A Study on Microbial Fuel Cell for Leachate Treatment and Bio Electricity Production

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Abstract: ***The need for renewable energy source is increasing in our society. Microbial fuel cell technology represents a new form of renewable energy source which converts organic matter into electricity with the help of various microorganisms present in the waste water. In the present study a double chambered microbial fuel cell with leachate as electrolyte was developed to simultaneously produce electricity and also for the removal of ammonia & total dissolved solids. Slurry from biogas plant was added to increase the number of microorganisms present in the leachate. Experiments were repeated by varying pH and the substrate concentrations. From the experiments it was observed that voltage production increases with pH and a maximum voltage of 33.4 mV was obtained at pH 9. The ammonia and total dissolved solids removal obtained at pH 9 were 14.94 % & 26.58 % respectively. It was also observed that with the increase of substrate concentration electricity production, ammonia and total dissolved solids removal were increases. Maximum of 92.6 mV was obtained at 12 g substrate concentration and ammonia & total dissolved solids removal obtained were 24.8 % & 32.91% respectively.***

Keywords: Microbial fuel cell, Electrolyte, Substrate, Biogas

1. Introduction

1.1 General

Industrialization and urbanization leads production of more waste materials to the environment [12]. In bio-electrochemical systems (BESs), which include microbial fuel cells (MFCs) and microbial electrolysis cells (MECs), living microorganisms catalyze anode and/or cathode reactions. In a microbial fuel cell, organic matter is oxidized by microorganisms at the anode. The liberated electrons travel through an external circuit to the cathode where oxygen is reduced. Electrical energy can be recovered from the external circuit because the overall reaction is thermodynamically favorable. In a Microbial electrolysis cell, a voltage is applied to the system to drive a thermodynamically unfavorable reaction at the cathode. For example, hydrogen gas can be produced by reduction of hydrogen ions in the water. In most Microbial fuel cell and microbial electrolysis cell designs, the anode and cathode are separated by an ion exchange membrane. As electrons travel from the anode to the cathode through the external circuit, ions migrate through the membrane to maintain charge balance in the system. This phenomenon could potentially be used to improve nitrogen removal or recovery in wastewater treatment plants [19].

1.2. Microbial fuel cell

Microbial fuel cells (MFCs) are devices that can use bacterial metabolism to produce an electrical current from a wide range organic substrates. Due to global environmental concerns and energy insecurity, there is emergent interest to find out sustainable and clean energy source with minimal or zero use of hydrocarbons. Electricity can be produced in different types of power plant systems, batteries or fuel cells [03]. Bacteria can be used to catalyze the conversion of organic matter into electricity. Fuel cells that use bacteria are classified as two different types: biofuel cells that generate electricity from the addition of artificial electron shuttles (mediators) and microbial fuel cells (MFCs) that do not require the addition of mediator. Unlike a battery, a fuel cell does not store energy. Instead, it converts energy from one form to another (much like an engine) and will continue to operate as long as fuel is fed to it. However, unlike internal combustion generators, fuel cells convert chemical energy directly into electricity without an intermediate conversion into mechanical power. Fuel cells, if used for wastewater treatment, can provide clean energy for people, apart from effective treatment of wastewater. The benefits of using fuel cells include: clean, safe, quiet performance; high energy efficiency; low emissions; and ease in operating [04]. Biofuel cells use biocatalysts for the conversion of chemical energy to electrical energy. It is a device that directly converts microbial metabolic or enzyme catalytic energy into electricity by using conventional electrochemical technology. The biocatalysts participate in the electron transfer chain between the fuel-substrate (organic or inorganic) and the electrode surfaces. That is, microorganisms or redox-enzymes facilitate the electron transfer between the fuel substrate and the electrode interface, thereby enhancing the cell current. It has been shown that, direct electron transfer from microbial cells to electrodes occurs only at very low efficiency. Most of the redox-enzymes lack in direct electron transfer with conductive supports and a variety of electron mediators (electron relays) are used for electrical contacting of the biocatalysts and the electrode. Since, most microbial cells are electrochemically inactive; electron transfer from microbial cells to the electrode is facilitated by the help of mediators such as thionine, methyl viologen, humic acid, etc.

