Wastewater Microbial Fuel Cell Stack with the Ability of Driving Low Power Electronic Load

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***Abstract*—Microbial Fuel Cell (MFC) uses bio-electrochemical process to generate electricity. It is considered as a new approach in renewable energy generation. However, due to low output voltage and current, supplying power to loads from MFC is quite challenging. Research so far done on MFC mainly focused on material analysis, creating new designs, bacterial activity in MFC and so on. But very few attempts have been done on delivering power to loads from MFC. In this research, using waste water as input, three Double chamber MFCs and two single chamber membrane-less MFCs have been constructed using Aluminum as anode and Copper as cathode. Constructed MFCs were connected in series which generated maximum 2.6 V. The MFC combination could light up a small Light Emitting Diode (LED).**

***Keywords—microbial fuel cell, wastewater, bacteria, double chamber micorbial fuel cell, membrane-less microbial fuel cell*.**

I. INTRODUCTION

Due to rapid increase in demand, energy crisis throughout the world is escalating. A large percentage of energy demand is fulfilled by means of fossil fuels. But fossil fuels are non-renewable energy source which will one day extinct. Therefore, the importance of renewable and environment friendly energy sources is becoming crucial.

Microbial fuel cell (MFC) is a promising technology that uses bio-electrochemical process to convert chemical energy stored in biological components into electricity [1]. With the new research and inventions, this technology is getting quite impressive to consider as an alternative process for electric energy generation. MFC uses microorganisms which decomposes organic and inorganic materials to generate electricity. It is considered as a new process for electricity generation and water purification in wastewater treatment process [2]. However, output power level of MFC is subjected to different factors. These factors include pH level, microorganism growth rate, food (biomass and substrate) concentration, temperature, and load [3]. Moreover, output power of MFCs are quite low to drive a load.

In this research, low-cost MFCs were constructed to convert wastewater into electricity. The main focus of this research is to deliver power to an electronic load. The MFCs generated enough power to drive a Light Emitting Diode.

II. EXISTING WORK

Researchers are constantly working on the advancement of MFC technology to make it more efficient. Due to low output power, it is still quite challenging to deliver power to real loads. Therefore, a significant amount of research has been conducted in the recent years to enhance the output power of MFC.

Different materials can be used as input in MFC to generate electricity. R. Regmi and R. Nitiseravut used paddy plants as biomass in MFC to generate electricity [4]. In accordance to [5], Black Tea waste was used in MFC that generated power in nano-watt level [5]. Using Salt Bridge as membrane, a double compartment MFC was designed using starch and sucrose as substrates (input) [6]. Low cost salt-bridge membrane was used which reduced MFC cost significantly. The organic matter of food waste can also be used as input to MFC [7]. Moreover, MFC has the potential to use sediments as input to drive underwater biosensors [8]. Such kind of MFC will definitely remove the hectic maintenance work of changing the batteries of biosensors in the near future. D. Zhang, Y. Ge and W. Wang developed a Terrestrial MFC and analyzed its performance [9]. The most promising application of MFC lies in wastewater treatment process because huge amount of wastewater is generated in urban areas everyday [10]. Wastewater contains a large quantity of bacteria and organic materials that work as a great input resource for MFC. Moreover, MFCs can also be utilized as a good solution to deliver power to low power devices using residential waste [11]. However, all the research works stated above mainly focused on output power delivered by different materials in MFC. No energy harvesting technique had been mentioned to transfer power to load.

III. THEORY

Theoretical information of this paper is divided into the following sub-sections.

A. Basic Working Principle of MFC

The basic working process of MFC lies in Oxidation and Reduction reaction. MFC uses bacterial respiration- usually a redox reaction where electrical ions are transferred from one compound to another which results in formation of new compounds. Since electron is being transferred from one compound to another, the redox reaction produces an electromotive force (emf) by which work can be done. Typical

MFC consists of an Anodic Chamber and a Cathodic Chamber. Anode is placed inside Anodic Chamber and Cathode is placed in Cathodic Chamber. Different types of anode and cathode have different impacts on the overall performance of MFC. Both anode and cathode are surrounded by certain types of electrolyte needed depending on the operation of MFC. The anode electrolyte consists of organic materials and bacteria which serves as an input to the MFC. Microorganisms in Anodic Chamber oxidize the organic materials which generate protons and electrons. The protons drift towards the cathode. The electrons pass through an external circuit with a load. Then the electrons enter the cathode chamber. The trick of this process is to collect the electrons generated in anode and make them pass through a load towards the cathode.

