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Analysis of Electricity Generation Using Rod based Microbial Reactor

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Abstract

Due to increasing population every year, there is an increase in the global energy demand and over-consumption of non-renewable sources of energy to meet the never-ending demands. It has become important to identify and use renewable yet cost-effective sources of energy. With respect to the above context, wastewater containing high levels of degradable organic material can be used as a source for generating electricity through a microbial reactor. This produces electricity by anaerobic fermentation of organic/inorganic matter by converting metabolised biomass to complex wastewater using microbes as catalysts.

This project work deals with the operation of reactor using STP wastewater, graphite and carbon rod 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 Chemical Oxygen Demand removal efficiency of 80% and 70.5% were achieved, respectively.

Introduction

Due to exponential growth in population, there has been a phenomenal depletion of resources to meet the energy demand. Available energy is classified into fossil fuels, nuclear and renewable energy sources based on their mode of origin and reliability. Major portion of the world's energy requirements are being met by fossil fuels and nuclear sources. To overcome this and achieve sustainability, fuel cell technology has gained importance in recent years. Microorganisms have proven 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.

Motivation

Economically developed countries end up disbursing significant amount of money for treating wastewater. Fair amount of electricity is used to treat the generated wastewater. Wastewater approximately requires 0.5-2 kWh/m^3 of electric energy to undergo treatment. At the same time, it contains 3-10 times the energy that is required for treatment. Apart from treating the wastewater, microbial fuel cells/ bioreactors are employed to generate electricity from it. This helps on conservation of energy involved in the cycle.

Background Studies

When microbes respire, the electrons retrieved from sugars are donated. Some microbes donate electrons to metals or other elements and this property is made use of in a microbial reactor.

Due to the non-conducting nature of most of the microbial reactor surface structures involved in fermentation, electron transport to the electrode could not be efficient.

Electrochemical mediators are generally employed to render efficient electron transfer from the microbial cells to the electrode. The mediators are usually expensive and can be toxic to the microorganisms, hence may limit the long-term commercial application of mediated Microbial reactors for wastewater treatment. Producing electricity from organic matter with microbial reactors is a concept that arguably dates back almost 100 years. The disintegration of organic compounds by microorganisms was accompanied by electrical energy production. The potential of microbial reactor as an alternative source of energy has been studied extensively. Producing electricity from organic matter with microbial reactors is a concept that arguably dates back almost 100 years. The disintegration of organic compounds by microorganisms was accompanied by electrical energy production. The potential of microbial reactor as an alternative source of energy has been studied extensively.

Aim

To design Microbial reactor to treat STP wastewater and generate electricity.

Objectives of present work are:

1. Literature survey for the application of Microbial reactor in treating wastewater

2. To design Bio-Reactor for effective operation

3. To develop a lab scale model and automated data acquisition system

4. Optimization of Bio-Reactor

   i. Selection of electrodes based on modified conditions

   ii. Measurement of electricity generation for different electrode conditions

5. To study on pollution removal efficiency by establishing area of contact through electrode

Statement of contribution

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

Materials made use of

1.Graphite rod electrodes

Graphite as a rod electrode has useful applications such 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 1.5 cm diameter and 24 cm length were used as electrodes.

Figure.1 Graphite Rod Electrodes

2. Carbon rod electrodes

Carbon is a good conductor and is a key requirement for successful operation of a microbial fuel cell. By using carbon as an electrode, the vast number of free moving electrons result in a highly conductive material. Relatively, carbon is inexpensive to purchase, stable at high temperatures and is tough and durable in nature. Carbon rod electrodes of 1.2 cm diameter and 24cm length were used as electrodes.

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Figure.2 Carbon Rod Electrodes

3. Acrylic

Acrylic is a transparent material which is known for its outstanding strength, stiffness and optical clarity. Acrylic is easy to fabricate and bonds well with adhesives without melting. It is easy to thermoform and resistant to weathering 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.

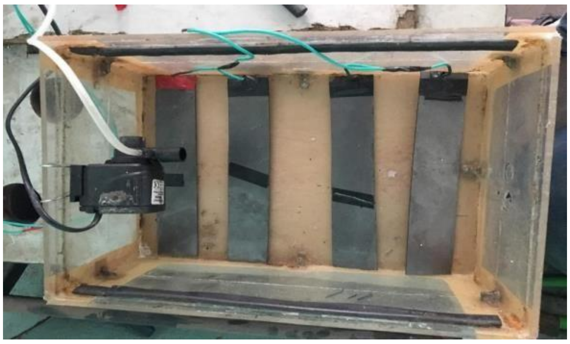

Figure. 3 Acrylic Bioreactor Model

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. A sedimentation tank is structure in which wastewater is filled and stored for some time to remove the suspended particles present in the water. These particles may settle at the bottom of the tank and are removed by using scrapers. If the suspended particles have low specific gravity than water, they settle at the top of the tank. For this project, fill and draw type of sedimentation tank is employed.