Enzyme catalyzed generation of NADH (dihydro-nicotinamide adenine dinucleotide) from alcohol, lactic acid, amino acids, formate or other abundant substrates could provide the bio-transformations that activate the anodic compartment of the fuel cell [06].

2. Objectives of study

In this study, a two chambered microbial fuel cell is used to simultaneously produce electricity and for the removal of ammonia & total dissolved solids from leachate. The leachate is the liquid that drains or leaches from a landfill of solid waste. It varies widely in composition regarding the age of the landfill and the type of the waste that it contain. Leachate from the landfill also infiltrate into the nearby water bodies which pollute the drinking water source of the local area. The treatment of highly concentrated liquid waste from landfill of solid waste is very essential to protect the surrounding potable water source from pollution.

The objectives of this study are listed as below,

- To fabricate a two chambered microbial fuel cell for electricity production from leachate.
- To determine the percentage of ammonia and total dissolved solids removal from leachate.
- To optimize the electricity production, ammonia removal and total dissolved solids removal from leachate by using the Microbial fuel cell.

3. Materials and Methods

3.1 Microbial fuel cell

Microbial fuel cell was made up of fiber glass sheet. It consists of cathode chamber and anode chamber. Both the chambers have a dimension of 10cm x 9cm x 14 cm. Cathode chamber and anode chambers were separated with glass wool which acts as the proton exchange membrane. Anode chamber has inlet. Cathode chamber has outlet and air pump. Anode chamber and cathode chamber consists of two and one carbon rods respectively. Carbon rods were connected to a multimeter to measure the voltage through copper wire. Figure1 shows the schematic diagram of the two chambered microbial fuel cell used in this study.

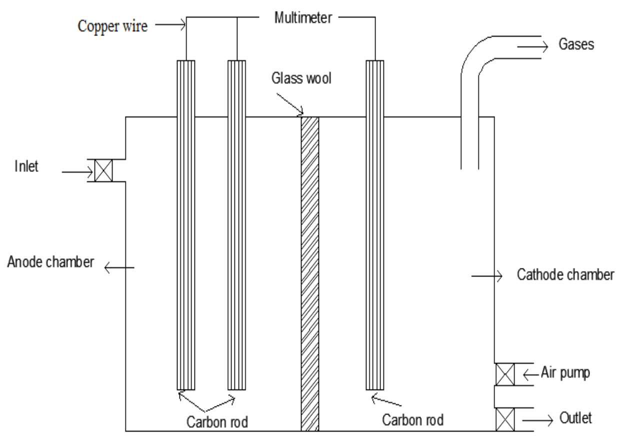

Figure 1: Schematic diagram of microbial fuel cell

3.2 Electrodes

Carbon rods were used as both cathode and anode. One carbon rod was used in cathode chamber. Two carbon rods were used in anode chamber to increase the surface area. The increased surface area enhances the power production due to biofilm formation by microbial activity.

3.3 Glass wool

Glass wool is an insulating material. It made from fibers of glass arranged using a binder into a texture similar to wool. This process traps number of small pockets of air between the glass. These small air pockets result in high thermal insulation properties of glass wool. Moreover it is a waste which creates health problems like irritation to skin, eyes etc. It is used as the proton exchange membrane in this microbial fuel cell and it was placed in between the anode chamber and the cathode chamber. Figure 2 shows the glass wool used in this study.

Figure 2: Glass wool

3.4 Digital multimeter

It is used to measure the voltage developed in this microbial fuel cell. Figure 3 shows the digital multimeter used in this study.

