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PERFORMANCE OF DUAL CHAMBER MICROBIAL FUEL CELL WITH NAFION MEMBRANE USING SYNTHETIC WASTE WATER

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Abstract: -
Microbial Fuel Cell (MFC) Technology can be used as a source of renewable energy. But economy and performance of MFC are the two major parameters required to be considered. MFC technology is being experimented for generation of electricity and waste water treatment. In this experimental work, dual chamber MFC set up is used with Nafion membrane and synthetic waste water with anaerobic sludge from upflow anaerobic sludge blanket (UASB) reactor. The average open circuit voltage 429 mV and operating voltage 82.57 mV is obtained. The study shows that Nafion membrane with synthetic waste water is an option for wastewater treatment and energy generation however there is need of further study to keep output constant at the maximum achievable power and replace of Nafion with economical membrane.
Keywords: - Microbial Fuel Cell (MFC), Dual chamber MFC, Nafion, Synthetic Waste Water

1. Introduction

Microbial Fuel Cell (MFC) system uses microorganisms to transform the chemical energy of organic compounds into electrical energy through electrochemical reactions. This involves the oxidation of organic carbon in the anodic chamber which consists of electrons, protons and by products such as volatile fatty acids, biomass and carbon dioxide. Electrons generated in an anaerobic chamber by an anode electrode pass through an electrical device and transfer to the cathode reactor which is aerated and exposed to air.

The protons released from the oxidation of organic carbon migrate to the cathode through a selective membrane that limits diffusion of oxygen into the anode chamber. In cathode reactor electrons, protons and oxygen react and produce water. The most commonly used substrates include amino acids, carbohydrates, microalgae, alcohols and waste water from organic industries. [Du t al.2007]. All substrate is not completely oxidized as some mass being used for biosynthesis. All high energy electrons are not supplied in the substrate are transferred to the cathode and available for work. [A. Muralidharan,2011]. A typical dual chamber set up is shown in figure 1 below.

This technology in future may save energy cost of industrial operation. The rate of microbial electron transfer and current output is affected by the degradation of organic material in substrate used and anodic microbial ecosystem. MFC technology have gained considerable progress in in electricity generation and organic matter removal, however the main constraint is high electrode material costs, unstable performance, expensive catalyst and low energy harvesting efficiency. [F. Li, Y. Sharma, F. Zhang, T. Saito, 2010].

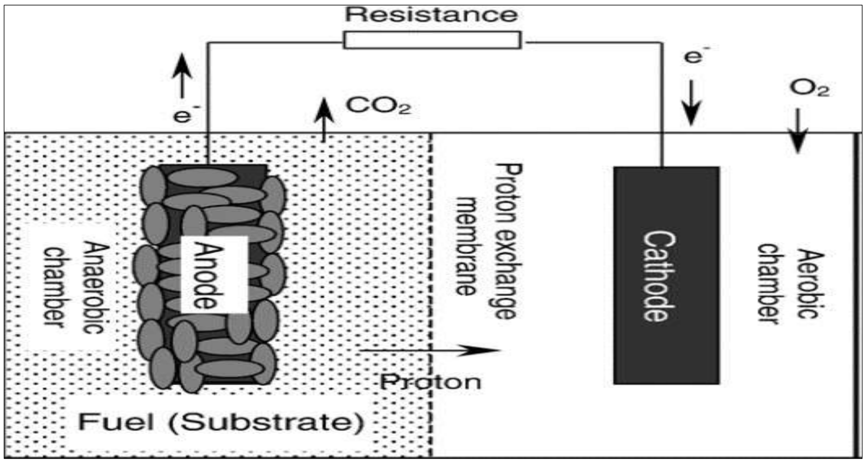

Figure - 1: Typical Dual Chamber MFC Set Up (Source: G. Bhargavi1 et al.)

The percentage of electrons which are transferred is expressed in terms of columbic efficiency, which is essentially a percentage ratio of the number of electrons supplied against the number of electrons transferred [K. Rabaey and W. Verstraete ,2005]. This parameter is useful measure of power output. Power output of MFC is useful quantity to measure. This is measured in terms of a polarization curve which shows the relationship between current and voltage over a range of resistance. By using the relationship V=IR and P=IV where V =voltage, I=current, R= resistance and P=power information about power output can be obtained. This experimental work is aimed to design dual chambered MFC using synthetic waste water as a substrate inoculated with anaerobic sludge and nafion membrane to generate electricity.

