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Waste Water Treatment and Generation of Electricity Using Microbial Fuel Cells

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ABSTRACT

Renewable energy will one day be a large portion of global energy production and usage. Microbial fuel cell technology represents a new form of renewable energy by generating electricity from what would otherwise be considered as waste. According to this technology it uses the bacterium already present in wastewater as catalysts for generating electricity by converting organic matter into electricity while simultaneously treating wastewater. Application of microbial fuel cell for wastewater treatment is an attractive alternative to reduce the cost of treatment of waste water and generation of electricity.

My objective in this study is to create a double chambered MFC by using a clay ware mixed with 20 % montmorollonite as the proton exchange membrane and graphite felt as the electrodes and to compare the COD value of the waste water before and after the experiment to know the extent of waste water treatment. The main attraction of such a setup is that the by product formed after the chemical reaction is no chemical but pure water. MFC technology represents a unique and novel platform to process waste and wastewater sources that allows for energy and resource recovery along with water sanitation in a single configuration. They have the potential to provide the paradigm shift for wastewater treatment from "environmental protection" to "resource recovery."

KEYWORDS : Microbial fuel cell, COD

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INTRODUCTION

Increasing human activities are consuming the natural energy sources in a considerably high rate which leads to the depletion of fossil fuels. The present day energy scenario in India and around the globe is precarious. The need for alternate fuel has made us to initiate extensive research in identifying a potential, cheap and renewable source for energy production. The making of the sustainable society will require reduction of dependency on fossil fuels and lowering the amount of pollution that is generated.

Current methods to produce energy are not sustainable, and has extensive concerns about climatic conditions and global warming issues which requires development of new methods of energy production using renewable and carbon-neutral sources. Microbial Fuel cell (MFC) is a device designed for the purpose of electricity generation in the process of wastewater treatment. Hence it is an ideal solution for sustainable renewable source of energy

MICROBIAL FUEL CELLS

Working of fuels cells

Microbial fuel cells (MFCs) are electrochemical devices that uses the metabolic activity of microorganisms to oxidise fuels, generating current by direct or mediated electron transfer to electrodes. The device comprises of an anode chamber, a cathode chamber, electrodes, proton exchange membrane and an external circuit. The MFC convert a biodegradable substrate directly into electricity. The anode holds the bacteria and the organic material in an anaerobic environment. The cathode holds water in a double chamber type MFC or air if it's the single chamber. The bacteria generate protons and electrons as the organic substrate is being converted into energy. This energy is used and stored by the microbes for growth. The electrons are transferred directly to the anode electrode (in a mediator-less set-up) and to the cathode electrode via a conductive material. Protons pass through the ion exchange membrane to the cathode chamber to produce water as a result of the reduction process which is in terms of hydrogen transfer. The bacteria grow in the anode, oxidising matter and releasing electrons as they break down the substrate. Some bacteria require exoelectrogenic biofilms in order to effectively transfer the electrons to the electron accepter whereas some transfer electrons directly without the need of a mediator. The cathode is supplied with air or other inoculum to provide dissolved oxygen for the reaction of electrons via an external circuit, protons and oxygen at the cathode, completing the circuit and producing power. Chemical energy is converted into electricity by the microbes which releases electrons and hydrogen ions which from water. The oxygen is supplied in the cathode chamber by air or other oxygen source. The materials used in the electrodes significantly influences the overall efficiency.

Anodic Reaction

When bacteria consume an organic substrate like sugar under aerobic conditions, the products of cellular respiration are carbon dioxide and water. However, when placed in an environment void of oxygen, cellular respiration will instead produce carbon dioxide, protons and electrons. It is therefore necessary to impart an anaerobic environment in the anode chamber of the MFC.

Cathodic Reaction

The positively charged half of the cell, the cathode chamber consists of an electrode subjected to a catholyte flow consisting of an oxidizing agent in solution. The oxidizing agent is reduced as it receives electrons that funnel into the cathode through a wire originating from the cathode.

Power Generation

In order for any fuel cell to work you need to have a means of completing a circuit. In the case of the MFC you have a cathode and an anode separated by a cation selective membrane and linked together with an external wire.. Protons, electrons, and carbon dioxide are produced as by-products, with the anode serving as the electron acceptor in the bacteria's electron transport chain. The newly generated electrons pass from the anode to the cathode using the wire as a conductive bridge. At the same time protons pass freely into the cathode chamber through the proton exchange membrane separating the two chambers. Finally an oxidizing agent or oxygen present at the cathode recombines with hydrogen and the electrons from the cathode to produce pure water, completing the circuit.