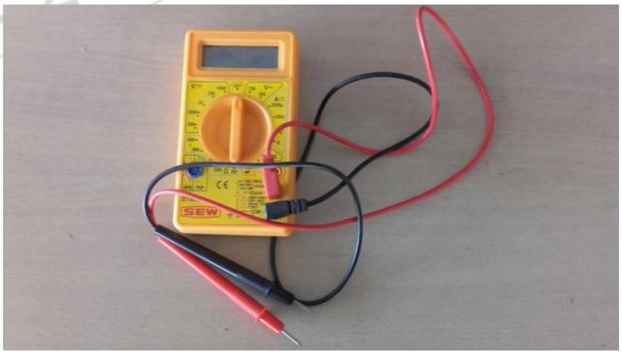

Figure 3: Digital multimeter

3.5 Air pump

One air pump is used in cathode chamber of the microbial fuel cell to provide sufficient dissolved Oxygen in the cathode chamber. Figure 4 shows the air pump used in this study.

Figure 4: Air pump

3.6 Connecting wires

Copper wires were used to connect the anode and cathode electrodes to the multimeter to measure the voltage developed in the microbial fuel cell.

3.7 Electrolyte

Leachate is used as the electrolyte in this study. The leachate was collected from the solid waste landfill site of Kozhikode Corporation at Njeliyanparambu.

3.8 Chemical analysis

Initially leachate used for this study was analyzed for various parameters such as pH, turbidity, Chloride, conductivity, ammonia and total dissolved solids. Effluent from the cathode chamber was also collected at the end of each run of the experiment to determine the removal of ammonia and total dissolved solids in the leachate.

3.9 Experimental set up

Figure 5: Experimental setup

The leachate collected from the landfill site at Njeliyanparambu was initially filled in the anode chamber with the biogas slurry in the ratio of 1:4. The entire setup was left for 1 hour for stabilization. Then the multimeter was used to detect voltage generation. Experiments were conducted by varying the pH and the substrate concentration to determine the optimum pH and the substrate concentration. Acetate was added in the anode chamber as the substrate. Figure 5 shows the experimental setup used for this study.

3.10 Electricity production

In microbial fuel cell, bacteria catalyze the oxidation of organic substrate and produce electrons. These electrons are used to reduce an electron accepter (i.e. O_2) in the cathode chamber and as a result multimeter shows reading. Then the reading in the multimeter was noted down in one hour interval until the multimeter shows zero reading.

3.11 Determination of ammonia concentration

To find out the ammonia concentration to a 10 ml of sample in a 50 ml beaker adds 1 ml of Manganous sulphate solution. Place the beaker on a magnetic stirrer and add 0.5 ml of Hypochlorous acid reagent. Immediately add 0.6 ml of phenate reagent. Color formation complete within 10 minutes and is stable for 24 hours. Read the absorbance of standard and sample against the blank at 630 nm wavelength.

3.12 Determination of total dissolved solids

To find the total dissolved solids heat the clean evaporating dish to 180°C for 1 hour. Cool in the desiccator, weigh and store in the desiccator until ready for use. Filter a portion of the sample through filters, Pipette this volume to a weighed evaporating dish placed on a drying oven.. Transfer the dish to an oven at 103-105°C and dry to constant mass. Drying for a long duration (1 to 2 hours). Weigh the dish as soon as it has cooled.

4. Results and Discussion

4.1 Analysis of raw leachate sample

Collected leachate was analyzed for various parameters as per standard methods. Table 1 shows the different characteristics of the leachate.

Table 1: Characteristics of collected raw leachate sample

S. No	*Parameter*	*Value*
1	pH	8.06
2	Chloride	4199 mg/L
3	Conductivity	28.25 mS/ppt
4	Turbidity	126.7 NTU
5	Ammonia	394.15 mg/L
6	Total dissolved solids	7.9 mg/L

4.2 Measurement of voltage using raw leachate as electrolyte

The anode chamber of the microbial fuel cell was filled with raw leachate. The entire setup was left for one hour for stabilization. The digital multimeter was connected between anode and cathode using copper wire. The voltage was measured down in one hour interval from day 1 onwards.