Types of Sedimentation Tanks

Categorizing on the methods of operation, the sedimentation tanks can be classified into

a) Fill and draw type tank
b) Continuous flow type tank

Fill and Draw Type Tank

In case of fill and draw type sedimentation tank, water from inlet is stored for some time. The time may be 24 - 48 hours. In that time, the suspended particles are settled at the bottom of the tank. After 24 hours, the water is discharged through outlet.

Continuous Flow Type Sedimentation Tank

In this type of sedimentation tank, the water is not allowed to rest. Flow constantly takes place, but with a very minute velocity. In such flow, the suspended particles are allowed to settle down at the bottom of tank. The flow could either be in horizontal direction or vertical direction.

The organic matter concentration is higher in the initial stages wastewater treatment. A plain sedimentation tank under normal conditions may remove as much as 60-65% of the suspended solids and 30 to 35% BOD from the sewage. Hence, sedimentation tank can be incorporated with electrodes to act as a bioreactor.

Design Calculations

Sedimentation Tank (Bioreactor):

1. Assuming Quantity of effluent to be treated per day = 0.230 m^3

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Assuming a detention period as 86 min,

Quantity of effluent to be treated in 86 min or capacity of the tank required
0.230 (86 minutes / 24 x 60) = 0.01400m^3

2. Assuming that flow velocity through the tank is maintained at 0.3m/minutes,

L, Length of the tank required = (Velocity of flow × Detention period)

(0.3 cm minute^{-1}/100) X 86 minute = 25.8 cm

3. Cross sectional area required

(Capacity of tank / Length of tank) =

(0.0135/0.258) = 0.0523 m^2

4. Assuming the water depth in the tank to be 15 cm,

Width of the tank required= (Area of tank / Depth of tank) = (0.0523m^2/15cm) = 35 cm

Development of bioreactor model

Acrylic sheets of 0.5cm thick was used to set up a tank of dimensions 26 cm length, 36 cm width and 15cm height. Silicone sealant was used to achieve a waterproof, protective joint seal. The flexible and rubbery nature of this sealant along with its low toxicity makes it ideal to be used in microbial fuel cell fabrications. Aluminium angled pieces were screwed into the model to provide additional strength.

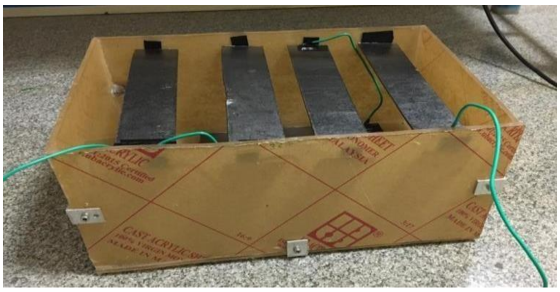
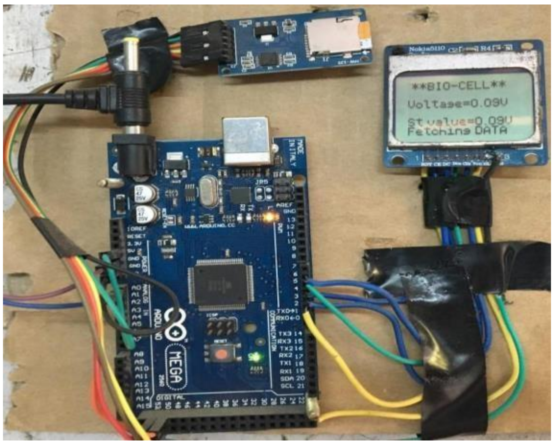


Figure 4. Microbial Reactor Model

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, where it connects with the Arduino development environment (IDE). The Arduino code is written 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 module is used for data logging. The Arduino creates a file in an SD card to write and save 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.

Figure 5. Development of automated data logging system



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 factors which effect the efficiency of microbial fuel cells. 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 rod electrodes was measured as ohms. Graphite rod- electrode resistance is 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.

Fig6 Multimeter test probes at the ends of electrode

Methods and methodology

- The membrane-less microbial fuel cell used in this study was made of acrylic chamber(rectangular)
- Two set of electrodes were used in this study for comparative analysis.
- Solid graphite rods were used for anode and solid carbon rods for cathode, separated by distance of 13 cm.
- Copper wires were used for contact with electrodes after carefully sealing.
- Anode was placed at the bottom sludge of 1 cm thick in the bioreactor.
- Top portion of cathode was exposed to air in bio reactor.
- The reactor was operated in batch mode at temperature (29 ± 2˚C).
- Different modes of testing were carried out such as providing aeration and developing thin bio-film on the surface of electrodes by submerging in wastewater for 48 hours.
- The wastewater of volume 13 litres collected from domestic wastewater, and operated for 48 hours without any pre- treatment.
- Samples were collected before and after the retention time of 48 hours.

