Analysis Of Electricity Generation Using Plate Based Microbial Reactor

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Abstract

Due to increasing population every year, there is a surge in the energy demand globally and exhaustion of non-renewable energy sources to meet the never-ending demands. It has become important to identify and utilise renewable yet cost-efficient energy sources. With respect to the above context, wastewater containing extreme amounts of degradable organic material can be used as the source for generating electric current through a microbial reactor. Electricity is produced due to the anaerobic fermentation of organic/inorganic matter by converting metabolised biomass to complex wastewater using microbes as catalysts, in this process. This project work deals with the operation of reactor using STP wastewater, graphite and carbon plate electrodes under varying conditions of aeration and biofilm. The electricity generation potential of the electrode was tested for different conditions and a maximum of 0.33 V was generated. The maximum Biological Oxygen Demand and removal efficiency of CODof 80% and 70.5% were obtained, respectively.

Key-words: Microbial reactor, Biofilm, Electricity generation

1. Introduction

Due to exponential growth in population, there has been a phenomenal depletion of resources to meet the energy demand. Available energy is categorised as fossil-fuels, nuclear-powered and renewable sources of energy depending on their means of origin and dependability. Major portion of the world's energy requirements are being met by fossil fuels and nuclear sources. To overcome this and achieve sustainability, in the recent years, fuel-cell technology has obtained importance. Microbes have shown their worth in generating electricity. Electrons are retrieved from sugar when microorganisms respire. Microbes which donate electrons or metal or other elements are made use of in microbial fuel cell (MFC). Under the influence of a circuit, metabolic activities of microorganisms can be used to retrieve electricity.

Generating electric current from the biological matter using microbial-fuel cell (MFCs) has been recorded in history dating 100 ago in the past [1,2]. According to Potter [3], disintegrating organic compounds with microorganisms led to generation of electric current. The potential of such MFC as a substitute source of energy has been researched expansively [4]. Due to absence of a conducting nature in microbial cell surface structure used in fermentation, there in inefficient transfer of electrons to the electrode. To aid in efficient electron transfer, electrochemical mediators are employed to transit electrons from microbial-cells to the electrode. These intermediators are costly, and become hazardous environment to the microbes, thereby limiting long-term use of the mediated MFCs in treatment of wastewater [5]. Generally, MFCs have lower power output when compared to other type of fuel cells. It can be made economical if the cost of production of these cells become cheaper and easier. In large-scale water treatment plants, the suspended solids and soluble contaminants lead to fouling which reduces the proton transfer mechanism through the membrane. Economically forward countries have to contribute decent amount of electricity to treat their wastewater [6]. Taking other countries into consideration, the United States of America disburse 3-4% of their total annual electricity for treating their wastewater. This electrical consumption/utilization is the same as that of the average annual electrical consumption of 9.6 million residential homes. On the other hand, the amount of energy expended by United Kingdom to treat wastewater is quite low. It is equivalent to an average of 1% of total daily electrical consumption in England and Wales[7]. Based on the analysis of statistics regarding electricity associated with water treatment, wastewater needs roughly 0.5-2kWh/m^3 of electric energy. Also it can be considered that waste-water contains energy 3-10 times more than what is used for treatment [8]. The energy that can be drawn out from waste water is majorly fragmented into forms. They can be easily categorized into heat energy, nutritional energy in elemental form (P, N2 etc.) and degradable organic matter. Extracting heat from wastewater is a tedious process. It is not advised as it is not an economical process. Roughly 26% of chemical energy is generated by carbon. It is quantified in the form of COD and nutrients [7]. By trapping and harnessing this chemical energy, electricity can be generated from wastewater. Therefore, treating wastewater can lead to net positive energy and can be considered as a feasible method that does not contribute to environmental pollution [9]. Wastewater treatment plant can be used as a substrate to generate electricity. Wastewater from hostels, canteen, college washrooms and various laboratories contain dissolved material which can be used as a substrate for microbial growth and generation of electricity. Apart from generation of electricity, pollution removal can also be achieved.

Very few researches have been carried out regarding generation of electricity using electrodes in bioreactor units. Thus, in the current study, an effort has been made to study the potential of microbial fuel cell to generate electricity and pollution removal efficiency of it under varying conditions of aeration and bio film layer on electrodes with the wastewater collected from our university.

2. Aim And Objectives

The main focus of this project work is to design a bioreactor to treat STP wastewater and generate electricity from the wastewater. The objectives set for the project are to design an effective bioreactor, develop a lab scale model and automated data acquisition system and optimize working conditions of the bioreactor along with the measurement of electricity from different working conditions and study on pollution removal efficiencies of the plate electrodes.