Table 2 shows the voltage variations with respect to time in leachate.

Table 2: Variation of voltage with respect to time

Time (hr)	**1**	**2**	**3**	**4**	**5**	**6**
Days	Variation of voltage with respect to time (mV)					
Day 1	3.1	9.2	**22.9**	21.8	20.6	20.5
Day 2	6.3	6.2	5.4	3.2	1.1	0

It was found that maximum voltage obtained was 22.9mV and it was obtained after two hours of experimental run. Then it starts decreasing steadily and found zero in the 2 day.

4.3. Analysis of ammonia and total dissolved solids removal using raw leachate as electrolyte

The ammonia and total dissolved solids concentration in the leachate was measured at the end of the day 1 and day 2. Table 3 shows Ammonia and total dissolved solids removal at first and second day of the experimental run.

Table 3: Ammonia and total dissolved solids removal

Days	Ammonia concentration (mg/L)	Ammonia removal (%)	TDS (mg/L)	TDS removal (%)
Day 1	388.08	1.54	7.5	5.06
Day 2	379.38	3.75	7	11.39

The ammonia and total dissolved solids removal obtained after 2 day was 3.75 % and 11.39 % respectively.

4.4. Optimization of substrate concentration

Electricity production, ammonia and total dissolved solids removal were evaluated by varying the substrate concentrations. Acetate is used as the substrate.

4.4.1. Generation of voltage at varying substrate concentrations

Various substrate concentrations were prepared by adding 8g, 10g and 12g of Acetate to 100ml distilled water. These substrates prepared were added to the raw leachate in the microbial fuel cell. The voltage was measured down in one hour interval from day 1 onwards. Table 4,5,6 respectively shows the variation of voltage by varying the substrate concentrations 8g, 10g and 12g diluted in 100 ml distilled water.

Table 4: Variation of voltage at substrate concentration 8g/100ml

Time (hr)	1	2	3	4	5	6
Days	Variation of voltage with respect to time (mV)					
Day 1	24.7	31.7	52.1	47.8	47	46.6
Day 2	25.4	25.4	25	24.8	24.5	23.5
Day 3	12.5	12.1	9.8	7.1	6.2	5.8

From Table 4 it was seen that when the substrate was added to the leachate electrolyte the voltage generation was found increased to 100%. Maximum voltage generation was on first day after second hour of the experimental run and it was found to be 52.1 mV, after that it decreased. The experiments were continued till 3rd day.

Then the substrate concentration was adjusted to 10g / 100ml. The voltage was measured down in 1 hour interval and continued 4th day. The results were tabulated in the Table 5.

Table 5: Variation of voltage at substrate concentration 10g/100ml

Time (hr)	1	2	3	4	5	6
Days	Variation of voltage with respect to time (mV)					
Day 1	42.1	58.9	63.4	68.6	**72.4**	72.2
Day 2	54.4	54.1	53.2	52.1	51.9	51.6
Day 3	42.8	42.6	42	41.9	41.7	41.6
Day 4	29.8	25.6	21.4	20.6	16.4	13.3

From Table 5 it was seen that when the substrate concentration increased to 10g the voltage increased to almost 150 % to that without substrate. The maximum voltage generation was on first day after fourth hour of the experimental run and it was found to be 72.2 mV, after that it decreased.

Then the substrate concentration was adjusted to 12g / 100ml. The voltage was measured down in 1 hour interval and continued 4th day. The results were tabulated in the Table 6.

Table 6: Variation of voltage at substrate concentration 12g/100ml

Time (hr)	1	2	3	4	5	6
Days	Variation of voltage with respect to time (mV)					
Day 1	61.2	88.1	92	92.4	**92.6**	92.2
Day 2	78.6	77.8	76.8	76.1	75	74.5
Day 3	60.8	60.7	60.6	60.3	59.1	58.2
Day 4	35.6	32.2	29.3	24.1	19	17.5

From Table 6 it was seen that when the substrate concentration was increased to 12 g the voltage generation increased to almost 200% to that of without substrate. The maximum voltage generation was on first day after fourth hour of the experimental run and it was found to be 92.6 mV, after that it decreased.

