Experimental Study and Analysis of Microbial Fuel Cell to Harvest Energy

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A thesis submitted to the Department of Mechanical Engineering, Sonargaon University of Bangladesh in partial fulfillment of the requirements for the degree of Bachelor of Science in Mechanical Engineering.

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Abstract

Now a days the demand of renewable energy increases day by day. Microbial Fuel Cell (MFC) could be one of this. There is no doubt of its significance to have sustainable energy in this generation. MFC is a system which converts chemical energy from organic matter to electrical energy directly by using microorganisms as provoking. Another function of MFC is the capability to clean the waste water in terms of reducing the level of organic materials. This system consist of an anode and cathode and an external load connecting to electrode. During this operation bacteria takes nutrients like glucose inside the mud and release electron which is generally a small amount of volts. If we store this voltage into a battery then we can use it when power cuts.

There are three kinds of material and two kinds of mud we use on this system. And try to observe its performance. Our main focus on this project is try to find out by using which kind of mud and materials output generation voltage is better.

Chapter One

Introduction

The microbial fuel cell (MFC) technology is one of the most attractive technologies at present for renewable energy production and simultaneous wastewater treatment where cost is low. Also decrease environment pollution.

1.1 Microbial Fuel Cell

Microbial Fuel Cell (MFC) is that process where bacteria is the main object because it converts the chemical energy into electrical energy inside the mud by releasing electron. This is achieved when bacteria transfer electron to an electrode.

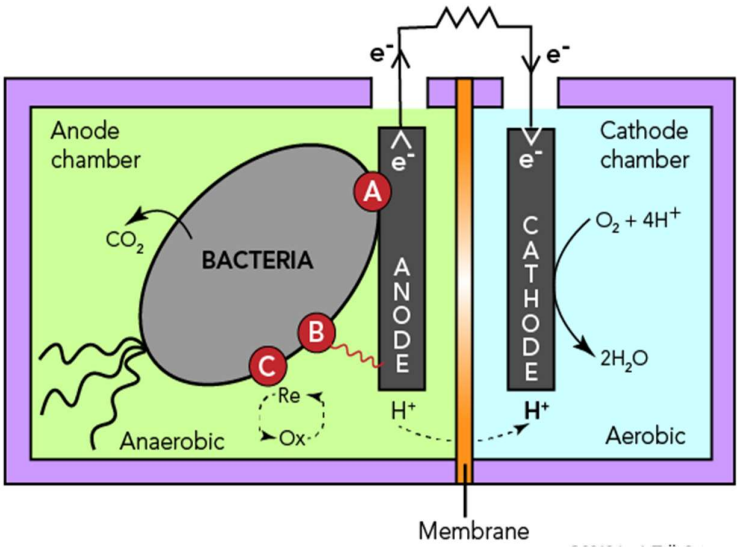

Figure 1.1:- Microbial Fuel Cell (MFC)

If certain bacteria are grown under anaerobic conditions (without the presence of oxygen), they can transfer electrons to a carbon electrode (anode). The electrons then move across a wire under a load (resistor) to the cathode where they combine with protons and oxygen to form water. When these electrons flow from the anode to the cathode, they generate the current and voltage to make electricity [1]

1.2 Background Study

Application of MFC for wastewater treatment has several advantages, such as a high efficiency for energy conversion of the organic matter into electricity, even working at lower temperatures, and the absence of any toxic products. In addition a wide diversity of organic. Compounds present in wastewaters can be used as substrates in MFC to produce electricity and compensate the cost of treatment. MFCs, if used for wastewater treatment, can provide clean and safe energy for people, apart from effective treatment of the wastewaters with and low noise and emissions. The property of using bacteria or enzymes as a catalyst in electrochemical reactions opens up several potential applications for this technology.

MFC is an emerging technology which holds promise towards sustainable power generation and wastewater treatment along with applications in broad areas of life sciences. The use of microbial extracellular electron exchange processes for catalyzing oxidation and reduction reactions at electrodes, also referred to as microbial electro-catalysis , has led to the development of several microbial electrochemical technologies (METs) over the last decade[2,3].

1.3 Aim of this project

The aim of this work is to achieve knowledge about MFC. Efforts will be made to reduce the activation losses by improved electrode designing to enhance the power density. If it can build up in a wide range then it can be generate more energy. A future scale-up of the MFC identified and its application towards industrial and developing countries will be calculated in terms of sustainability and cost savings.