2. Materials and methods

Double chamber MFC was constructed by using transparent poly acrylic material with synthetic waste water to operate under batch mode with two days' reaction cycle. MFC has two compartment of 450 ml capacity for both anolyte and catholyte. Anaerobic compartment was provided with two ports at the top for electrode wire and addition and sampling of solutions. Carbon Felt (Nickunj Eximp Entp.P.Ltd.) of 16 cm^2 projected surface area was used as electrode material in both the chambers. Nafion 117 (Nickunj Eximp Entp.P.Ltd.) of size 4.5cm X 5 cm was inserted between two compartments and sealed water tight. Nafion of size 4.5 cm X 5 cm is used as proton exchange membrane. One of the most commonly utilized PEMs is Nafion (a product of DuPont, USA) on account of its exceptionally specific penetrability of protons. Protons created at the anode move through the arrangement across a proton transfer layer to the cathode, where they consolidate with oxygen and electrons to frame water.

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PEM's main capabilities are to keep wastewater and oxidants separate and to lead protons. This is one of the critical components of MFC frameworks, as it can influence the interior opposition and fixation polarization misfortune, and thus the MFC's influence result. Nafion membrane allow not only proton but also other cations in the heterogeneous, complex wastewaters in which various ions are present. The higher oxygen ermeability of Nafion can inhibit anode respiring bacteria (ARB) metabolism and deteriorate BES performance in terms of electrical power or hydrogen gas production.

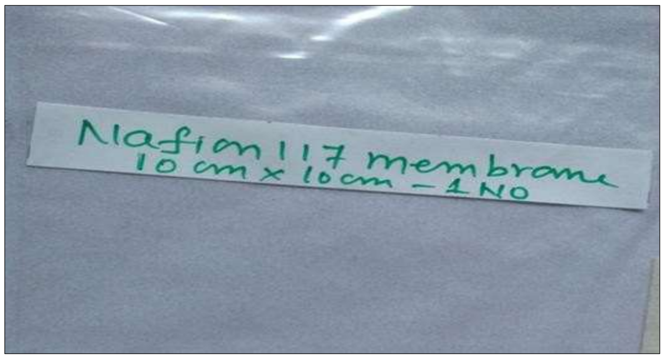

Figure - 2: Nafion Membrane

The anodic chamber was inoculated with mixed anaerobic sludge obtained from bottom of upflow anaerobic sludge blanket reactor after giving heat treatment at 100 ^{o} C for 15 minutes. [G.S. Jadhav, M.M. Ghangrekar 2008].

Figure- 3: UASB sludge from Panchak STP, Nashik

Synthetic wastewater containing sodium acetate as sole source of carbon with chemical oxygen demand (COD) of 1500 mg/lit was used in this study. The sodium acetate medium was prepared by adding 3843 mg/lit CH_3COONa, 4500 mg/lit $NaHCO_3$, 954 mg/lit NH_4Cl, 81 mg/lit K_2HPO_4, 27 mg/lit K_2HPO_4, 750 mg/lit $CaCl_2.2H_2O$, 192 mg/lit $MgSO_4.7H_2O$ as per composition suggested by Jadhav and Ghangrekar [2008] for 3000 mg/lit COD.

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Figure- 4: Chemicals Used for Synthetic Waste Water

Influent and effluent COD concentration and pH were measured as per the APHA standard methods [15]. MFC performance was evaluated in terms of voltage and current measured using digital multimeter. Open circuit voltage (OCV) and operating voltage (OV) across 100 Ω resistance were measured using digital multimeter after reaching to a stable value. Power density and power per unit volume were calculated by normalizing power to anode surface area and net liquid volume of anodic chamber respectively. Polarization studies were carried out after achieving stable potential in MFC by varying external resistance from 10000 Ω to 10 Ω using resistance box (information). [B.E. Logan 2008]. MFC was operated in batch mode and DC voltage and current was measured using digital multimeter. Experimental set up details were mentioned in table1.

Table 1. Experiment Set Up Details

Materials	**Anodic chamber**	**Cathodic chamber**
Substrate	Synthetic waste water	-
Microbes	No	No
Madiator	No	No
Distilled water	-	450 ml
Electrode	Carbon felt	Carbon felt
Membrane	Nafion	-

3. Results and Discussion

COD concentration in the reactor is around 1500 mg/lit for synthetic waste water. The reactor was operated in batch mode for 5 days' cycle. The voltage produced by the MFC system was recorded. The artificial membrane Nafion was used as a first combination of experimentation. pH of the synthetic waste water is observed on alkaline side in between 6.5 to 9 throughout the experimentation. It never turned to acidic. The variation in Chemical Oxygen Demand (COD) values is observed during the experimental work.