Samples were analyzed for chemical oxygen demand (COD), pH, turbidity, total dissolved solids (TDS) and for biochemical oxygen demand (BOD).

Results

Wastewater is collected from the initial stages of Ramaiah University, sewage treatment plant and graphite rod electrodes were placed at the bottom of 1 cm thick sludge in bioreactor. Bioreactor was operated by placing the carbon rod electrodes as anode and graphite rod 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 such as by providing aeration unit and by providing biofilm 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 rod electrodes setup were tested. Wastewater samples were collected before and after every operation and were analyzed for BOD, COD, Turbidity, Total dissolved solids, pH

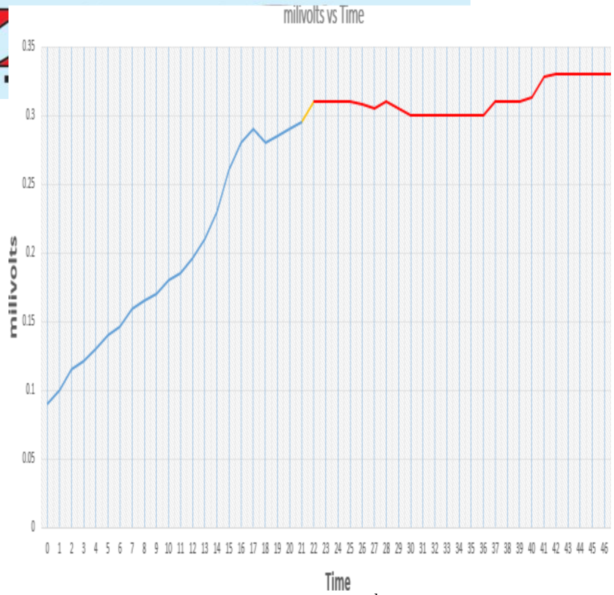
Table.1 Pollution Removal Efficiency of Rod Electrodes

SL	Parameters	Unit	Before operation	After operation	Standards as per KSPCB
1	pH value @ 25˚C	---	8.0	7.7	6.5 - 9
2	Turbidity	NTU	148.0	62.5	--
3	Bio-chemical oxygen demand (3 days @ 27˚C)	mg/L	228.0	188.0	10 max
4	Chemical oxygen demand	mg/L	463.0	357.0	50 max
5	Total dissolved solids	mg/L	1258.0	1235.0	--

Pollution removal efficiency of sedimentation tank incorporated with rod electrodes for:

- pH was at 4%
- Turbidity was at 58%
- BOD was at 17%
- COD was at 23%
- TDS was at 1.82%

Electricity of ≥0.30 V was observed for a total of of 26hours 30minutes from time stamp of 21:30 – 48 hours. First peak of 0.29 volts was observed at 17th hour and it kept on increasing up to 0.34 volts until 48th hour.



Considering the peak value at 17th hour more than one slot for treatment can be arranged in 24 hours.

Figure.7 Graph for rod electrodes is plotted between Time(60 min) and millivolts

Table.2 Pollution Removal Efficiency of Rod Electrodes with aeration (48 hours)

- Sedimentation tank incorporated with rod electrodes by providing aeration increase in pH was 9%
- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing aeration, Turbidity was at 93%
- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing aeration,

SL	Parameters	Unit	Before operation	After operation	Standards as per KSPCB
1	pH value @ 25˚C	---	7.9	8.7	6.5 - 9
2	Turbidity	NTU	240.0	15.5	--
3	Bio-chemical oxygen demand (3 days @ 27˚C)	mg/L	298.0	10.0	10 max
4	Chemical oxygen demand	mg/L	694.0	46.0	50 max
5	Total dissolved solids	mg/L	1384.0	1270.0	--

Biological Oxygen Demand was at 96.7%

- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing aeration, Chemical Oxygen Demand was at 93.4%
- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing aeration, Total Dissolved Solids was at 8.3%
- ≥0.25volts was observed for 2hours 15minutes fromatimestamp of45:45 –48 hour
- First peak of nearly 0.20 volts was observed at 6th hour and it kept on increasing till 48th hour