1.4 Thesis Objective

Aim of this project on Microbial Fuel cell (MFC) is:-

- To study the performance of the various combinations of electrodes.
- Performance variation by using different types of Soil like as Pond mud and Top soil.
- Monitor the power output of Microbial fuel cell and compare power generation of different substances.
- To measure electrical Voltage generated in a working MFC.

1.5 Thesis Outline

MFC might provide a solution to several of the bottlenecks in traditional wastewater treatment processes such as high energy cost, complicated procedures and large operational requirements. Hence, this study was initiated with the objective of generating energy from the wastewater to offset the energy and operational costs. Optimization through reactor design development and operational knowledge augmentation. Technological optimization of electrodes

through increased knowledge towards the interaction between anode materials and bacteria and the alternative cathode materials, in order to increase MFC power performance and decrease investment costs. Identification and addressing the embedded MFC barriers to further understand the MFC principles and limitations for further improvements of the MFC performance .Outlining a industrial MFC solution based on this work

Chapter Two

Literature Review

Some observation about Microbial Fuel Cell described below which are recently reviewed on different recent thesis paper.

According to Liu, H.; and Logan [4] Microbial fuel cells (MFCs) are an emerging technology that directly converts the chemical energy stored in organic matter to electricity. Driven by the increasing concern over the energy–climate crisis and environment pollution, MFCs have been developed rapidly in the past decade. This is because MFCs are not only an alternative approach for electric generation; but they can also be used to treat wastewater. MFCs can generate bio-energy from the organic matter while simultaneously removing carbon and nitrogen.

Minghua Zhou [5] the electrodes used in the construction of microbial fuel cells should have a good electrical conductivity, more surface area, less resistance, and should be non-corrosive, biocompatible, chemically and mechanically stable to obtain a reproducible result. The anode materials such as graphite rod, graphite fiber brush, carbon cloth, carbon paper, carbon felt and RVC have been used in the microbial fuel cells.

Feng et al. [6] reported that a nitrogen-doped grapheme catalyst (of 2–8 layers) gave rise to the oxygen reduction reaction at facile potentials, comparable to that of a platinum catalyst, therefore in a MFC configuration this could give rise to beneficial outputs of the MFC. The advantages of nitrogen-doped graphene

include being less expensive than platinum with improved long-term operational stability in comparison to commercial platinum electrodes as measured within alkaline electrolytes.

G.Antonopoulo, K.Stamatelatou [7] A MFC typically consist of two chambers, an anaerobic anode chambers and an aerobic cathode chamber separated by an ion conducting membrane usually a proton exchange membrane (PEM). At the anode organic substrates are oxidized by bacteria. The produced electrons are transferred from the anodic electrode (negative terminal) through an external circuit to the cathode electrode (positive terminal) where the electron acceptor is reduced. Protons produced at the anode migrate through the solution of the anode across the proton exchange membrane (PEM) to the cathode where they combine with oxygen and electrons to form water.

Kim, B.H. et al. [8] It is a surprise to many researchers that the most significant block to achieving high power densities in MFCs is the system architecture, not the composition of the bacterial community. Early systems produced very low power densities (<0.1 mW/m2, normalized by the anode surface area)

Kim, B.H. et al. [9]Although there have been dramatic recent improvements in MFC architecture to increase power densities from these systems, advancements in understanding the microbiology of MFC biofilms and the implications of the ecology on system performance are just beginning to emerge. Electrochemically active communities are readily developed from a diversity of environmental sources and maintained with a remarkable range of pure and complex substrates, with stable MFC performance observed for more than five years.

Zuo, Y. et al. [10] with further development, MFCs or modified MFCs could become practical methods for hydrogen production from the same materials envisioned for ethanol production (sugar and cellulosic wastes) and from other biodegradable materials. Either the electricity produced by MFCs can be used for the electrolysis of water or, more efficiently, hydrogen could be produced directly from biomass sources using the BEAMR process. It was recently shown, for example, that electricity could be produced from corn stover hydrolysates produced by a steam explosion process that liberates sugars from cellulose and hemi-cellulose components.