The following Figure 6 represents the maximum voltage generated at different substrate concentrations.

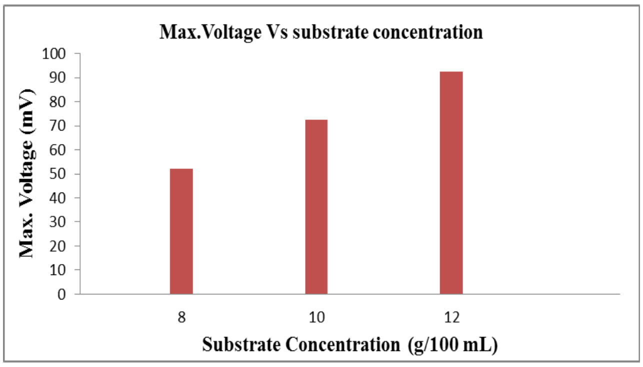

Figure 6: Voltage generations at various substrate concentrations

The above graphical representation of different substrate concentration clearly indicates that the voltage production increases with increase in substrate concentration. The microbial activity increased with the addition of substrate and intern produce more electricity.

4.4.2. Ammonia and total dissolved solids removal at varying substrate concentrations

The ammonia and total dissolved solids concentration were also measured during the end of the 1st day, 2nd day & 3rd day with different substrate concentrations. Table 7, 8, 9 respectively shows ammonia and total dissolved solids removal at varying the substrate concentrations 8g, 10g and 12g diluted in 100 ml distilled water.

Table 7 : Ammonia and TDS removal at substrate concentration 8g/100ml

Days	*Ammonia concentration (mg/L)*	*Ammonia removal (%)*	*TDS (mg/L)*	*TDS removal (%)*
Day 1	381.4	3.23	6.9	12.66
Day 2	375.94	4.62	6.1	22.78
Day 3	354.49	10.06	5.8	26.58

The ammonia and total dissolved solids concentration removal continues even on 3rd day. From Table 7 after three days ammonia removal obtained was 10.06 % and total dissolved solids removal obtained was 26.58 %. This shows the microbial fuel cell has a potential to remove ammonia and total dissolved solids from the leachate while generating the electricity.

Table 8 : ammonia and TDS removal at substrate concentration 10g/100ml

Days	*Ammonia concentration (mg/L)*	*Ammonia removal (%)*	*TDS (mg/L)*	*TDS removal (%)*
Day 1	379.98	3.6	6.3	20.25
Day 2	364.81	7.44	6.1	22.78
Day 3	346.19	12.17	5.6	29.11
Day 4	320.09	18.79	5.5	30.38

When the substrate concentration increases to 10g the ammonia and total dissolved solids removal was also increased and the tendency extends to 4th day also. From Table 8 after four days ammonia removal obtained was 18.79 % and total dissolved solids removal obtained was 30.38 %.

Table 9: ammonia and TDS removal at substrate concentration 12g/100ml

Days	Ammonia concentration (mg/L)	Ammonia removal (%)	TDS (mg/L)	TDS removal (%)
Day 1	354.49	10.06	6.1	22.78
Day 2	317.06	19.56	5.8	26.58
Day 3	312.61	20.69	5.6	29.11
Day 4	296.42	24.8	5.3	32.91

When the substrate concentration increases to 12 g the ammonia and total dissolved solids removal was also increased than 8g & 10 g substrate concentration. From table 9 after four days ammonia removal obtained was 24.8 % and total dissolved solids removal obtained was 32.91 %.

The following Figure 7 and 8 shows the graphical representation of ammonia and total dissolved solids removal at varying substrate concentrations.

