DESIGN AND OPTIMIZATION OF ALGAE ASSISTED MICROBIAL FUEL CELL FOR ELECTRICITY GENERATION FROM FOOD WASTE

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INTRODUCTION

Consumption of fossil fuels causes an increase in pollution which is also a major cause of global warming. Fossil fuel consumption is predicted to increase by 36% by 2030. Researchers are seeking alternative sources of electricity for industrial and home uses [1]. Food waste management is one of the major concerns in India. According to the food waste index report 2021 by United Nation Environment Programme (UNEP), in India, 90 kg/capita/year of food waste was recorded in the high-income group which was 68 and 63 in middle- and low-income groups [2]. Large quantity of food waste is disposed to landfill without processing. Food waste is rich in carbohydrates, lipids, and proteins that can be essentially utilized to generate energy. Anaerobic digestion is an old and matured technique used to process food waste and generate biogas.

Microbial fuel cells (MFCs), which directly convert organic matter to electric energy without the need for intermediary stages, have recently been the subject of substantial research. The biodegradation efficiency of organic matter and the electron transfer efficiency have a significant impact on the generation of bioelectric energy in MFCs. In fact, appropriate anodic respiring bacteria on the anode can further improve or enhance the performance of MFCs [4]. Xin et al [5], demonstrated the working of hydrolysis and MFC setup through which they obtained the energy of 0.245 kWh per kg of food waste. A typical dual-chambered MFC comprises an anode and a cathode chamber where oxidation and reduction occur respectively. Microbial fuel cells provide a promising technology to handle the continuous exhaustion of fossil fuels and the steady increment in the cost of fuels.

Keywords: Algae assisted MFC; Exoelectrogens; Food Waste; Electricity; Carbon sequestration.

OBJECTIVES

The main objective of this project is to optimize the performance of algae-assisted microbial fuel cell and to measure the voltage and power characteristics generated with varying electrode and substrate parameters.

The objectives of our project are:

1. Design and fabricate a double-chambered microbial fuel cell to treat food waste.
2. Optimization of the performance of MFC.
3. Enhancement of power generation through series connection.

Designing and optimization of the microbial fuel cell includes the fabrication of the dual-chambered MFC by replacing the salt bridge with a proton exchange membrane. Optimization is done using different electrode materials and sizes and by varying the density of food waste to obtain maximum power. Also, enhancing the voltage output by connecting multiple setups in series instead of scaling up a single cell.

METHODOLOGY

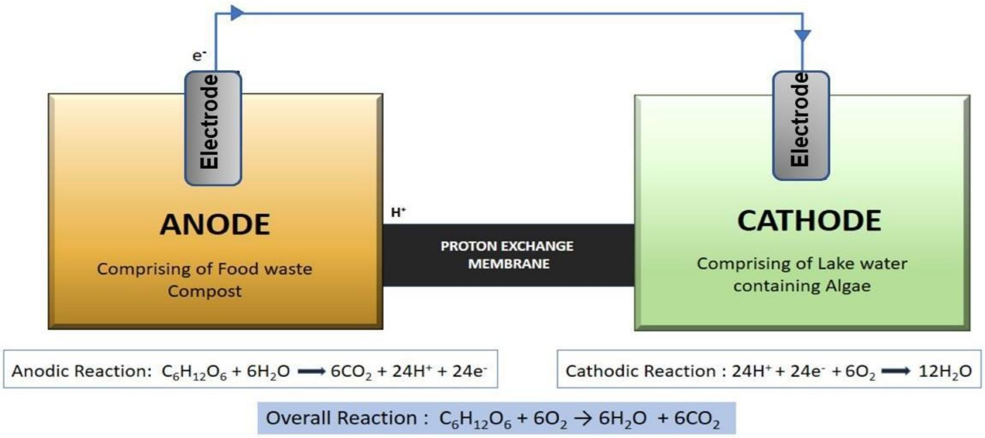


Fig. 1. Schematic of the constructed Algae assisted microbial fuel cell.