Logan, B.E. and Regan [11] The MFCs currently in existence are exciting systems for studying microbial communities and improving the understanding of how bacteria transfer electrons to solid substrates. Harnessing that power in an economical manner, however, remains a greater challenge. It is generally considered that the first applications of MFCs will be as power sources for monitoring devices in the environment and for water treatment.

Lovley, D.R [12] to iron and other metal oxides, to carbon electrodes and possibly to other bacteria suggest that a new term is needed to classify this functional capability of bacteria. We suggest the term ‘exoelectrogens’ as a general classification because this name captures the ability of bacteria to generate and transfer electrons outside of the cell. It has recently been suggested that these bacteria be called ‘electricigens’

Rabaey, K. et al. [13]The ability of bacteria to transfer electrons to a distant surface is also supported by several studies showing the presence of bacterial mediators or electron shuttles (wireless communities), or highly conductive nanowires produced by the bacteria (wired communities). Pseudomonas

aeruginosa produces phenazines capable of electron transfer between cells and surfaces.

Du et al. [14] Microbes in the anodic chamber degrade organic matters and produce electrons, protons and carbon dioxide. Electrons and protons produced by microbes are then transported to the cathode chamber via external circuit and a proton exchange membrane (PEM), respectively. In the cathode chamber, protons and electrons react with oxygen to form water. Because the terminal electron acceptor (*i.e.*, oxygen) is kept away from the anodic chamber, electrons are allowed to pass through the external load to generate electricity.

Chang et al. [15] They used sludge collected from a corn-processing wastewater treatment plant as inoculum for the anodic chamber of an MFC and fed it with wastewater from the same source. Initially the MFC generated a current of 20 μA with an external load of 10 Ω. When the anode solution was replaced with a more nutritious wastewater from a difference source, the current increased with concomitant COD (Chemical Oxygen Demand) reduction. After repeated replenishments of the wastewater the current output eventually reached 1.2 mA.

Lens et al. [16] With the continued increased consumption of paper products and other natural fiber products, the recycling and use of recovered paper is growing worldwide. The average amount of recycling content in paper production was increased by 22% from 1990 to 1998. In 2005, 78% of paper and paperboard mills in America used some recovered paper, and 149 mills used only recovered paper. By 2012, it is projected that the paper industry will recover 55% of all the paper Americans consume.

Chapter Three

Methodology

The design and use of various MFCs have attracted interest due to the increasing demand for sustainable production of energy from biodegradable waste materials. However, the slow microbial kinetics and high cost of construction materials have limited the large-scale commercial applications of the technology. Researchers are working to evolve the design and develop a universally acceptable MFC, but this is not yet available. Various efforts have been made to classify MFCs according to various criteria such as configuration, reactor structure, separator, flow type, cathode type, etc.

3.1 Double-chamber MFCs

As the name suggests it consist of anode and cathode compartment separated by a Proton exchange membrane or salt bridge. Anode chamber contains microbes, media (Glucose, acetate etc.) and electrode whereas cathode chamber contains electrode, fresh water, and oxygen supply. Copper, stainless steel mesh, graphite, carbon paper, graphite fiber brush and carbon cloth is commonly used as electrode [17]. If the anaerobic condition is to be maintained in anode compartment then nitrogen should be supplied continuously.

Figure 3.1: - Double-chamber MFCs

The basic design in this category is H type MFC. Logan et al on 2004 designed the basic H type MFC. It was constructed using two borosilicate glass bottles of capacity 300 mL. The glass bridge of two chambers was connected together by clamp system. The two chambers were separated by PEM. The carbon paper of dimension 2.5 X 4.5 cm was used as an electrode for both anode and cathode. But the cathode was impregnated with platinum catalyst (0.35 mg/cm^2). The sediment obtained from the lake was used as an inoculum. The microorganism were grown in mineral salts medium (MSM) and stored in 4 ºC for further use. The maximum power density was 19mW/m2 and was increase 39 mW/m^2 by increasing the concentration of cysteine (0.770 g/L).

