or sodium salt bridge. The microbial fuel cell consists of an anode and cathode chamber. The anode chamber is filled with sewage water. The cathode chamber is then filled with tap water. Both the chambers are connected using PVC segments which has the proton exchange membrane in it. The anode chamber consisting of waste water is maintained at an anaerobic condition where there is no oxygen supply and the lids are air tight with an opening for methane and some other gases produced by the organisms. The cathode chamber on the other hand is constantly maintained under aerobic conditions that helps to generate oxygen. These two chambers are connected with a salt-agar bridge. The entire MFC set up is shown in figure 1. The electrons produced by bacteria are transferred on the anode and electrochemical reduction reaction takes places in the cathode. The electrodes used are carbon electrodes taken from lithium batteries which proves to be cost effective. The higher electrode surface area speeds up the performance of microbial fuel cells. The electrons and protons produced in microbial fuel cell during oxidation are transferred directly to a salt–Agar Bridge which are further converted to produce electricity by some microbial actions. The microbial fuel cell is set for 5 days in the laboratory. A multi-meter is attached externally in order to test and record the electrical output of the microbial fuel cell.

Figure 1. Microbial fuel cell set up
4. Tests conducted

4.1. pH
The function of metabolic enzymes are affected by pH. The change in the structure and the growth factor of the enzyme are mostly affected by acidic conditions (low pH) or basic conditions (high pH). A pH range of 6.5 to 8.5 is suitable for most microorganisms. The pH of the wastewater used in the experiment was 6.97.

4.2. Conductivity
Conductivity is usually measured with the help of a probe and a meter. Firstly, Voltage is applied between two electrodes in a probe which are immersed in the water sample. The resistance of the water causes a drop in voltage which is then used to calculate the conductivity of the water per centimeter. The conductivity of wastewater used here was found to be 0.77 mS/m.

4.3. Alkalinity
Alkalinity refers to the ability of water to neutralize acid. It is associated with the degree of expression of buffering capability. Alkalinity is usually associated with hardness. It’s as a result of the most important reason for pH scale is presence of carbonates. The hardness of CaCO₃ is up to its pH scale. Water has additional carbonates and therefore is more alkaline. The sulphates in H₂O don't contribute more to pH scale. Therefore water has less buffering capability and is also vulnerable to modification or fluctuations in hydrogen ion concentration. The alkalinity of wastewater used in this experiment was 950mg/L.

4.4. Hardness
Hardness may be a main facet of water quality and checks out if the water is to be used for domestic functions. Before analyzing the hardness, one should know about what hardness is and the way it happens. Water has high quantity of dissolved minerals. Hardness is sometimes expressed as milligrams of carbonate equivalent per cubic decimeter. The hardness of wastewater used in this experiment was 150mg/L.
5. Results and discussion

Table 1. Results of tests conducted.

| S. No | Test conducted | Before experiment | After experiment |
|-------|----------------|-------------------|------------------|
| 1.    | pH             | 6.97              | 7.5              |
| 2.    | Conductivity   | 0.77mS/m          | 0.7mS/m          |
| 3.    | Alkalinity     | 950mg/L           | 925mg/L          |
| 4.    | Hardness       | 150mg/L           | 140mg/L          |

Table 2. Experimental results of voltage produced using carbon electrode.

| S No | Time (hours) | Electrode                     | Voltage produced(mV) |
|------|--------------|-------------------------------|----------------------|
| 1.   | 0            |                              | 0.33                 |
| 2.   | 2            | Carbon electrode from batteries | 0.34                 |
| 3.   | 4            |                              | 0.35                 |
| 4.   | 6            | Carbon electrode from batteries | 0.38                 |
| 5.   | 7            |                              | 0.38                 |

Table 1. Represents the values obtained after the various tests conducted on wastewater before the experiment and after the experiment. Table 2. Represents the voltage produced in the microbial fuel cell by using carbon electrode for varying time intervals. The voltage produced varied from 0.33 mV to 0.38 mV. Only 0.05 mV increased for a duration of 7 hours. Figure 3 shows the graphical representation for the voltage produced during different time intervals.
Problems were faced during the construction of MFC. The microbial fuel cell technology is undergoing immense research which touches upon various aspects like its way of design, its power optimization, internal resistance reduction and potential scale-up. It is significant to take the cost reduction of the electrodes into consideration by avoiding precious metals like platinum at the cathode. Not only this, it is also essential to try out different types of proton exchange membranes (PEM) that is cheap as well as efficient in terms of separating the chambers and at the same time allowing the movement of protons while hindering the migration of various other substrates. In this experimental study of carbon electrodes like graphite rod was also used and tested. But the main disadvantage was its less surface area. Saw dust was burnt and then heated in a furnace for about 450 degrees Celsius. Then it was solidified it with sugar solution and heated again with aluminum foil sheet. But it was soluble in water. Hence the electrode inside the batteries was used at the anode and cathode. Hydrothermal Carbonization (HTC) quickly tracks the slow procedure of geothermal transformation of wet waste with an acid catalyst at high heat and pressure to increase the production of 'hydro-char' that has properties similar to the non-renewable energy sources. The advantages of this anaerobic digestion (AD) are the lower handling time and comparable working conditions which are used to create the same amount of energy. Dendro Liquid Energy (DLE). It is a ‘zero-waste’ waste to energy advancement from Germany. It is supposed to be multiple times more effective than anaerobic digestion and proves to be cheaper.

6. Conclusion
In this experimental study, the maximum voltage generated was only 0.38 mV with 1 litre volume of wastewater for a contact period of 7 hours. There was only an increase of 0.05 mV even after the contact period of 7 hours. From this experimental study it is inferred that, though the technology proves to be economical, only a small amount of energy is produced. Hence this has to be studied under large scale to infer the difference in the energy production. Possibility of implementing this technology in households to meet some part of the energy needs has to be studied.

7. Further study
Further study is required to increase the generation of output power. Since the microorganisms present and the type of electrode used are the two major factors which affect the cost and also the performance of Microbial fuel cells, the type of electrode is to be varied and the difference in voltage production has to be studied. Seeding may be done for the wastewater and change in the voltage production may also be studied in future. Activated sludge from Sewage treatment plant may be used for seeding. Proper
implementation of the above two factors can greatly increase the application of Microbial fuel cells for commercial purpose.

8. Reference
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