Water Treatment

The most immediately foreseeable application of an MFC is in waste water treatment. Microbes love sewage, and the conditions of a waste water treatment plant are ideal for the types of bacteria that can be used in an MFC. Exoelectrogens are more than happy to breakdown and metabolize the carbon rich sewage of a waste water stream to produce electrons that can stream into a cheap conductive carbon cloth anode. The electricity generated from the MFC also offsets the energy cost of operating the plant. As an added bonus, the bacteria eat a lot of the sludge normally present in waste water.

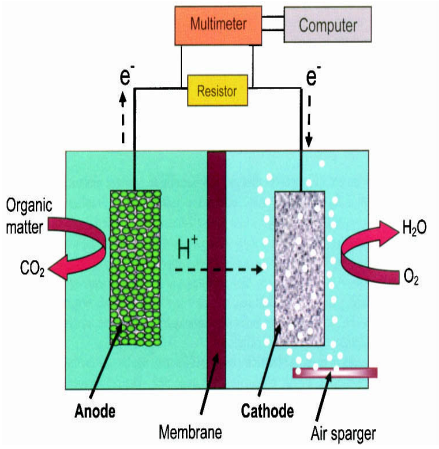


Figure 1 Working of a MFC

MATERIALS AND METHODS

The aim of the project is to create four cells of MFC using two different kinds of waste water so as to compare their efficiency both in terms of treatment of water and generation of electricity. The main objectives for doing this project is listed below:

- To identify an exchange membrane which can be utilized for dairy waste as well as domestic waste water treatment
- Treatment of waste water ensuring the conversion of chemical energy contained in organic matter into electricity by means of catalytic (metabolic) activity of the living microorganisms
- To compare the COD value before and after the process thereby indicating the Treatment of waste water.
- To compare the waste waters to for the better electricity generation.

Materials

Type Of Waste Water

Each type of waste water have different biochemical parameters which will give different results. The process was carried out with 2 cells of Dairy waste water and 2 cells of Domestic waste water. The Dairy waste water was collected from Milma , Ernakulam and the domestic water was collected from the Federal City, Angamaly. The initial CODs of both the samples were taken so as to compare after the process.

Selection Of Proton Exchange Membrane

Oxygen in the anode chamber will inhibit electricity generation, so the system must be designed to keep the bacteria separated from oxygen. This separation of bacteria from oxygen can be achieved by placing a membrane that allows charge transfer between the electrodes and at the same time restrict the passage of oxygen from the cathodic chamber to anode chamber, forming two separate chambers: the anode chamber, where the bacteria grow; and the cathode chamber, where the electrons react with the catholyte. The cathode is sparged with air to provide dissolved oxygen for the reaction which accelerates the reaction as oxygen is an electron acceptor. In principle, the membrane is permeable to protons that are produced at the anode, so that they can migrate to the cathode where they can combine with electrons transferred via the wire and oxygen, forming water.

Such a proton exchange after detailed study was chosen. As mentioned, presence of ion selective separator is essential to ensure an efficient and stable operation of MFCs. Clay ware separators with the addition of Montmorollonite is the Proton exchange membrane (PEM) is used as they are more economical. Presence of Montmorillonite in ceramic separator improves the performance of MFC by enhancing its cation transport ability, and reducing the substrate crossover and oxygen diffusion. Addition of 20% Montmorillonite (M-20) in clay yielded better conductivity of the separator, and hence higher energy recovery and superior performance is facilitated by using this separator in MFC treating wastewater. Ceramic separator incorporated with Montmorillonite has a comparatively low resistance. This separator demonstrates lesser oxygen diffusion in anodic chamber and such separators can ensure a long-term stable operation of MFCs. [2]

Figure 2 Proton Exchange Membrane

Selection Of Electrode

The selection of the proper electrode material is crucial for the performance of MFCs in terms of bacterial adhesion, electron transfer and electrochemical efficiency. There are many studies to scale up the power production using different carbon-based materials such as carbon paper, carbon felt, carbon fiber as well as carbon nanotube-based composites [16]. To implement the MFC technology in practice, the cost of materials must be reduced and power densities must be maximized. In addition, the cathode materials should have catalytic properties for oxygen reduction.

In addition, materials used for the anode must have biocompatible properties. A superior biocompatible material will increase the bacterial adhesion and hence the life of the MFC.Considering all these factors, the electrode chosen is graphite felt for both anode and cathode.

Bacterias will decompose the organic matter in the inoculum and generate electrons and protons in the anodic chamber. These electrons are attached to the anode and taken to the cathodic chamber through an external circuit. The graphite felt has high surface area which results in more space for the bacterias to get attached to.