3.2 Single-chambered MFCs

The single-chambered MFC is a simple and cost-effective design. Single-chamber MFCs combine both electrodes, the anode and the cathode, without a proton exchange membrane (PEM). Single-chambered MFCs may have various shapes of compartments, which have been reviewed in various studies [18]. The

single-chamber MFC has a drawback: it acidifies easily due to microbial action. Therefore various buffer solutions are used to control the acidification. Shortterm alkaline intervention is an effective strategy to enhance the performance of single-chamber MFCs. When KCl and alkali-treated anion exchange resin was used to release hydroxyl ions (OH^-) and neutralize the hydrogen ions (H+), the maximum power density achieved was 307.5–542.8 mW m^{-2}.

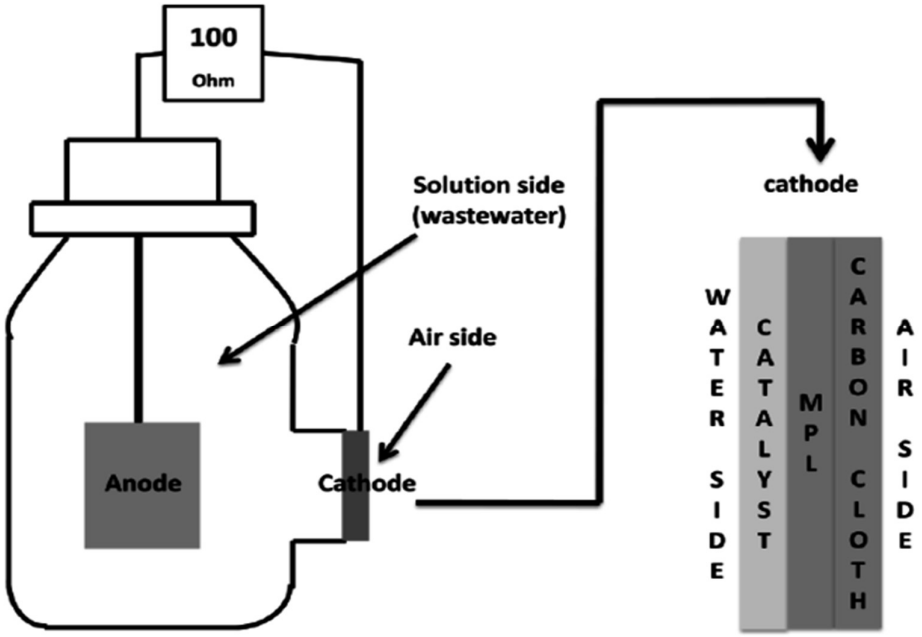

Figure 3.2: Single Chamber Microbial Fuel Cell (MFC)

A microalgae bio-cathode was developed by Logrono et al. [19], which had 42% microalgae population on the surface of cathode and achieved a COD removal efficiency of 92–98%. Also, it performed well in terms of metal remediation: 6 H. M. SINGH ET AL. Cr 54–80%; Zn 98%. The power density of the bio-cathode MFC is 123.2 mW. Bio-cathodes are an alternative to replace high-cost Pt cathodes. A bio-anode MFC was also constructed with an air-cathode and was found to have a high nitrobenzene removal capacity. The maximum power

capacity was 25 Wm^{-3} with a loading rate of up to 6.2 mol m^{-3} d^{-1} . The other researchers also standardized the loading rate of nitrobenzene to 1.2– 14.7 mol m^{-3} d^{-1} with respect to 13.7 Wm^{-3} electricity generation. Similarly, cefazoline sodium-contaminated wastewater produced a maximum power of 30.4 Wm^{-3} and a stable power of 18.2 Wm^{-3} , and the removal rate was 1.2–6.8 mg L^{-1} h^{-1} without any apparent inhibition of electricity production [20].

3.3 **Membranes**

The majority of MFC designs require the separation of the anode and the cathode compartments by a membrane. The purpose of the membrane is to keep anode and cathode solutions separated while allowing ion transfer. This prevents direct oxidation of organic matters that happens when oxidants cross into the anode chamber from the cathode chamber. Nafion is the most commonly used CEM to allow the passage for ion exchange while partitioning the anode chamber and the cathode chamber. Besides CEM, AEM, bipolar membrane (BPM), charge mosaic membrane (CMM), ultrafiltration membrane (UFM) may play the role of facilitating the transport of ions through the membrane in order to maintain electroneutrality in MFC systems.. Theoretical working principle of membrane charge transport in four different types of ion exchange membranes (C+ : Na+ , K+ , NH4 + , Mg2+; A- ; Cl- , HCO3 - , H2PO4 - , CH3COO-) .Laboratory MFCs often use membranes to partition the anode chamber and the cathode chamber. A major disadvantage of using membranes is their high costs and fouling. Membranes also present significant internal resistances that lead to reduced power production. There is a growing consensus among MFC researchers that it is not essential to use membranes in MFC to separate the biological anode from the cathode reactions. Salt bridge porcelain septum, microporous filter and physical barriers are alternative ion exchange systems. In