3. PROBLEM SOLVING

Materials:

To check the performance of bioreactor and properties of wastewater in conventional sedimentation tank, graphite plate electrodes were used in varying conditions. Comparison was done based on the varying conditions

Graphite plate electrodes:

Graphite in the form of plate electrode has useful applications as microbial fuel cell electrodes. It conducts electricity with ease due to its vast electron delocalization within the carbon layers. Graphite with high electrical conductivity of dimensions 24 cm length, 4cm width and 0.3cm thickness were used as electrodes.

Acrylic

Acrylic is a transparent material which is known for its incredible strength, stability and optical-clarity. Acrylic is rather easy to fabricate and gels well with adhesives without melting. It stays calm during the rmoforming and is resistant to wear and tear when compared to other transparent plastics. Acrylic bioreactor model of dimensions 26 cm length, 36 cm width and 15 cm height is developed as bioreactor. The thickness of acrylic sheets was 5 mm.

Scope of adoption of bioreactor in wastewater treatment:
For the bioreactor to function, sedimentation tank is adopted to aid in both pollution removal and generation of electricity.Sedimentation tank aids in removal of suspended particles from wastewater. Wastewater is stored here for set time duration. The settled particles are removed by scraping it out with manual scrapers. Considering the fill-and-draw type of sedimentation tank, Influent waster is retained for a set time duration between 24 and 48 hours. After the set time duration, the water is discharged through a set outflow port. During the time where wastewater is idle, suspended-solid particles settle at the bottom of the tank. The organic matter concentration is higher during the initial stage wastewater treatment. A plain sedimentation tank under standard conditions removes as much as 60-65% of the suspended solids and 30 to 35% of the BOD from the sewage. Hence, sedimentation tank can be incorporated with electrodes to act as a bioreactor.

Bioreactor model:
Acrylic sheets of 0.5cm thick was used to set up a tank of length 26 cm, 36 cm width15cm height. Adetention period of 86 minutes is provided to treat effluent quantity of 0.01400m^3

Development of automated data logging system:
The Arduino board is used to collect and tabulate the voltage readings with respect to set time interval. The Arduino board in integrated to a computer via USB, which connects with the Arduino-development environment (IDE) The Arduino-code is typed in the IDE, and uploaded to the microcontroller, where the code is executed based on the interactions with inputs and outputs. Arduino was coded to record voltage generated from Microbial Fuel Cell (MFC) with time interval of 5 minutes. Voltage is measured using voltage sensor incorporated in to Arduino system. The SD card is used for data-logging. The contraption creates a file in an SD card to save the data using the SD library. SD card module is setup with Arduino to automatically store reading values in .txt format. Stored values can be retrieved using WordPad with respect to time interval.

Method of testing resistance in electrodes and circuits used:
Resistance can be described as the opposition offered by a substance to the flow of electric current. It is one of the major influences which affect the efficiency of MFC. The resistance of electrodes was tested by placing the multi-meter test probes at the end of electrodes. Resistance was measured and recorded in ohms. Resistance of carbon plate electrodes was measured as 0.28 ohms. 1mm square, copper wires were used to minimize or completely reduce the resistance. Entire electrode materials and circuits of microbial fuel cell is adopted in such a way that resistance and electric losses are kept to negligible or minimum.

Methods and methodology:
The mentioned membrane-less MFC made use of in this study was constructed with rectangular acrylic-chamber . The graphite plate electrodes weremade use of as both anode and cathode. They were spacedat a distance of 13 cm. Copper wires were employed for contact with electrodes and then sealed. Anode was placed at the bottom sludge of 1 cm thick in the bioreactor. The cathode was nearer to the surface and the top-portion of it was revealed to air. The setup was operated in batch mode at temperature of (29 ± 2˚C). The test was carried out in different conditions like plain sedimentation, aeration, developing bio film on the electrode surface and combination of all 3 for a time duration of 48 hours. The wastewater of volume 13 litres was collected domestically and operated for 48 hours without any pre-treatment. Samples were collected before and after retention time of 48 hours and analysed for chemical oxygen demand, pH, total dissolved solids and for biochemical oxygen demand (BOD).

4. Results

Wastewater is collected from the initial stages of Ramaiah University, sewage treatment plant and graphite plate electrodes were placed at the bottom of 1 cm thick sludge in bioreactor. Bioreactor was operated by placing the plate electrodes as anode and graphite plate electrodes as cathode and treatment was carried out for 48 hours and electricity generation and water properties were analyzed for pollution removal efficiency. Bioreactor was tested with different conditions suchas by providing aeration unit and by providing bio film on the electrodes by placing them in the wastewater for 48 hours before operation. Voltage generated is measured every 5 minutes and stored in memory card with respect to time at which it is generated data is collected by Arduino data logging system.