The initial COD value of synthetic waste water was 1440 mg/lit. During the first cycle of operation COD value is observed as 835 mg/lit. COD removal efficiency is 42%. It shows that seeding of the reactor is proper and it had reached the maturity level. The bacteria were doing the degradation of organic material and it was indicated by the COD removal efficiency. For the 18 cycle, COD removal efficiency was observed as 72.5 %. The overall experimental program for Nafion membrane was found decreasing the COD values of waste water. Figure 6 shows the graphical representation of COD removal efficiency versus operation cycles.

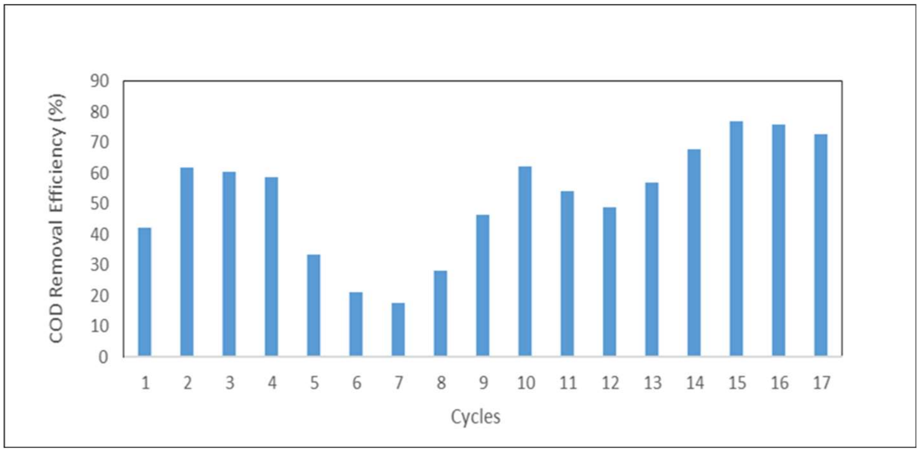

Figure – 6: Graphical representation of COD removal efficiency versus operation cycles

Operating Voltage (OV) was observed as 11.914 mV for the first cycle with external resistance as 100 ohm throughout the experimentation. The OV value was observed as 216.52 mV by the end of 18th cycle. The calculated P_{max} for the cycle 1 and cycle 18 was 0.6453 mW/m^2 and 208.3596 mW/m^2 respectively. It was observed that operating voltage goes on increasing during the 18 cycles of operation in case of Nafion membrane. Figure 7 shows the graphical representation of operating voltage versus operating cycles.

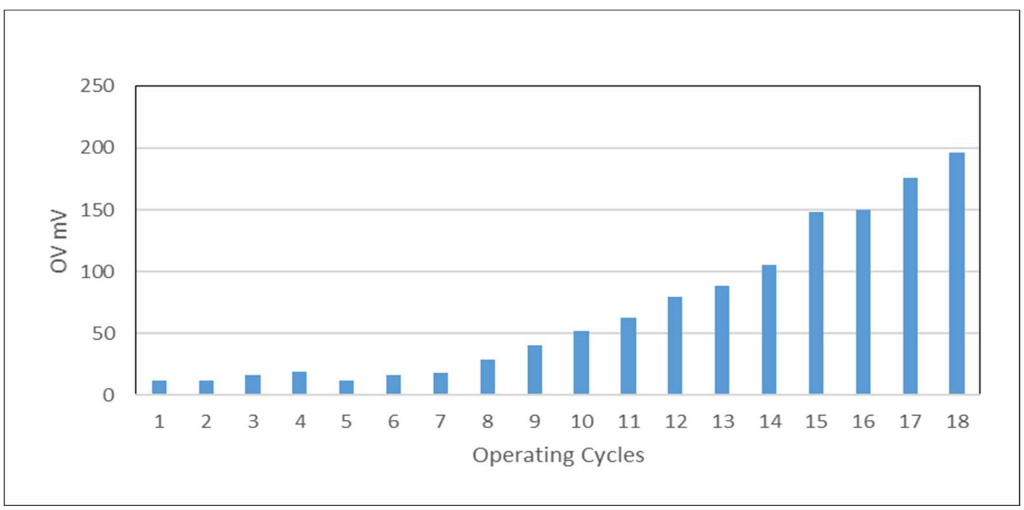

Figure- 7: Graphical representation of operating voltage versus operating cycles

Volumetric or working or sustainable power density was observed as 0.0025 W/m^3 for first cycle and 0.8371 W/m^3 at 18 th cycle of operation. Figure 8 shows the graphical representation of volumetric power density versus operating cycles.