fact, it was observed that the anode could even be kept anaerobic due to diffusional resistance between the anode and the cathode without any physical partitioning. For example, in a sediment MFC, nothing but the aqueous solution separates the anode and from the cathode. The distance between the two electrodes serves as the barrier for oxygen diffusion although it is not 100% efficient.

Figure 3.3: Membranes

3.4 **Electrodes**

There are different types of electrodes which can be used in a MFC. The different metals used in this study are Copper (Cu), aluminum (Al), Carbon (C), Brass. All the anodes and the cathodes used in MFC system have the same surface area so that they will allow to grow the microbes or have capability to take same electrons.

Figure3.4: - Copper Electrode

Figure 3.5:- Aluminum Electrode

Figure 3.6: - Zinc Electrode

Table 3.1: Size of Electrode

Electrode material	**Cross section**
Copper	13.2 cm*5.5 cm
Graphite	15.5 cm bar with 1 cm diameter
Zinc	13.2 cm*5.5 cm

Table 3.2: Composite of electrode materials

Materials	Composite
Cupper	Cu-99.78 Si-0.22
Zinc	Zn-97.82 Si-2.08 Fe-.1
Zinc	Zn-98.36 Si-1.64

3.5 **Working Procedure**

First one of the container was filled with water and another container was filled with mud. Then the zinc electrode were submerged into both of the container which contained water and mud. Next, the lids of the container were closed and the aerobic bacteria container should be exposed to small amount of oxygen. After that, the copper wire at the both container were attached to alligator clips, then the alligator clips were clamped to the multimeter probes. The black probes should be connected to the electrode at the mud where the electron emitted from the sludge were attracted by the anode. The current flow from the mud container were detected and measured by the multimeter in volt measurement. Figure shows the Schematic diagram of how the microbial fuel cell was set up.

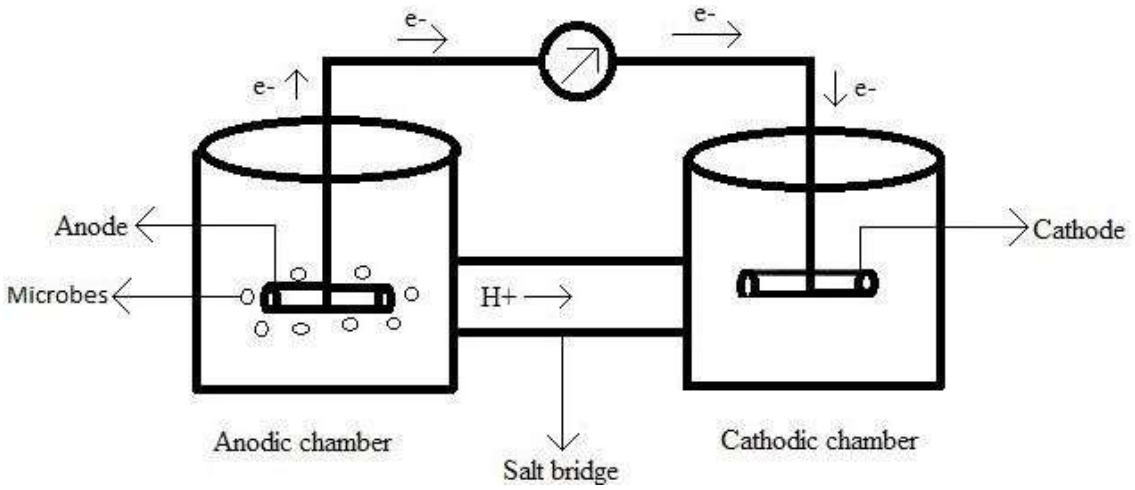

Figure 3.7: - Schematic diagram of how the microbial fuel cell.