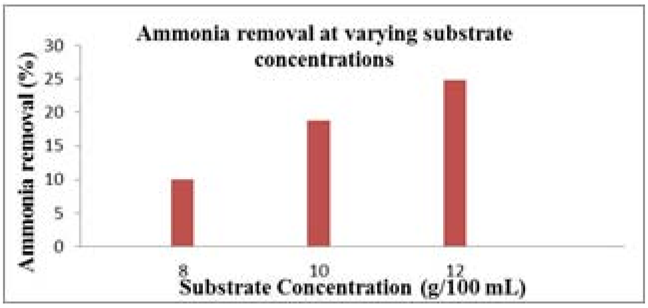

Figure 7: Ammonia concentration at varying substrate concentration

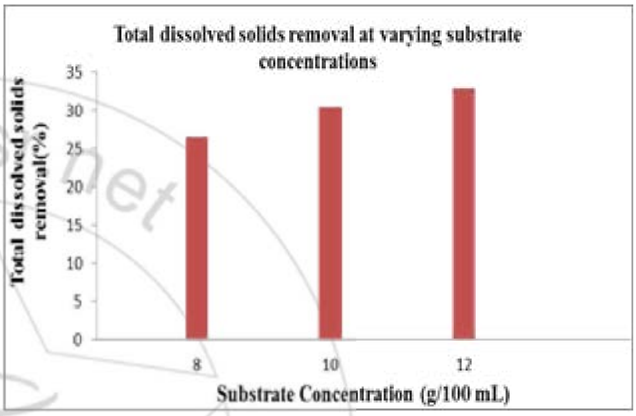

Figure 8: Total dissolved solids at varying substrate concentration

From the above graphical representation it is clear that with the increase in substrate concentration the ammonia and total dissolved solids removal in the microbial fuel cell increases.

From the optimization of substrate concentration it was found that with the increase of substrate concentration the microorganisms survive for more days and maximum voltage generation, ammonia and total dissolved solids removal increases. After a maximum value the voltage generation decreases due to lack of substrate or due to the death of microorganisms.

4.5. Optimization of pH

Electricity production, ammonia and total dissolved solids removal were evaluated by varying the pH from 7 to 11. The pH of the leachate collected from Njeliyanparambu was 8.06.

4.5.1. Generation of voltage at varying pH

The pH of leachate was adjusted to the desired value by adding sufficient quantities of NaOH or H_2SO_4 . Table 10, 11, 12, 13, 14 respectively shows the variation of voltage by varying the pH from 7 to 11.

Table 10: Variation of voltage at pH 7

Time (hr)	1	2	3	4	5	6
Days	Variation of voltage with respect to time (mV)					
Day 1	19.4	23.1	28.4	28.2	28	27.6
Day 2	19.2	19.1	18.4	16.2	14.4	15.2

From Table 10 at pH 7 it was seen that the maximum voltage generation was on first day after second hour of the experimental run and it was found to be 28.4 mV, after that it decreased.

Table 11: Variation of voltage at pH 8

Time (hr)	1	2	3	4	5	6
Days	Variation of voltage with respect to time (mV)					
Day 1	18.1	20.4	**29.8**	29.4	28.4	27.1
Day 2	17.8	16.4	15.2	14.1	14.1	13.9

From Table 11 at pH 8 it was seen that the maximum voltage generation was on first day after second hour of the experimental run and it was found to be 29.8 mV, after that it decreased.

Table 12: Variation of voltage at pH 9

Time (hr)	1	2	3	4	5	6
Days	Variation of voltage with respect to time (mV)					
Day 1	20.4	28.1	30.2	**33.4**	30.9	30.6
Day 2	22.4	21.1	20.5	19.4	19.1	18.7
Day 3	5.4	5.1	4.8	4.1	2.1	0

From Table 12 at pH 9 it was seen that the maximum voltage generation was on first day after third hour of the experimental run and it was found to be 33.4 mV, after that it decreased.