B. Types of MFC

Depending on chamber, MFCs are mainly two types: Single Chamber MFC and Double chamber MFC. Single chamber MFC can be further divided into two types depending on Membrane: Membraned MFC and Membrane-less MFC. The term Membrane represents any sort of biological medium that only allows to transfer ion from one medium to another. Semipermeable membrane is the perfect example of such kind of membrane.

C. Working Principle of Double Chamber MFC

Double Chamber MFC uses two separate chambers for cathode and anode. The chambers are typically separated by a membrane. Input (wastewater, urine, sediment etc.) to the MFC is put into anode chamber. Bacteria present in anode chamber reacts with the organic material and generate electrons which is responsible for electrical power in MFC.

The reaction that occurs in anode chamber is oxidation reaction. When bacteria react with organic substrates in presence of Oxygen, the reaction type is called aerobic respiration. In aerobic respiration process, the product is directly Carbon-di-Oxide. But when the reaction occurs in absence of Oxygen, the process is called Anaerobic Respiration which results in generation of Carbon-di-Oxide, Proton and Electron. In the Anode chamber of MFC, Anaerobic respiration takes place. Hence, the anode chamber is kept airtight so that no Oxygen can enter into the chamber. Schematic of Double Chamber MFC is represented by Fig. 1. The reaction that occurs in anode chamber is oxidation reaction. The positive ions (proton) generated in the anode chamber travel through the membrane to the cathode. The cathode accepts the oxidizing agent (electron) created in anode chamber. Then, Oxygen, Proton and Electron combine together to produce fresh water.

D. Working Principle of Single Chamber Membraned MFC

In this type of MFC, anode and cathode are placed in a single box or chamber. To make such kind of MFC, anode electrolyte (contains bacteria and organic materials) and the anode is placed in the bottom part of the chamber. Then, a layer of membrane is put on top of the anode electrolyte. The cathode electrolyte and cathode are put above the membrane. This part is exposed to the air. The membrane effectively divides the whole MFC chamber into two parts. One part contains anode and its electrolyte. The other part contains cathode along with its electrolyte.

The reactions and working principle of single chamber membraned MFC are exactly the same as double chamber MFC. The only difference is the number of box or chamber required. schematic of single chamber membraned MFC is represented by fig. 2.

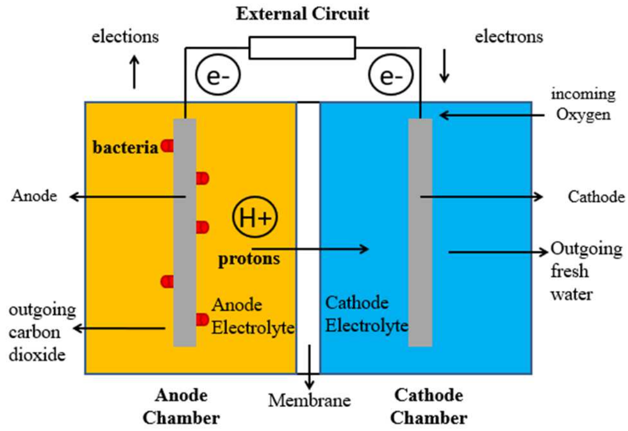

Fig. 1. Schematic of Double Chamber MFC.

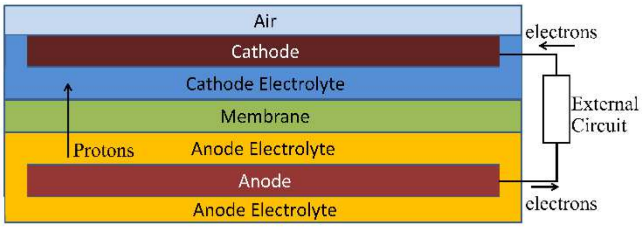

Fig. 2. Schematic of Single Chamber Membraned MFC.

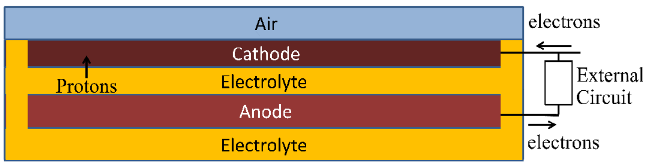

Fig. 3. Schematic of Single Chamber Membrane-less MFC.

E. Working Principle of single chamber Membrane-less MFC

In this sort of MFC, no membrane is used. Anode and cathode share the same electrolyte in a chamber. The electrolyte contains bacteria that reacts with the organic materials inside it. The reactions generate electron, proton and carbon-di-oxide. The electrons drift towards anode and protons drift towards cathode. The electrons pass through an external circuit and later reach the cathode where they react with proton and oxygen which generates water.