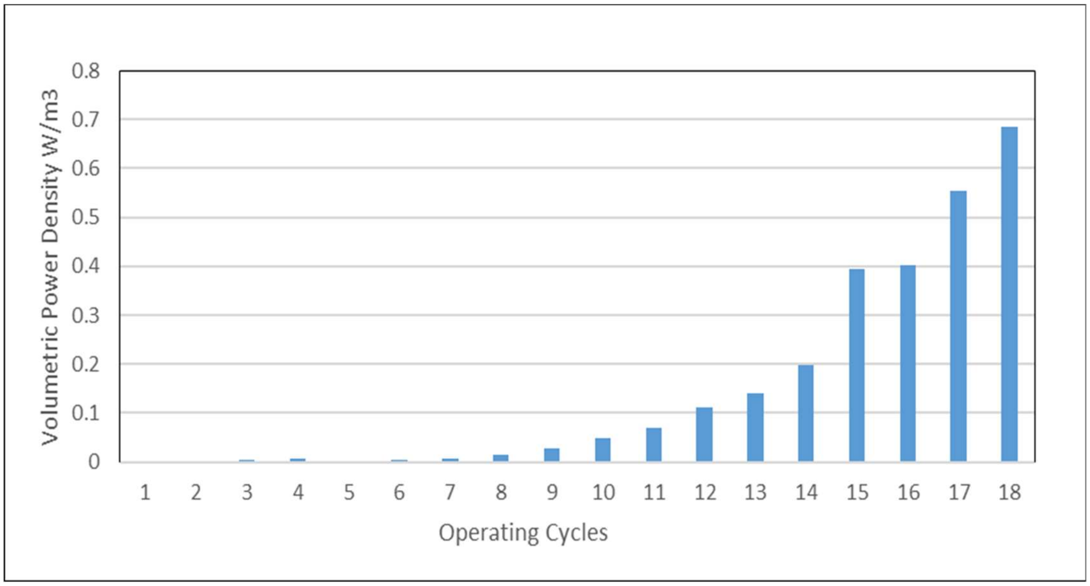

Figure- 8: Graphical representation of operating voltage versus operating cycles

Figure 9 shows the graphical representation of OV values and COD removal efficiency for cycles of a wastewater treatment process. A general negative association between COD removal efficiency and OV values can be seen in the plot, with greater OV values equating to poorer COD removal efficiency. However, certain cycles, such as cycles 6 and 7, depart from this pattern.