Table 13: Variation of voltage at pH 10

Time (hr)	1	2	3	4	5	6
Days	Variation of voltage with respect to time (mV)					
Day 1	19.3	20.8	27.1	**27.4**	27.1	26.9
Day 2	14.4	14.3	13.9	13.6	13.1	12.9

From Table 13 at pH 10 it was seen that the maximum voltage generation was on first day after third hour of the experimental run and it was found to be 27.4 mV, after that it decreased.

Table 14: Variation of voltage at pH 11

Time (hr)	1	2	3	4	5	6
Days	Variation of voltage with respect to time (mV)					
Day 1	20.1	20.9	**25.5**	25.4	24.1	23.9
Day 2	10.1	10	9.8	8.9	8.1	7.6

From Table 14 at pH 11 it was seen that the maximum voltage generation was on first day after second hour of the experimental run and it was found to be 25.5 mV, after that it decreased. The peak voltages were plotted in a graphical representation as shown in Figure 9.

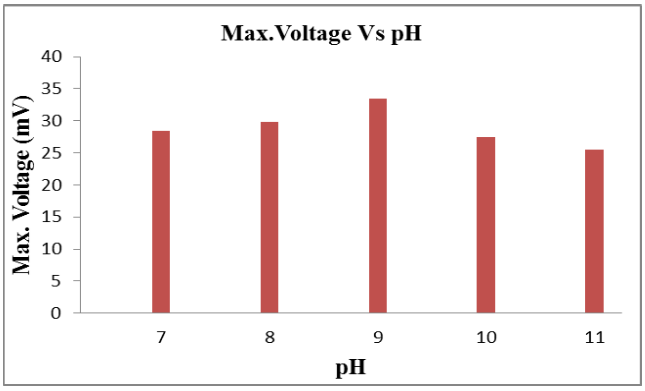

Figure 9: voltage generations at various pH

pH voltage generation increases till pH 9 after that it shows decreased voltage generation. Maximum voltage obtained was 33.4 mV and it was at pH 9.

4.5.2 Ammonia and total dissolved solids removal at varying pH

Experiments were conducted to find out the removal of ammonia and total dissolved solids at the end of each day for different pH values varying from 7 to 11. The values were tabulated in the table with percentage removal of ammonia and total dissolved solids from the raw leachate. Table 15, 16, 17, 18, 19 respectively shows ammonia and total dissolved solids removal at varying pH from 7 to 11.

Table 15: Ammonia and TDS removal at pH 7

Days	Ammonia concentration (mg/L)	Ammonia removal (%)	TDS (mg/L)	TDS removal (%)
Day 1	384.03	2.57	7.5	5.06
Day 2	379.38	3.75	6.9	12.66

From Table 15 it was seen that after two days the maximum ammonia removal obtained was 3.75 % and total dissolved solids removal obtained was 12.66 % at pH 7.

Table 16: Ammonia and TDS removal at pH 8

Days	Ammonia concentration (mg/L)	Ammonia removal (%)	TDS (mg/L)	TDS removal (%)
Day 1	373.31	5.29	7.3	7.59
Day 2	363.19	7.85	6.6	16.46

From Table 16 it was seen that after two days the maximum ammonia removal obtained was 7.85 % and total dissolved solids removal obtained was 16.46 % at pH 8.

Table 17: Ammonia and TDS removal at pH 9

Days	Ammonia concentration (mg/L)	Ammonia removal (%)	TDS (mg/L)	TDS removal (%)
Day 1	370.47	6.01	7	11.39
Day 2	348.82	11.5	6.1	22.78
Day 3	335.26	14.94	5.8	26.58

From Table 17 it was seen that after three days the maximum ammonia removal obtained was 14.94 % and total dissolved solids removal obtained was 26.58 % at pH 9.