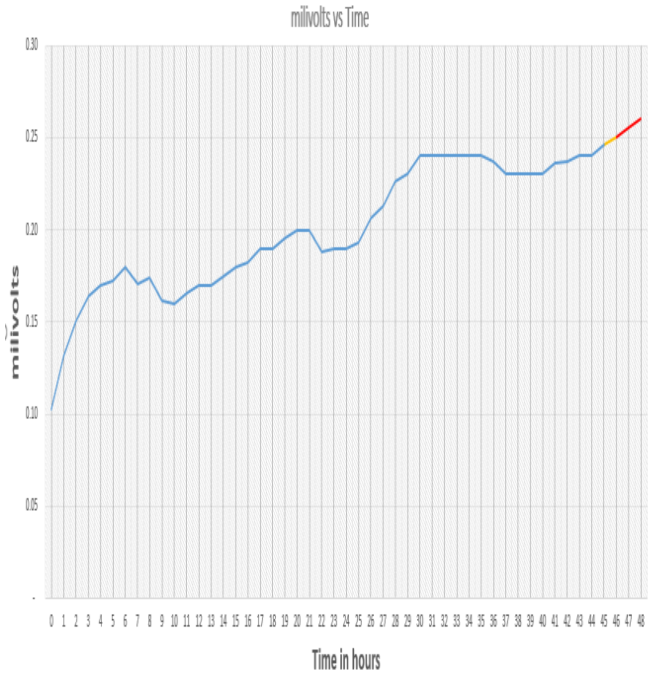


Figure.8 Graph for rod electrodes with aeration is plotted between Time (60 min) and millivolts

Table. 3 Pollution Removal Efficiency of Rod Electrodes with Biofilm

SL	Parameters	Unit	Before operation	After operation	Standards as per KSPCB
1	pH value @ 25˚C	---	7.9	7.4	6.5 - 9
2	Turbidity	NTU	279.0	203.5	--
3	Bio-chemical oxygen demand (3 days @ 27˚C)	mg/L	1056.0	836.0	10 max
4	Chemical oxygen demand	mg/L	2159.0	1612.0	50 max
5	Total dissolved solids	mg/L	1465.0	1336.0	--

- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing biofilm, pH was at 6.4%
- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing biofilm, Turbidity was at 27%
- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing biofilm, Biological Oxygen Demand was at 21%
- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing biofilm, Chemical Oxygen Demand was at 25.3%
- Pollution removal efficiency of sedimentation tank incorporated with rod electrodes by providing biofilm, Total Dissolved Solids was at 8.9%
- Electricity of ≥0.30 volts was observed for time interval of 2hours at time stamp 0-2 hour
- A sharp peak of 0.32 volts was observed at 1st hour before drastically decreasing with time

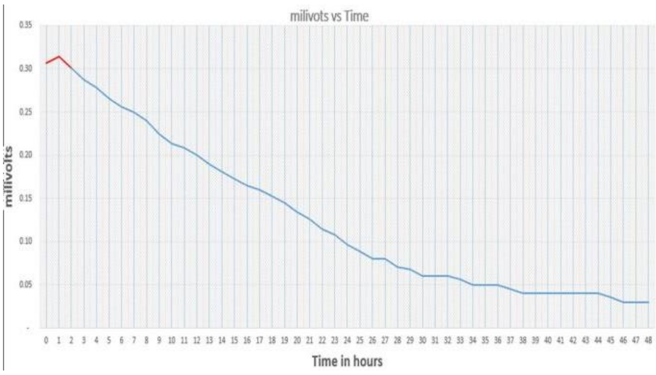


Figure.9 Graph for rod electrodes with biofilm is plotted between Time (60 min) and millivolts

Conclusions

Pollution removal efficiency of sedimentation tank with rod electrodes for BOD, COD and TDS was 17.6%, 22.9% and 2% respectively. Maximum of 0.33 volts was obtained at 22nd hour of bioreactor treatment for rod electrodes. Pollution removal efficiency of rod electrodes with aeration for BOD, COD and TDS was 96.65%, 93.4% and 8.3% respectively. Maximum of 0.27 volts was obtained at 48th hour of bioreactor treatment for rod electrodes with aeration.

Pollution removal efficiency of rod electrodes with biofilm for BOD, COD and TDS was 21%, 26% and 9% respectively. Maximum of 0.32 volts was obtained at 1st hour of bioreactor treatment for rod electrodes with biofilm. High pollution removal efficiency was obtained when bioreactor treatment was carried out using rod electrodes with aeration.

High electricity generation is observed while using rod and plate electrode treatment for 48 hours. Rod electrodes with biofilm produced higherelectricity atthe earlystagesofbioreactor

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treatment. The pollution removal efficiency of rod electrodes with aeration unit over sedimentation tankwith rodelectrodewas 80% for BOD, 71% for COD and 6.5% for TDS.

Pollution removal efficiency of rod electrode with biofilm overplane sedimentationtankwith rodelectrodewas 4% for BOD, 3% for COD and 7% for TDS.

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