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Effect of Pure Culture and Wastewater Dilution on Power Generation in a Double Chambered Microbial Fuel Cell (DCMFC)

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Fossil fuels are the main resources for the generation of electricity, which have been considered as major contributors to environmental problems. One potential alternative to explore is the use of Microbial Fuel Cells (MFCs), which generate electricity using microorganisms. MFCs employ microbes to generate electricity from biochemical energy produced during the metabolism of organic substrates. In a Double-Chamber Microbial Fuel Cell (DC-MFC) the voltage and power production from pure culture under the continuous mode of operation. Additionally, mediator potassium permanganate ($KMnO_4$) is used in a DC-MFC to reach the maximum current density and power using parallel connection mode. Various experimental studies have been carried out on DC-MFC though, the usage of DC-MFC is more reasonable due to its simple construction, maintenance, and mechanism maintenance. The voltage and current values obtained in DC-MFC using Dairy wastewater was 1006 mV and 4.89 mA, respectively, which was found to be higher than the voltage and current values of 825 mV and 2.18 mA, respectively, obtained from Hospital wastewater. It was also found that, Copper electrodes were more effective in electron transfer and electricity generation when compared to Aluminium electrodes.

Keywords: Double Chambered Microbial Fuel Cell, Pure culture, Current density.

INTRODUCTION

Energy plays an essential role, which is one of the powerful components in human development; determining the prosperity of all countries. The steady growth in the population has increased global energy demands. In a continuous attempt to attain the challenge of a powerful country, the energy sector has come across a significant extension. The human being is one of the major consumers, who are responsible for the depletion of non-renewable resources, whereas in the case of renewable resources, are generated by continuing phases that can assist unspecified human utilization. The non-renewable energy sources are being reduced more rapidly in the present day [1]. Also, fossil fuel is one of the major non-renewable sources of energy. This source can still be manageable with the pre-send wanting demand, although their exclusion and utilization can have an adverse effect on the society and environment. The oil and gas sources are effortlessly available and have already been, utilized. Thus, their utilization will become more difficult by giving maximum costs and being a contributor in the surroundings and society as well [2].

In the last decades [3], the technology has gained massive popularity among the academic researchers who they have used Microbial Fuel Cells (MFCs) which are held responsible for converting the energy reserved in chemical forms inorganic compounds to electrical energy (gained by the enzymatic effects by microbes). The fuel cell which is used for the power production rely upon many components such as size and type of fuel cell, the degree to which it regulates, and the pressure at which gases are moved to the cell. The single fuel cells are combined into a fuel cell stack to form hundreds of fuel cells, and then the electric energy generated from a single fuel cell can be utilized for lower power requirements. Fuel cells are identified essentially by the kind of electrolyte they considered, which says the types of chemical reactions that are placed in the cell and the type of catalysts required. MFCs are one among the several fuel cells which have been developed recently, having their merit and demerit, and potential applications [5].

MFCs employ microbes generated from biochemical power produced through the metabolism of organic substrates. To generate electricity, Two electrodes i.e. anode and cathode are separated by Proton Exchange Membrane (PEM) and those electrodes are connected by an external circuit. The responsibility of anode is to generate electrons (e^-), which are decomposed by the organic microbes and protons (H^+) that are transferred to the cathode through the circuit and membrane, respectively. Here the energy source is the organic substrates and the end high-energy electrons are released that are moved to electron acceptors (molecular oxygen). Micro-organisms shuttle electrons onto the anode surface under anaerobic conditions in the anodic chamber of MFC. Thus, electrons get transferred throughout the external circuit, which results in the production of electrical energy. [6]

Here two main steps are involved in the power generation. In the first step, matters are degraded because of the absence of oxygen which shows the removal of electrons from organic matter, and the complete process is termed oxidation. In the second step, transferring of electrons takes place in the cathodic chamber. In anaerobic condition, certain bacteria can transfer electrons to an anode. Water is formed with the combination of protons and oxygen where electrons then move across a conductor at a specific resistance value to the cathode. Further, these electrons are carried from the anode to the cathode, which induces current and voltage to produce electricity. As discussed above bacteria is responsible for generating electricity being used in MFC. Biodegradable organic-rich waters such as industrial, agriculture wastewaters, and municipal solid waste are perfect as an endurable energy resource for production of electrical energy [6].