Then this voltage generated from MFC transferred to a battery through a DC to DC charging module. This little voltage will store in battery so that it can use later. MFC output voltage and power must be increased for practical uses. So far, several MFCs were simply connected in series or in parallel to overcome the low voltage or power issue.

The system of power storage by using a charging module and a battery is given bellow by an observation figure.

Figure 3.8: - Voltage transfer system on battery

3.6 Data collection Procedure

After the full setup we start to observe the MFC. In the meantime there was no result but after some time it shows a small amount of voltage on multimeter reading. In the beginning the reading was quite low. But after passing some time the generation of voltage were increasing. We measured that reading and noted. Continuously that reading were measured at a certain time (one hour) later.

First time copper electrode were used. Its performance was observed about two days. And its proper result were noted and described on Result and Description.

Similarly we use Zinc and Aluminum electrode in turns. Among of those electrode zinc shows the better result than others.

Chapter Four

Result Analysis

On the basis of the experimental results, we conclude that a MFC powered by benthic mud sample produces the greatest amount of electricity, although its decline in electricity production over time is steepest. During this experiment we find some result variation due to using different type's material of electrode and the different source of mud. This variation happens because different types of materials electrode have different conductivity. Some of electrode have more conductivity then others. Also we used different type of mud collected from different locations. Those different mud have different amount and types of microorganisms. Those microorganisms act and release different amount of electrons. That's why we get the variation of results.

4.1 Zinc Electrode

When using the zinc electrode we get the much valuable voltage. In case starting voltage was found as 0.43V and the maximum voltage was 1.8V. The observation data and graph pattern showed in Figure:-

Table 4.1: Observation data of Zinc Electrode

Observation	Time(Hour)	Voltage(volt)
1.	0	0.43
2.	1	0.49
3.	2	0.81
4.	3	0.97
5.	4	1.13
6.	5	1.50
7.	6	1.60
8.	7	1.80
9.	8	1.70
10.	9	1.5
11.	10	1.4
12.	11	1.4
13.	12	1.2
14.	13	0.98
15.	14	0.95
16.	15	0.70
17.	16	0.68
18.	17	0.53
19.	18	0.50

	time(hours)	voltage(Volt)
2	0	0.43
3	1	0.49
4	2	0.81
5	3	0.97
6	4	1.13
7	5	1.5
8	6	1.6
9	7	1.8
10	8	1.7
11	9	1.5
12	10	1.4
13	11	1.4
14	12	1.2

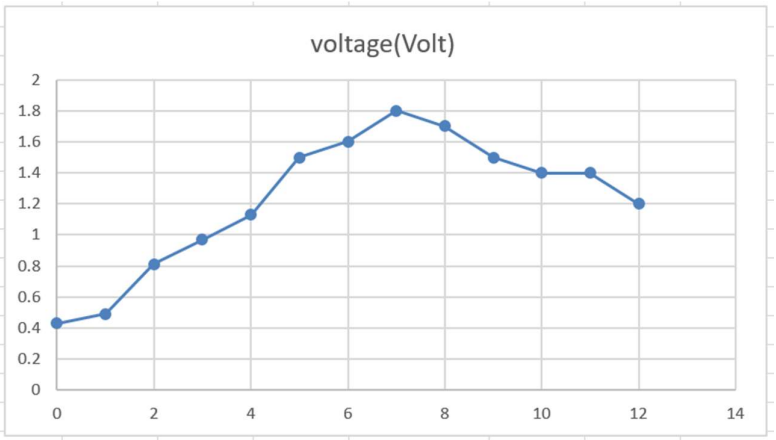

Fig: Time vs voltage graph for zinc electrode

Figure 4.1 :- Time vs. voltage for zinc electrode

4.2 Copper Electrode

When using the copper electrode we get the much valuable voltage. In case starting voltage was found as 0.34V and the maximum voltage was 1.1V. The observation data and graph pattern showed in Figure:-

Table 4.2: Observation data of Copper Electrode

Observation	Time(Hour)	Voltage(volt)
1.	0	0.34
2.	1	0.41
3.	2	0.47
4.	3	0.52
5.	4	0.61
6.	5	0.79
7.	6	0.94
8.	7	1.1
9.	8	0.99