F. Bacterial Reactions in Wastewater inside MFC

Wastewater contains several microorganisms, organic and inorganic materials that make wastewater a perfect material to be used in MFC. Different bacteria react with different substrates. Few of them are listed in table I.

TABLE I. DIFFERNET BACTERIA AND THE SUBSTRATES THEY WORK

Bacteria	Organic Substrate
E.coli	Sucrose, Glucose
Acino Bacillus	Glucose
Clostridium Butyricum	Molasses, Lactate, Glucose, Starch
Aeromonas hydrophilia	Acetate ion

Anodic and Cathodic reactions for different substrates are presented below.

1) Reactions for Sucrose as Substrate.

a) Anodic reaction: $C_{12}H_{22}O_{11} + 13H_2O = 12CO_2 + 48H^+ + 48e^-$

b) Cathodic reaction: $O_2 + 4e^- + 4H^+ = H_2$

2) Reactions for Glucose as Substrate.

a) Anodic reaction: $C_6H_{12}O_6 + 6H_2O = 6CO_2 + 24H^+ + 24e^-$

b) Cathodic reaction: $O_2 + 4e^- + 4H^+ = H_2O$

3) Reactions for Acetate Ion as substrate.

a) Anodic reaction: $CH_3COO^- + 4H_2O = 2HCO_3^- + 9H^+ + 8e^-$

b) Cathodic reaction: $O_2 + 4e^- + 4H^+ = H_2O$

From the equations, we can see that the cathode chamber only generates water using the Oxygen from air even though the substrates were different.

IV. Proposed Methodologies

In this research, three double chamber MFCs and two single chamber membrane-less MFCs have been constructed. Materials, MFC construction procedure and method used to light up an LED are stated in the following sub-sections.

A. Materials used

The material we used as electrolyte in anode chamber is wastewater (muck). For cathode, we used freshwater as electrolyte. Plastic jars were used as chambers. For double chamber MFC, salt-bridge membrane was chosen due to its low cost compared to the other membranes. Plastic pipe was used to create the bridge between the chambers which contained the salt-bridge membrane. Copper was used for cathode and Aluminum was used for Anode.

B. Salt-Bridge Membrane for Double Chamber MFC

Salt-Bridge was used to connect the anode half cell (anode chamber) and cathode half cell (cathode chamber). To make salt bridge, Kosher Salt and Cotton were used. Kosher salt is mainly made out of Sodium Chloride. But its grains are much larger than typical table salt. Unlike typical table salt, Kosher Salt does not contain Iodine. Kosher salt is chosen because it doesn't get involved in reaction with the chemical and organic materials present in anode and cathode chamber. At first, Sodium Chloride (Kosher Salt) was dissolved in distilled water and a 0.1 molar Sodium Chloride Solution was created. Then, we took 0.1 molar Sodium Chloride into a flux and adder 0.4 gm of Agar. Next, the solution was heated until it reached 100 °C. After that, cotton was put into the solution. After the cotton was completely soaked, it was taken out of the solution. Finally, the soaked cotton was put inside the plastic pipe.

C. Construction of Double Chamber MFC

At first, holes were made in the plastic jars. Then, we took the plastic pipe which contained salt-bridge and put it in between the holes of the two plastic bottles. After that, we sealed the connections between plastic jar and pipe with silicon-based glue. Wastewater (muck) was added into one plastic bottle (anode chamber) and distilled water in another plastic bottle (cathode chamber). Copper metal bars were put into both of the bottles and a conducting wire was connected between the metal bars. Finally, using glue and cap, the mouth of anode chamber was sealed.

D. Construction of Single Chamber Membrane-less MFC

To construct single chamber MFC, wastewater (muck) was put into the bottom of a plastic jar. Then, Aluminum foil sheet was placed on top of the wastewater layer. Next, a layer of wastewater (muck) was put on top of Aluminum foil. After that, copper sheet was placed on top of wastewater. Wires were connected with the copper sheet and aluminum foil. In this way, single chamber membrane-less MFC was constructed.

E. Method Used to Light Up LED

Output voltage of single MFC is not enough to drive any sort of electronic load. Therefore, the MFCs were observed for 7 days and then connected in series to enhance the output voltage level.