For electron transferring from microorganisms to the MFC anode, certain mechanisms are used for the electron transfer. In this way, the electron movement in MFCs can be made into categories as given types: The first type is the direct electron transfer, where electrons are moved through membrane-bound redox proteins; and mediated electron transfer, which involves dissolved redox mediators [7]. There are two well-used terms "electrochemically active bacteria" [8], "anode respiring bacteria" [9] and "exoelectrogens" [10] are taken into account for the moving of electrons outside the cell membrane (extracellular electron transfer).

Carbon is, among all the electrode materials one which is widely used for MFCs. Graphite plates, granules, rods, and fibrous carbon materials (carbon cloth, mesh, felt, fibers, paper, and foam) have been studied as electrode materials for MFCs [11, 12]. Most commonly used anodes are carbon cloth [14], graphite fiber brush [13], graphite felt and 30% wet proof carbon cloth [15], copper, aluminum, stainless steel, zinc, carbon, and mild steel [16].

Commonly used cathodes are carbon cloth [13, 14] graphite felt and 30% wet proof carbon cloth [15], Copper, Aluminum, Stainless steel, Zinc, Carbon, and Mild steel [16]. Fe2+, that has been chemically reduced from Fe3+ on the cathode surface [17] or they can directly use the cathode as an electron donor by unknown means yet with electron acceptors such as oxygen and nitrate [18].

MATERIALS AND METHODS

Fabrication of reactors

Laboratory scale DC-MFC modules are made-up of acrylic plexiglass used in the present study. Lab tests were carried out using a DC-MFC reactor through a functioning volume of 2-liter capability and the reactors dimension is 10.00 cm X 10.00 cm X 20.00 cm.

Electrode material

For this experimental study, aluminum and copper electrodes are used to experiment. The length and width of these electrodes are 13cm (height) X 7cm (width) respectively. Those aluminum and copper electrodes are located at a distance of 6cm from each other in the DC-MFC reactor. Before experimenting, electrodes are immersed in distilled water for 24 hours, to increase their effectiveness of electrodes.

Membrane

For the preparation of agar salt bridge, 10% agar (i.e. 2.5g) is dissolved into 25mL of boiled water, and into that hot water (while boiling) 1M of KCl (i.e.1.46g) is added with constant stirring. After stirring properly and the mixture is poured into the glass tube while the mixture was still warm and then allowed to cool. The mixture thickens and will be solidified. The experiment is conducted at room temperature.

Catalyst / Catholyte

In the present experimental study, $K_3[Fe(CN)_6]$, Sodium Hydroxide, phosphate buffer, $KMnO_4$, and Sulphuric acid are used as mediators to retain the pH value of wastewater between 7.0 and 7.7. To prepare phosphate buffer by taking 900 ml of distilled water with 19.5 ml of mono-basic potassium phosphate and 80.5ml of di-basic potassium phosphate were properly diluted. Using 3.292 gm crystals of $K_3[Fe(CN)_6]$ were diluted in 100ml distilled water 0.1 M $K_3[Fe(CN)_6]$ solution is prepared. In 1 liter distilled water, potassium permanganate crystals weighing 0.1 gm is diluted to get 600 µM of potassium permanganate solution. $KMnO_4$ and phosphate buffer are better to improve the efficiency of electron transfer.

Wastewater samples

The Hospital and Milk Dairy wastewaters are used as a substrate in the present study. Milk dairy wastewater is considered the substrate for the microbes because of its high organic content and hospital wastewater is used as the other substrate because it contains simple compounds which can be easily degraded by the micro-organisms. Wastewater is collected from JSS Hospital, Agrahara, India, and Nandini Milk Diary, Nazarbad, Mysuru, Karnataka India, is used. To increase the development of microorganisms available in the hospital and milk dairy industry wastewaters some amount of glucose has been added. COD, BOD, and pH concentration have been analyzed for both the industrial wastewater.