10.	9	0.91
11.	10	0.88
12.	11	0.70
13.	12	0.66
14.	13	0.58
15.	14	0.55
16.	15	0.51

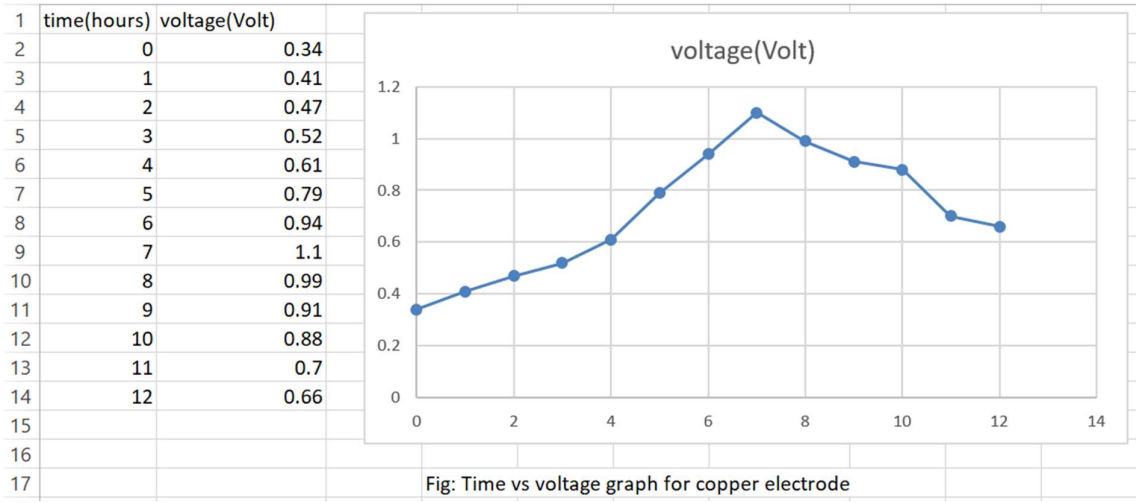

Figure 4.2: - Time vs. voltage graph for copper electrode

4.3 Aluminum Electrode

When using the Aluminum electrode we get the much valuable voltage. In case starting voltage was found as 0.57V and the maximum voltage was 0.91V. The observation data and graph pattern showed in Figure:-

Table 4.3: Observation data of Aluminum Electrode

Observation	Time(Hour)	Voltage(volt)
1.	0	0.57
2.	1	0.53
3.	2	0.55
4.	3	0.58
5.	4	0.61
6.	5	0.67
7.	6	0.73
8.	7	0.80
9.	8	0.84
10.	9	0.91
11.	10	0.88
12.	11	0.81
13.	12	0.75
14.	13	0.68
15.	14	0.63
16.	15	0.59
17.	16	0.50
18.	17	0.48
19.	18	0.48

	time(hours)	voltage(Volt)
1	0	0.57
2	1	0.53
3	2	0.55
4	3	0.58
5	4	0.61
6	5	0.67
7	6	0.73
8	7	0.8
9	8	0.84
10	9	0.91
11	10	0.88
12	11	0.81
13	12	0.75
14	13	0.68
15	14	0.63
16	15	0.59
17	16	0.5

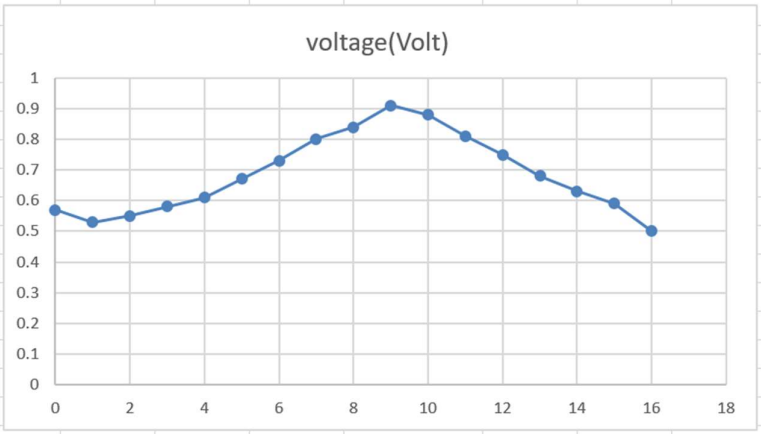

Fig: Time vs voltage graph for Alluminium electrode

Figure 4.3: - Time vs. voltage for Aluminum Electrode

4.4 Comparison of Used Electrodes

By comparing this three observation we realized that zinc electrode is generating better voltage then copper and aluminum. The comparison graph showed in Figure:-