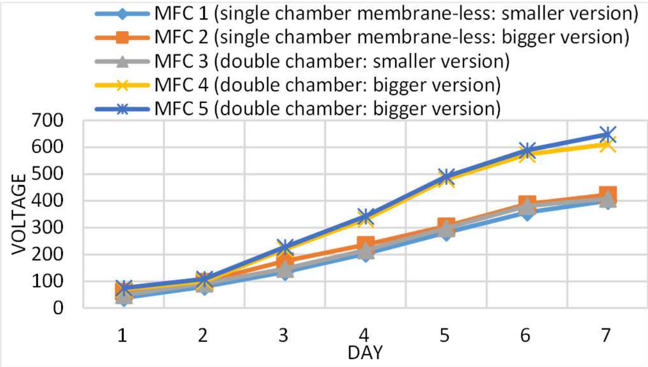

Fig. 4. Voltage obtained from proposed Microbial Fuel Cells.

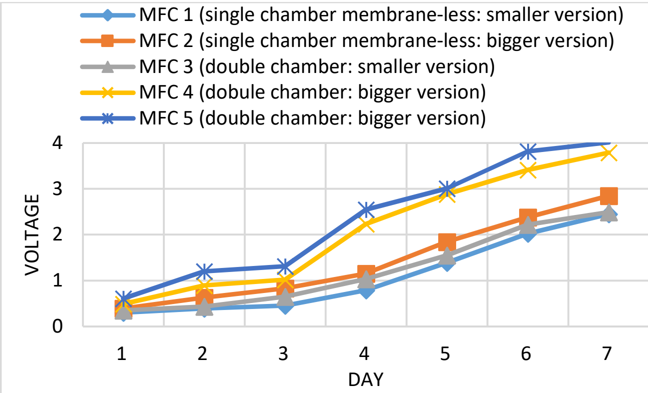

Fig. 5. Current obtained from proposed Microbial Fuel Cells.

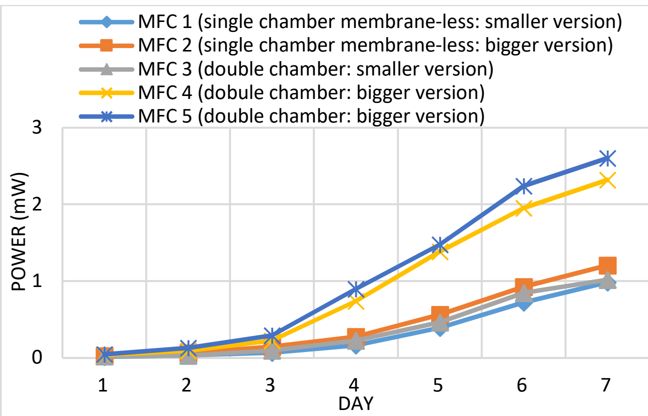

Fig. 6. Power obtained from proposed Microbial Fuel Cells.

V. Result Analysis And discussion

The practical output of proposed MFCs, a comparative analysis with existing wastewater MFCs and a comparative study between double chamber MFC and single chamber membrane-less MFC based on practical data is represented in the following sub-sections.

A. Voltage, current and power level of the MFCs

The series combination of 5 MFCs produced about 2.6 V and 2.45 mA which was sufficient to light up an LED. Before connecting in series, the individual MFCs were observed. The observed data of voltage, current and power of the MFC cells are represented by fig 4, fig. 5 and fig. 6 respectively. The final output voltage, current and power obtained from each of the MFC in day 7 are listed in table II.

TABLE II. Voltage, Current and Power Level of Each MFC

MFC no.	MFC type	Voltage (mV)	Current (mA)	Power (mW)
1	Single chamber membrane-less: smaller	401	2.45	0.98
2	Single chamber membrane-less: bigger	423	2.85	1.20
3	Double chamber: smaller version	409	2.49	1.02
4	Double chamber: bigger	612	3.79	2.32
5	Double chamber: bigger	649	4.01	2.60

B. Comparative analysis with existing MFCs

MFC developed using food waste (Black Tea waste) in [5] generated power in nano-watts. Using residential organic waste as input, the MFC in [10] with Plain Carbon Rod Anode produced 0.05 mW (voltage level: 302 mV and current level: 0.165 mA) power after 7 days of observation. Due to having very low output power, the MFCs in [5] and [10] are quite insignificant for practical applications. MFC developed using food waste in [7] generated 0.41 mV power. In comparison, the least power level obtained in our study is 0.98 for MFC 1. Maximum power was obtained from MFC 5 which generated 2.60 mW. Hence, power level of the proposed wastewater MFCs are much higher than the existing waste material based MFCs in [5], [7] and [10].