Bioreactor is operated for 48 hours for different conditions and for every condition; both the plate electrodes setup was tested. Wastewater samples were collected before and after every operation and were analyzed for BOD, COD, Turbidity, Total dissolved solids, pH For plain sedimentation tanks, the removal efficiency of pH, turbidity, BOD, COD and TDS was 2.7%, 34%, 33%, 29% and 8.3% respectively. Total electricity of 0.30 – 0.33 volts was observed for 17 hour duration between timestamp of 21 –38 hours.

For sedimentation tanks with aeration, the removal efficiency of turbidity, BOD, COD and TDS was 66.4%, 66%, 54% and 13% respectively.15% increase in pH was observed when aeration was provided. Electricity of ≥0.25volts was observed for 9 hours 45 min time duration between timestamp of 14:25 – 24:30 hours. Sharp peak voltage of 0.28 volts was observed at 20th hour which decreased continually till 48th hour. For sedimentation tank plus biofilm around the electrodes, the removal efficiency of pH, turbidity, BOD, COD and TDS was 3.6%, 20%, 14%, 14% and 83.4% respectively. Electricity of ≥0.25volts was observed for 3 hours 20 min time duration between timestamp of 2:40 – 6:00 hours. Sharp peak voltage of 0.28 volts was observed at 5th hour before decreasing. Considering the peak value at 5th hour, 5 set of treatments can be carried out.