MFC operation

The experiment is conducted by placing single aluminum and copper plate electrodes in anodic and cathodic chambers respectively. The schematic diagram and the experimental setup of DC-MFC used in the present study are shown in Fig- 1. In the middle of the lid of both the reactors a diameter of 5 mm hole has been drilled and a 20 cm length conductor wire is placed through the hole. On the walls of both chambers of the reactor opposite to each other, where an empty tube of 6 cm length is placed, was acting as a salt bridge. Agar salt bridge was used in place of PEM, using potassium chloride and an agar medium salt bridge is prepared. The aluminum and copper plate electrodes are externally connected through a single conductor and both are situated at a distance of 6 cm apart.

Hospital and Milk dairy wastewaters have various COD concentrations used as a substrate. The anaerobic microorganisms present in the anodic chamber, the addition of 250ml yogurt to the wastewater as a source for them. Certain anaerobes are present in hospital and milk dairy wastewater which helps to degradation of organic matter present in wastewater. To get fast acclimatization of microbes with wastewaters adds 25 gm of glucose to the anode chamber. 7.0 to 7.7 pH has been maintained by using $KMnO_4$, phosphate buffer, and $K_3[Fe(CN)_6]$ is added to the reactor. Adding mediators can improve microbial activity in the reactor which increases enhanced electrons passed on to the anode. To provide an anaerobic condition for the chambers, drilled parts of the reactor chambers are sealed with glue to protect them from air, while the lid of the reactor has been inserted into the chamber, and then using glue tape close the sides of the reactor lid.

Fig- 1: The experimental setup of Double-Chamber MFC

RESULTS AND DISCUSSION

Characteristics of Wastewater

In this present experimental study hospital wastewater, and milk dairy wastewater, are used as substrates. The wastewaters are collected from JSS Hospital, Agrahara, India, and Nandini Milk Diary,Nazarbad , Mysuru, Karnataka India, are analyzed for pH, COD, and BOD concentrations, and standards are mentioned in Table 1. Given the table shows can be seen that, the COD and BOD values of JSS Hospital wastewaters are 1012 mg/lt and 496 mg/lt, respectively, the COD and BOD values of Nandini Milk Diary wastewaters were 646 mg/ lt and 180 mg/ lt.

Table 1: Characteristics of Wastewater

Sl. No.	Type of wastewater	COD in mg/lt	BOD in mg/lt	pH
1	JSS Hospital, Mysuru	1012	496	5.6
2	Nandini Milk Diary, Mysur	646	180	10.2

Effect of pure culture on power generation from Hospital and Milk dairy wastewater

In this present study, laboratory tests are carried out using hospital wastewater obtained from JSS Hospital, Agrahara, Mysuru, Karnataka, India, and Nandini milk dairy Mysuru, Karnataka, India. Aluminum and copper plate electrodes are taken into account to experiment with the timeline of about 48 hours. Seeding substances such as curd along with glucose is taken into account.

graphs are plotted for output voltage and current concerning time with hospital wastewater in the DC-MFC reactor shown in Fig-2 and Fig-3. From the plots it is observed that initially Voc was found to be 825 mV and it remained constant for consecutive fifteen hours, later it drastically reduced followed by an immediate increase in the voltage. Finally, voltage of 646 mV is observed at the 48th hour of the experiment. On the other hand, the current was found to be 0.5 mA initially, later it drastically increased to 2.18 mA and immediately reduced to 1 mA. Finally, current of 0.76 mA was observed at the 48th hour of the experiment. The inequality of current density and power concerning time using hospital wastewater in DC-MFC modules are made appeared in Fig-4 and Fig-5. The current density and power curves were found to follow similar trends as observed in the plot showing current variation with time. From these plots, it is observed that the current density was found to be 0.045 A/m^2 at the 0th hour, 0.151 A/m^2 at the 20th hour, and 0.058 A/m^2 at the 48th hour, and the corresponding power was found to be 0.482 mW at 0th hour, 1.735 mW at 20th hour and 0.504 mW at 48th hour, respectively. Maximum power, current density, current, and voltage are 1.735 mW, 0.151 A/m^2, 2.18 mA, and 825 mV respectively.