Figure 3 Graphite Felt

PROCEDURE

1. Two cells of dairy waste water and two cells of domestic waste water is made to compare for the experiment. For each cell 30% of the volume of the cell is filled with septic tank sludge for getting the required bacterias for doing the process.
2. As per studies, it was seen that pre-heating of sludge for 15 minutes under $100^{o}c$ increased the amount of electricity generated and the extend of waste water treated. So two of each set of samples were heated for 15 min under $100^{o}c$ and two were left non-heated so as to compare their efficiency.
3. Graphite felt is being used as both anode and cathode. It has to be wound around the inner and outer surface of the membrane and connected using a conducting wire.

Figure 4 Electrodes wound around the membrane

4. The conducting wire used here is stainless steel due to its outstanding mechanical properties, electrical conductivity, and corrosion resistance.

5. After filling the cell with waste water up to the brim, it has to properly sealed in order to provide anaerobic condition for the bacterias to survive and undertake the process for treating the waste water. In order to do so, the top of the cell is covered with a transparent sheet and sealed using a sealant to provide an air tight atmosphere.
6. The cells are then immersed in a tray of tap water which acts as the cathodic chamber. The water in the tray is aerated using an electric motor. This is done so as to increase the amount of oxygen in the cathodic chamber which accelerates the electron transfer from the anode to cathode.

Figure 5 Working of reactor setup

7. The initial COD value is measured for each cell sample and the apparatus is left undisturbed for three days. Three days constitutes a cycle. After three days, the COD value is measured again and compared with the initial value.
8. During each cycle the electricity generated is also monitored using a galvanometer. And the comparison is done with each type of waste water to know which gives the maximum result. Five cycles was done to get the initial and final COD values

RESULTS AND DISCUSSIONS

Waste water treatment

The chemical oxygen demand is indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. It is a measure of water and wastewater quality. This test is useful for the monitoring and control of waste water treatment plants. It is generally used to measure the degree of contamination and is expressed in milligrams per litre of oxygen (mg/l).

After measuring the COD value of the waste water before and after the process, the following results were obtained.

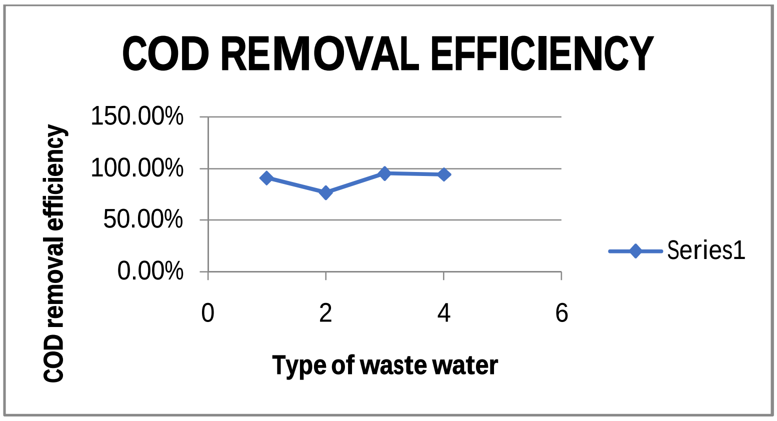
Table1 Variations in COD values during the cycles

TYPE OF WASTE WATER		1st Cycle		2nd Cycle		3rd Cycle		4th Cycle		5th Cycle	
		Initial (mg/l)	Final (mg/l)	Initial (mg/l)	Final (mg/l)	Initial (mg/l)	Final (mg/l)	Initial (mg/l)	Final (mg/l)	Initial (mg/l)	Final (mg/l)
Domestic	Heated	423.28	86.58	465	102	460	40.4	454	38	440	—
	Non heated		1731.6		496		348.6		246		98
Dairy	Heated	4444	13468	4397	4617	4366	2828	4326	1094	4324	201
	Non heated		19624		8686		4733		1984		243

Cod removal efficiency

Table 2 COD removal efficiency

TYPE OF WASTE WATER	COD REMOVAL EFFICIENCY
Heated domestic waste water	91.01%
Non- Heated Domestic Water	76.85%
Heated Dairy Waste water	95.47%
Non- Heated Dairy waste water	94.53%



1- Heated domestic waste water
2- Non- Heated Domestic Water
3- Heated Dairy Waste water
4- Non- Heated Dairy waste water