Figure 1. Graphite Plate Electrodes

Figure 2. Acrylic Bioreactor Model

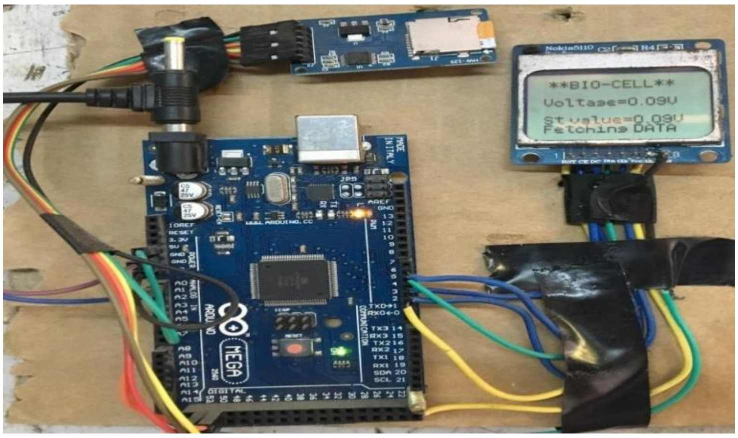

Figure 3: Bioreactor model

Figure 4. Automated Data Logging System

Figure 5. Multimeter test probes at the ends of electrode

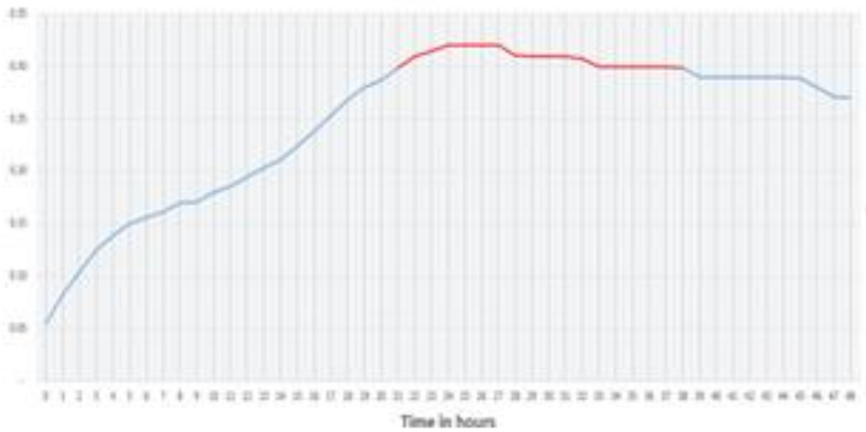

Figure 6. Graph for plate electrodes is plotted between Time(60 min) and volts

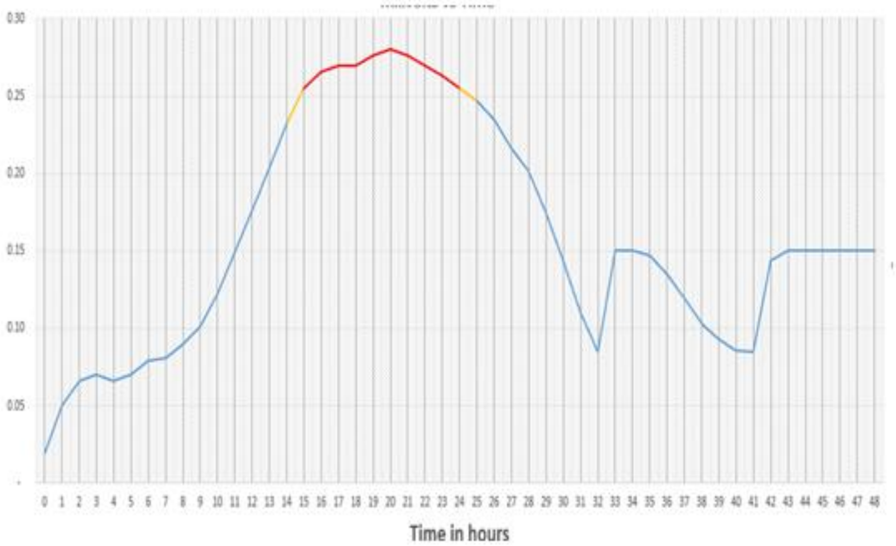

Figure 7. Graph for plate electrodes with aeration unit is plotted between Time (60 min) and volts

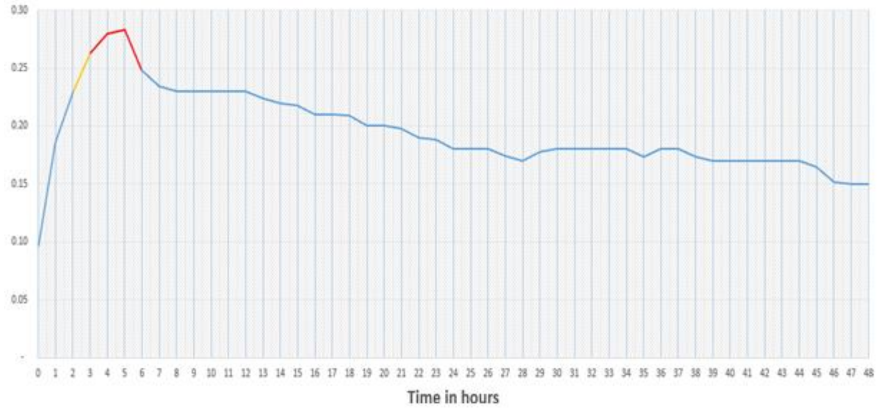

Figure 8. Graph for plate electrodes with bio film is plotted between Time (60min) & volts

Table1: Pollution removal efficiency of sedimentation with plate electrodes

SL	Parameters	Unit	Before operation	After operation	Standards as per KSPCB
1	pH value @ 25˚C	---	7.6	7.4	6.5 - 9
2	Turbidity	NTU	198.0	130.5	--
3	Bio-chemical oxygen demand (3 days @ 27˚ C)	Mg/L	445.0	296.0	10 max
4	Chemical oxygen demand	mg/L	843.0	595.0	50 max
5	Total dissolved solids	mg/L	1243.0	1140.0	--

Table 2: Pollution Removal Efficiency of Plate Electrodes with aeration

SL	Parameters	Unit	Before operation	After operation	Standards as per KSPCB
1	pH value @ 25˚C	---	7.3	8.6	6.5 - 9
2	Turbidity	NTU	588.0	198.5	--
3	Bio-chemical oxygen demand (3 days @ 27˚C)	Mg/L	1055.0	358.0	10 max
4	Chemical oxygen demand	mg/L	1984.0	913.0	50 max
5	Total dissolved solids	mg/L	1564.0	1360.0	--

Table 3: Pollution Removal Efficiency of Plate Electrodes with Biofilm

SL	Parameters	Unit	Before operation	After operation	Standards as per KSPCB
1	pH value @ 25˚C	---	8.5	8.2	6.5 - 9
2	Turbidity	NTU	372.0	298.5	- -
3	Bio-chemical oxygen demand (3 days @ 27˚C)	Mg/L	1255.0	1078.0	10 max
4	Chemical oxygen demand	mg/L	2696.0	2216.0	50 max
5	Total dissolved solids	mg/L	1302.0	1258.0	- -

5. CONCLUSIONS

Pollution removal efficiency of sedimentation tank with plate electrodes for BOD, COD and TDS was 33.5%, 29.5% and 8.3% respectively. Maximum of 0.33 volts was obtained at 24th hour of bioreactor treatment for plate electrodes. Pollution removal efficiency of plate electrode with aeration for BOD, COD and TDS was 66%, 54% and 13.04% respectively. Maximum of 0.28 volts was obtained at 20th hour of bioreactor treatment for plate electrodes with aeration. Pollution removal efficiency of plate electrodes with bio film for BOD, COD and TDS was 14.1%, 18% and 3.4% respectively. Maximum of 0.28 volts was obtained at 5th hour of bioreactor treatment for plate electrode with bio film. The pollution removal efficiency of plate electrode with aeration unit was 33% for BOD, 25% for COD and 5% for TDS.

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