For milk dairy wastewater the voltage and current have been measured by using a digital multi-meter and graphs are plotted for open-circuit voltage and current concerning time with milk dairy wastewater in DC-MFC reactor were shown in Fig-2 and Fig-3. From the plots, it is observed that Voc was found to be 1006 mV and it remained constant for consecutive three hours, later it drastically reduced to 890 mV and it remained constant for consecutive eleven hours. Finally, voltage of 786 mV was observed at the 48th hour of the experiment. On the other hand, the current is found to be 4.5 mA initially, later it drastically increased to 4.89 mA and immediately reduced to 2.3 mA. Finally, current of 1.8 mA was observed at the 48th hour of the experiment. Variability of current density and power concerning time using milk dairy wastewater in DC-MFC reactor is seen in Fig-4 and Fig-5. The current density and power curves were found to follow similar trends as observed in the plot showing current variation with time. From these plots, it is observed that the current density was found to be 0.27 A/m^2 at the 0th hour, 0.142 A/m^2 at the 20th hour, and 0.109 A/m^2 at the 48th hour, and the corresponding power was found to be 4.5 mW at 0th hour, 2.13 mW at 20th hour and 1.504 mW at 48th hour, respectively. Maximum power, current density, current, and voltage respectively are 4.5 mW, 0.27 A/m^2, 4.89 mA, and 1006 mV.