MFC in [11] used mixture of mud and municipal wastewater as input in anode chamber and Potassium Permanganate was used in cathode chamber. Moreover, sucrose and starch were added in the anode chamber in separate setup which worked as food to bacteria. In the first setup in [11], 125 gm sucrose was added to the mixture of mud and municipal wastewater mixture in anode. The MFC setup produced 1.809 V, 9.38 mA and 16.964 mW in day 6. But the voltage, current and power dropped to 1.536 mV, 6.38 mA and 9.781 mW in day 8. The second setup in [11] used 250 gm of Starch instead of 125 gm of Sucrose and it produced 1.282 mV, 1.515 mA and 1.99 mW in day 1. Then, the voltage, current and power dropped to 1.033 mV, 1.556 mA and 1.203 mW respectively in day 8. The reason for high voltage, current and power level is due to adding Sucrose and Starch. Sucrose and Starch are some of the simplest sort of organic compounds which can be easily consumed by bacteria. The MFC in [11] initially produced high voltage, current and power because the bacteria could directly consume sucrose and starch rather than decomposing and consuming the complex organic materials present in wastewater as food [13-17]. However, with the course of time, as the sucrose and starch concentration go down, the bacteria cannot get enough sucrose and starch to meet their food demand [18-21]. In this situation, bacteria start decomposing the complex organic materials present in wastewater which is lengthy and slow process. Hence, voltage, current and power level starts to drop [22-25]. The main objective of wastewater MFC is to consume organic waste so that the waste material gets utilized and reduced to generate electricity [26-30]. If simple organic materials such as Sucrose, Glucose, Starch etc. are added in wastewater MFC for showing higher initial voltage, current and power level, the original purpose and objective of wastewater MFC would not be served [31]. Moreover, adding these simple organic materials result in additional operation cost of MFC. Therefore, no simple organic materials (Glucose, Sucrose, Fructose, Starch etc.) has been added in our MFCs for showing high initial voltage, current and power [12].

Based on the information and discussion stated above, it can be said that the proposed MFC stack has very good performance parameter compared to the MFC systems available in the existing literature. Also, the MFC in the existing literature have very low power generation. Moreover, as per literature review conducted in this article, it can be found that none of the researchers in existing literature have tried to connect MFCs together to create a MFC stack and provide better output as compared to a single MFC unit. Above all, none of the researchers have tried to harvest energy from MFC and transfer it to a load.

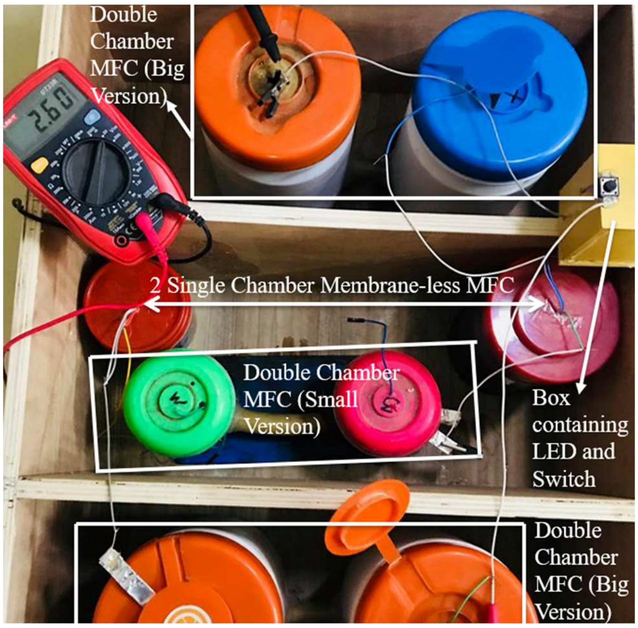

Fig. 7. MFC setup.

C. Comparative Study of Different Types of MFCs

In this study, it has been observed that single chamber membrane-less MFC consumes half of the volume of a double chamber MFC, but its output voltage, current and power is almost the same as double chamber MFC. Chamber size, electrode size and electrolyte (muck) quantity of small single chamber membrane-less MFC and small double chamber MFC were same. The power levels were 0.98 mW and 1.2 mW respectively. Hence, the double chamber-membraned MFC produced 3.66% more power than the single chamber membrane-less MFC utilizing twice as much as volume than the single chamber membrane-less MFC.

VI. CONCLUSION

In this research, a theoretical analysis as well as practical implementation of wastewater MFC has been presented. One of the most significant barriers of wide scale usage of MFC is to deliver power to load in real time. Using a combination of series connected MFCs, we have finally overcome the barrier and light up an LED. We believe that this research will contribute to the development of low-cost energy efficient MFC. The major variation of this research with the other works is to enable MFC to drive loads in real time. This will obviously add a new dimension in MFC technology. With this research work, we believe that the road to widespread usage of MFC will be opened.

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