	time(hours)	voltage(Volt) Allun	voltage(Volt) Copper	voltage(Volt) Zinc
2	0	0.57	0.34	0.43
3	1	0.53	0.41	0.49
4	2	0.55	0.52	0.81
5	3	0.58	0.61	0.97
6	4	0.61	0.79	1.13
7	5	0.67	0.94	1.5
8	6	0.73	1.1	1.6
9	7	0.8	0.99	1.8
10	8	0.84	0.91	1.7
11	9	0.91	0.88	1.5
12	10	0.88	0.7	1.4
13	11	0.81	0.66	1.4
14	12	0.75	0.58	1.2
15	13	0.68	0.55	0.98
16	14	0.63		0.85
17	15	0.59		
18	16	0.5		
19				

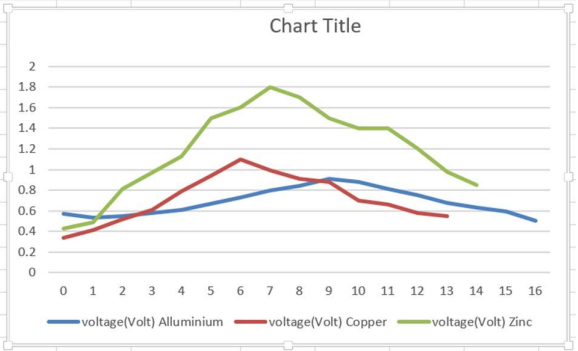

Figure 4.4:- comparison graph of used various electrodes.

The amount of power that is generated in these systems is affected by the surface area of the cathode relative to that of the anode and the surface of the membrane. Most of the microorganism in microbial fuel cell depends on the oxogeneous or endogenous mediator molecules transfer but a few can deliver electrons directly to the anode. As in the experiment, which is using biofilm as the factor, microorganism can transfer electrons directly from the cell envelope to the electrode or across the biofilm.

Chapter Five

Conclusion and Recommendation

The highest result for microbial fuel cell with the absence of air pump is 153mV. The difference shows that the higher amount of oxygen provided will produce a result that is more efficient. This microbial fuel cell's experiment that convert microorganisms activity inside mud into electricity by redox reaction was predetermined as one of a green solution as it have a possibility to instill a non-harmful energy and environmentally friendly. Systems beneath the microbial fuel cell would give out an extensive search of ways to operate the bio electrochemical device in more efficient and in high energy production. This fuel cell are feasible with the water treatment process in harvesting energy utilized by anaerobic digestion as a method used in the microbial fuel cell to collect bioenergy from wastewater, from this scope, MFC had clearly give an advantages in treating wastewater linearly producing electricity.[21]

An MFC has the ability to generate electricity from the wastewater while simultaneously removing carbon and nitrogen. The high rate of voltage generation is achieved when the MFC is operated with zinc (1.8V) followed by copper (1.1V) and Aluminum (0.91V). However based on the study of the graph pattern generated activated mud provide the most consistent record for the electricity.

The power density produced by these systems is typically limited by high internal resistance and electrode-based losses. When comparing power produced by these systems, it makes the most sense to compare them on the basis of equally sized anodes, cathodes, and membranes. In term of internal resistance of the MFC, it is dependent on both the resistance of the electrolyte between the electrodes and by

the membrane resistance. For optimal operation, anode and cathode need to be as close together as possible. Also proton migration significantly influences resistance-related losses. [22]

In future to improve the energy generation from MFC the surface modifications of anode materials are one of the most important factors. As the material used for anode is usually a limiting factor in power production in an MFC. Ideal anodic materials should be biocompatible, conductivity and chemically stable. MFCs still have a long way to go to reach application at large scale. Real use is much more complex than can be assessed at this stage and demonstrator units will need to be employed to go forward. This section suggests future potential research areas and directions that are worth study to reach this goal. Many factors need to be setup before reaching large scale demonstrator and eventually commercialization and have been summarized below.

Chapter Six

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