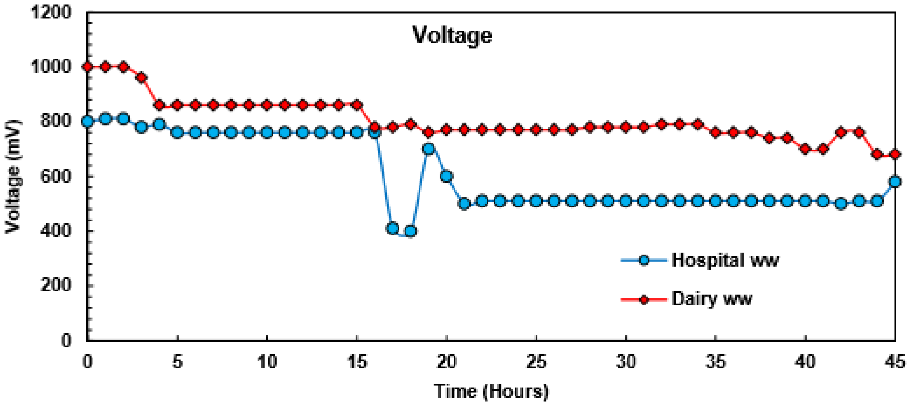

Fig-2: Variability in voltage concerning time in DC-MFC

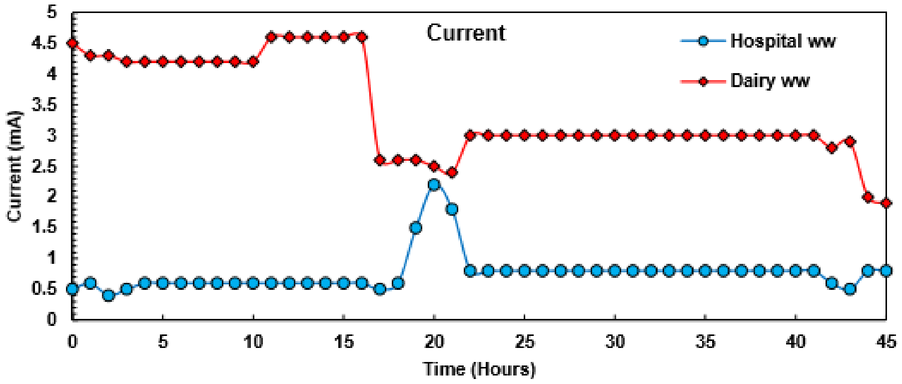

Fig-3: Variability in current concerning time in DC-MFC

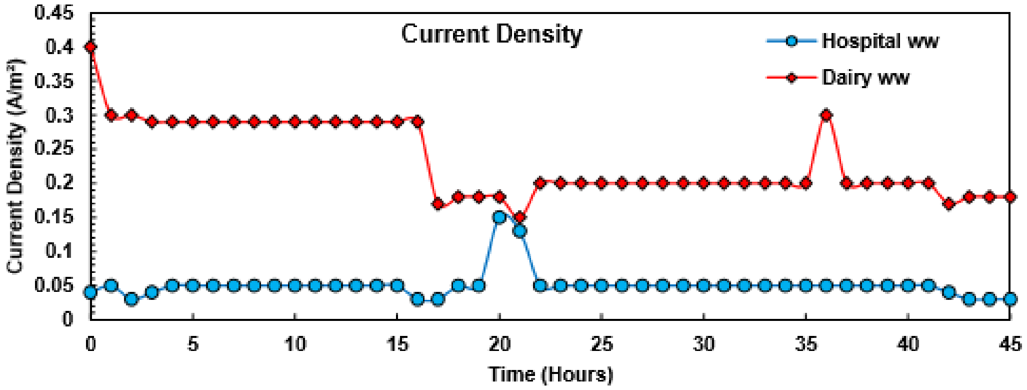

Fig-4: Variability in current density concerning time in DC-MFC

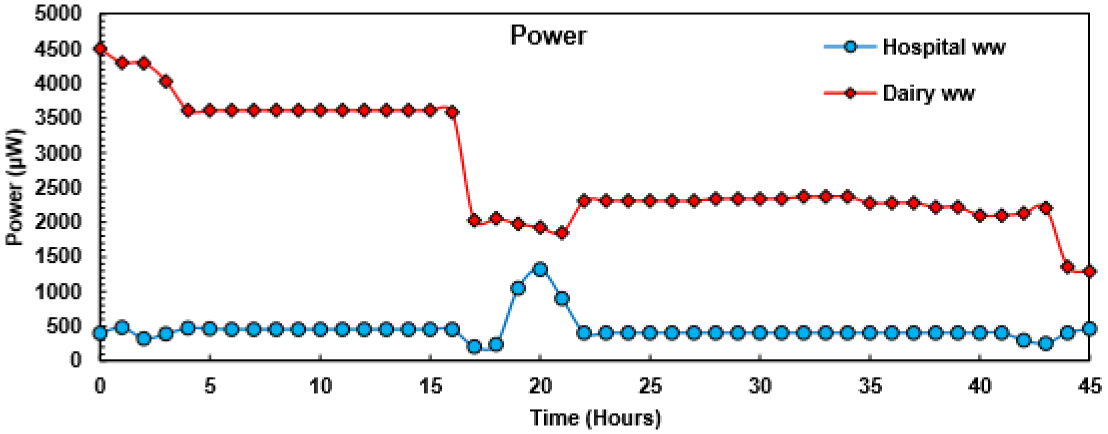

Fig-5: Variability in power concerning time in DC-MFC

CONCLUSION

Laboratory scale reactors are designed and fabricated to allow flow as a barrier between the anode and MFC cathode. Observation from the experiment, For hospital wastewater Maximum power, current density, current, and voltage are 1.735 mW, 0.151 A/m^2, 2.18 mA ,and 825 mV respectively. For milk dairy wastewater Maximum power, current density, current, and voltage respectively are 4.5 mW, 0.27 A/m^2 4.89 mA and 1006 mV. The maximum voltage and current obtained from milk dairy wastewater compared to hospital wastewater. Because in dairy sugar content and carbohydrate contents are more. For microorganisms, these two are more essential.

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