Figure 6 Graph plotting COD removal efficiency

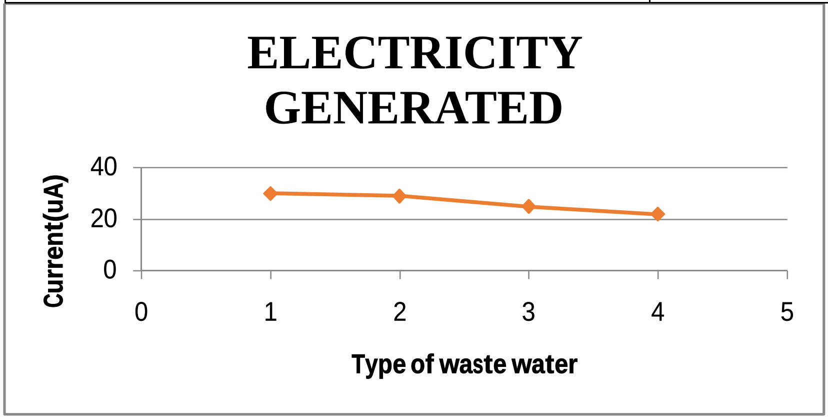
The initial increase in the COD value is caused because, in the initial cycle as there is possibility of microbia getting exposed to a different environment causing dying of the same , thus COD of the sludge gets added up to the COD of the waste water. But after a few cycles, the bacterias get adapted to the atmosphere and improves their capability in decomposing the organic matter and treating the waste water.

ELECTRICITY GENERATION

The electron flow is integral to microbial metabolism. Bacteria metabolize organic substrates For energy. In MFCs, biodegradable matter is oxidized in the absence of oxygen and the electrons and protons generated by respiratory bacteria are transferred to anode; such bacteria are called as “anode-respiring bacteria” or “exoelectrogenic bacteria”.

Table 3 Electricity generation

TYPE OF WASTE WATER	CURRENT (uA)
Heated domestic waste water	30
Non- Heated Domestic Water	29
Heated Dairy Waste water	25
Non- Heated Dairy waste water	22



1- Heated domestic waste water
2- Non- Heated Domestic Water
3- Heated Dairy Waste water
4- Non- Heated Dairy waste water

Figure 5.6 graph plotting electricity generation

CONCLUSION

The high energy requirement of conventional sewage treatment systems demands for the alternative treatment technologies which are cost effective and require less energy for efficient operation. In past two decades, high rate anaerobic processes are finding increasing application for the treatment of domestic as well as industrial wastewaters. The major advantages these systems offer are low energy requirement, less sludge production, and recovery of methane gas. Until now discussion has primarily centered on the use of MFCs for either wastewater treatment or as a method of renewable energy production in the form of electricity or hydrogen. Unlike conventional processes it can completely break down most of the acetate and carbon compounds to CO_2 and water. Some of the species used in MFCs can also utilize the sulphides and other forms of sulphur compounds. The upflow mode of MFCs and Single chambered like constructions are favoured because of large scale implementation**.**

1. Even though there is an increase in the COD level initially, gradually the COD value can be found decreasing which indicates the successful treatment of the waste water.
2. The initial increase in the COD value is caused because, in the initial cycle as there is possibility of microbia getting exposed to a different environment causing dying of the same , thus COD of the sludge gets added up to the COD of the waste water. But after a few cycles, the bacterias get adapted to the atmosphere and improves their capability in decomposing the organic matter and treating the waste water.

3. It can also be seen that the heated sample has better reduction in COD value compared to non heated sample which shows, the methanogenic bacteria are suppressed due to preheating done for the sludge which increases the efficiency.
4. The COD value of all the samples are found to be within the permissible limit of treated waste water which is 250 mg/l as per IS 2490.
5. The COD removal efficiency is found to be more for dairy waste water (95%).
6. Percentage reduction of COD value is considerably low for the domestic waste water.(38%).
7. While comparing the generation of electricity for each type of waste water it can be seen that electricity generation is more for the domestic water(30uA) when compared to that of dairy waste water (22uA).

Scope for the future

MFCs undoubtedly have potential in terms of energy recovery during wastewater treatment. They may occupy a market niche in terms of a stand-alone power source and also in the direct treatment of wastewater. They can also post-treat effluents from anaerobic digesters, even at ambient temperatures, as demonstrated by this study. Yet, it must be observed that several hurdles have to be faced, such as the need to implement sustainable cathodes, the fate of particular organics present in sewage and the removal of residual nutrients.

The success of specific MFC applications in wastewater treatment will depend on the concentration and biodegradability of the organic matter in the influent, the wastewater temperature, and the absence of toxic chemicals. Materials costs will be a large factor in the total reactor costs. Mainly anodic materials commonly used in MFC reactors, such as graphite foams, reticulated vitreous carbon, graphite, and others, are quite expensive. Simplified electrodes, such as carbon fibers, may alleviate these electrode costs. The use of expensive catalysts for the cathode must also be avoided. Another crucial aspect is the removal of non-carbon based substrates from the waste streams: nitrogen, sulfur, and phosphorus containing compounds often cannot be discharged into the environment at influent concentrations. Similarly, even particulate organic compounds will need to be removed and converted to easily biodegradable compounds, as part of an effective wastewater treatment operation [Kalathil et. al (2017)].

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