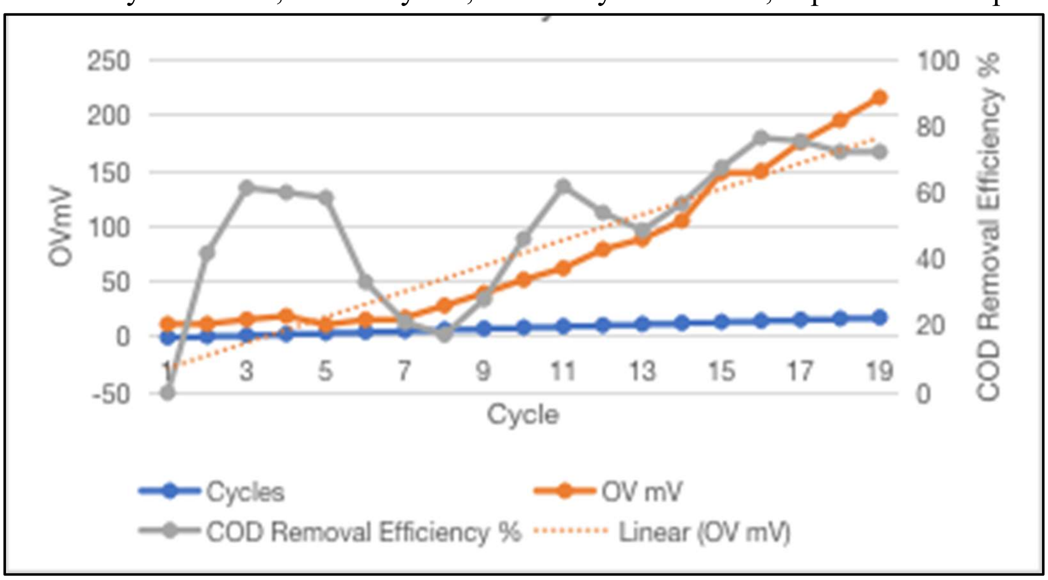

Figure - 9: Nafion- Volumetric Power Density Versus Operating Cycles

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Figure 10 shows the graphical representation of volumetric power density (mW/m3) and power density (mW/m2) values for a process in different cycles. To analyze the data, two separate line plots created, one for volumetric power density and another for power density, with cycle numbers on the x-axis. volumetric power density vs. cycle line plot. Power density vs. cycle line plot showed that both volumetric power density and power density increase with increasing cycle numbers, except for a decrease in a cycle 4 for both parameters. The increase in power density is more pronounced than the increase in volumetric power density due to the higher surface area of the electrodes at later cycles.

The correlation coefficient between cycle number and volumetric/power density to quantitatively measure the strength and direction of the relationship. Using a statistical software, the correlation coefficient for volumetric power density is found to be 0.954 and for power density is found to be 0.973, indicating a strong positive correlation between cycle number and both parameters. Therefore, we can conclude that the process in this study shows a strong positive correlation between cycle number and both volumetric power density and power density.

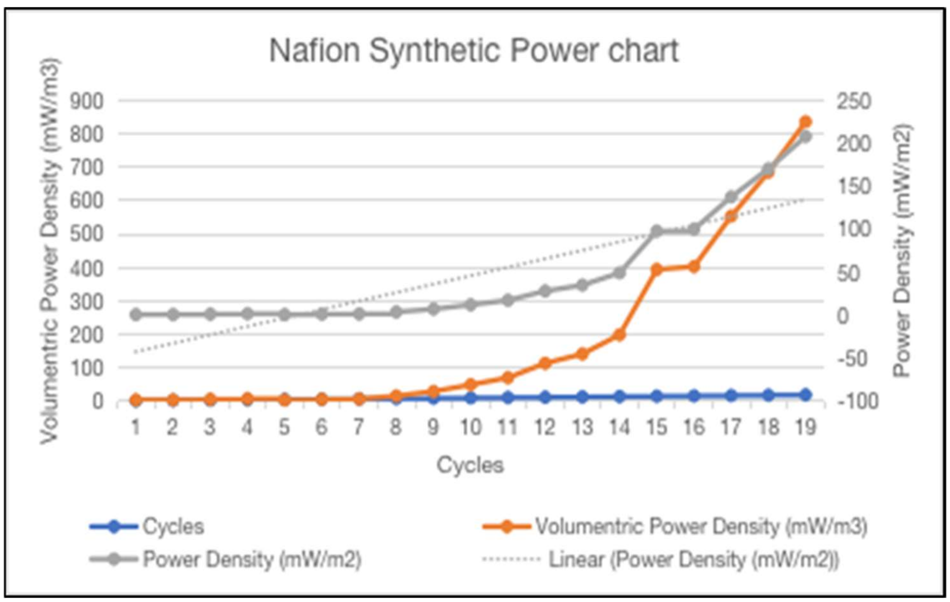

Figure - 10: Nafion- Volumetric Power Density, Volumetric Power Density Versus Operating Cycles

4. Conclusion

The configuration of MFC is studied properly before fabricating the MFC model. Through literature review, dual chamber configuration is selected and designed for experimentation.

The improved results can be obtained from dual chamber MFC. The performance of the model and materials used is judged through the COD removal efficiency of each membrane, OV and power density values.

The experimental work is carried out as per the procedure explained in methodology and the obtained results are compared for the solution. COD removal efficiency is observed as 72.5 %. P_{max}, the maximum power density or volumetric power density is calculated based on operating voltage and external resistance value 100 ohm. It is observed as 0.2083 W/m^2 for Nafion membrane. However, for wastewater treatment and energy generation, there is need of further study to keep output constant at the maximum achievable power and replace of Nafion with economical membrane.

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