Table 18: Ammonia and TDS removal at pH 10

Days	Ammonia concentration (mg/L)	Ammonia removal (%)	TDS (mg/L)	TDS removal (%)
Day 1	370.06	6.11	7.2	8.86
Day 2	360.15	8.63	6.6	16.46

From Table 18 it was seen that after two days the maximum ammonia removal obtained was 8.63 % and total dissolved solids removal obtained was 16.46 % at pH 10.

Table 19: Ammonia and TDS removal at pH 11

Days	Ammonia concentration (mg/L)	Ammonia removal (%)	TDS (mg/L)	TDS removal (%)
Day 1	372.5	5.49	7.2	8.86
Day 2	365.01	7.39	6.8	13.92

From Table 19 it was seen that after two days the maximum ammonia removal obtained was 7.39 % and total dissolved solids removal obtained was 13.92 % at pH 11.

The percentage removal of ammonia was plotted against varying pH in the graph shown below.

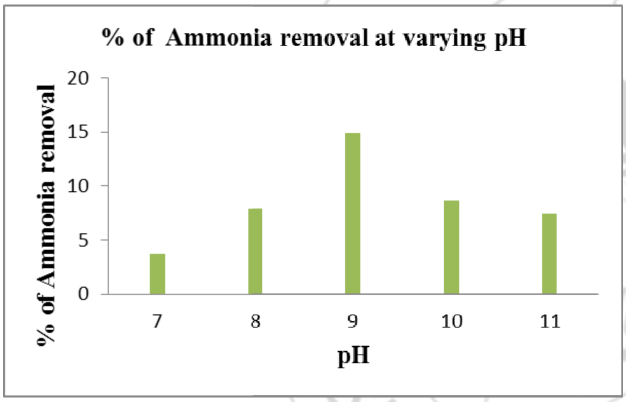

Figure 10: Percentage of Ammonia removal at varying pH

The percentage removals of total dissolved solids were plotted against varying pH in the graph shown below.

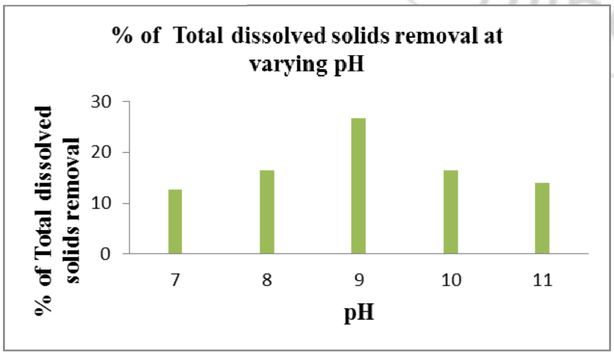

Figure 11: Percentage of Total dissolved solids removal at varying pH

Percentage of ammonia removal at pH 7, 8, 9, 10 & 11 were obtained as 3.75 %, 7.85 %, and 14.94 %, 8.63 % and 7.39 % respectively. Percentage of total dissolved solids removal at pH 7, 8, 9, 10 &11 were obtained as 12.66 %, 16.46 %, 26.58 %, 16.46 % and 13.92 % respectively. Ammonia and total dissolved solids maximum removal was also obtained at pH 9.

5. Conclusions

Two chambered microbial fuel cell can be used to simultaneously produce electricity and for the removal of ammonia & total dissolved solids.

- Microbial fuel cell can be effectively used to electricity production from leachate.
- It was observed that electricity production increased for few hours due to the action of microorganisms.
- After four or five hours the electricity production decreased because of the lack of substrate or due to the death of microorganisms.
- In the case of raw leachate maximum voltage production of 22.9 mV was obtained after two hours and 3.75% ammonia and 11.39% total dissolved solids removed two days of experimental run.
- Electricity production increased with increasing the substrate concentration.
- Voltage production increased with pH and optimum voltage production of 33.4 mV was obtained at pH 9.
- Microbial fuel cell can be used for leachate treatment for the removal of ammonia and total dissolved solids.

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