Food waste was prepared using fruit peels of orange, musambi, papaya, mango, muskmelon, and vegetable leftovers such as cabbage, tomato, radish peels, and dried flowers from institute canteen. This food waste was made into a paste using a laboratory mixer and then mixed with soil containing microbes. The food waste and soil were layered in alternative stacks and allowed to degrade for 3 weeks. Then the degraded semi liquid compost was taken in the anodic chamber of MFC. The Cathodic chamber was filled with algae water collected from the nearby lake. The salt bridge was constructed with PVC pipe filled with 10% agar and 10%. A Small-scale MFC with 0.5 kg of food waste in the anode and 500 mL of algae water was constructed. The photograph of the setup is shown in Figure 2a. Aluminium Mesh was used for the electrode having dimensions of 8.5 cm in length and 2 cm in breadth. Sparging of nitrogen gas was done intermittently to maintain anaerobic conditions in the anodic chamber. Two plastic containers were used to construct the MFC. Two containers were drilled with holes at the top and sides to fit the copper wires and salt bridge respectively. The holes were sealed with a hot glue gun, and an air inlet was made for the cathode chamber. Copper wire was soldered to the aluminium mesh electrode. A multimeter was used to measure the output voltage at different time intervals of one hour, the copper wires were connected to the multimeter using alligator clips and the readings were taken. The Current was measured in series using an LED as a load. A red LED was used as a load to connect into series with the MFC apparatus to measure current and in parallel to measure voltage.

Fig. 2. MFC setups used in the laboratory: (a) MFC with 0.5 kg of food waste, (b) MFC with 5 kg of food waste

CONNECTION OF MFCS IN SERIES

Three MFC setups were constructed following the same procedure as discussed previously and were connected in series, two transparent containers connected via a salt bridge of 10% concentration were prepared. Aluminium and copper were used at the cathode and anode respectively based on the results obtained from the comparison of different electrode materials in large-scale MFC. The circuit diagram representing the series connection of three MFC is shown in Figure 3. Each MFC contains 0.5 kg of food waste compost and 500 mL of algae water.

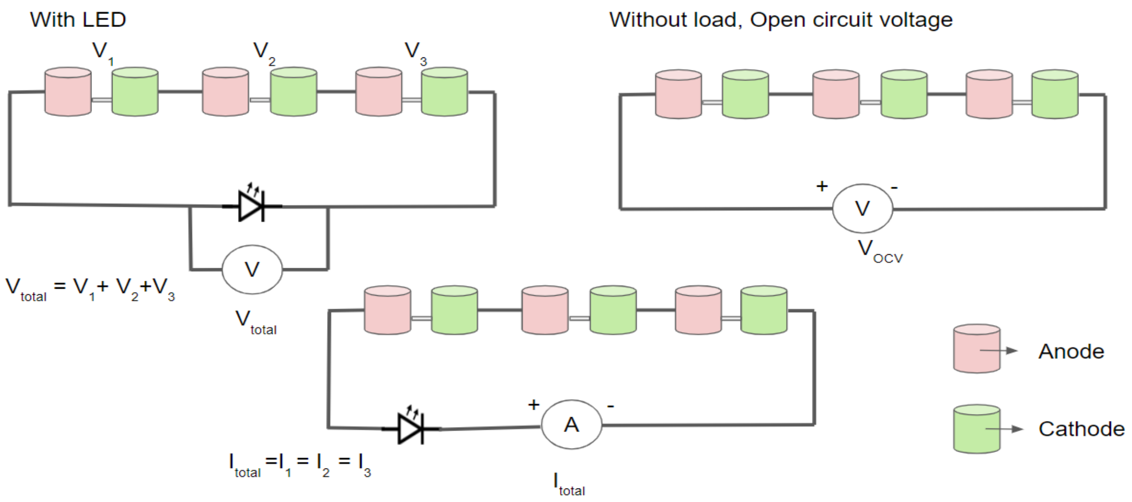


Fig 3: Circuit diagram representing the series connection of three MFC, each with 500 mL capacity

Results and Discussions

The voltage and the current characteristics were monitored frequently for a period of 30 days without adding any extra nutrients. The maximum voltage output was 702 mV and a current 200 μA was observed for 0.5 kg of food waste. The voltage characteristics were continuously monitored in 1-hour intervals (Figure 4b) at the beginning of the MFC operation and it was observed that there was a voltage drop during the morning compared to the readings obtained during the afternoon, this may be due to less production of oxygen during the night due to absence of photosynthesis since the light and dark cycles influence the oxygen production and also anaerobic bacteria in the anodic chamber take time to digest the substrate and grow. It can be observed from the trend of the graph that the value of voltage is obtained higher during mid-day due to more photoperiod exposure to the algae chamber.

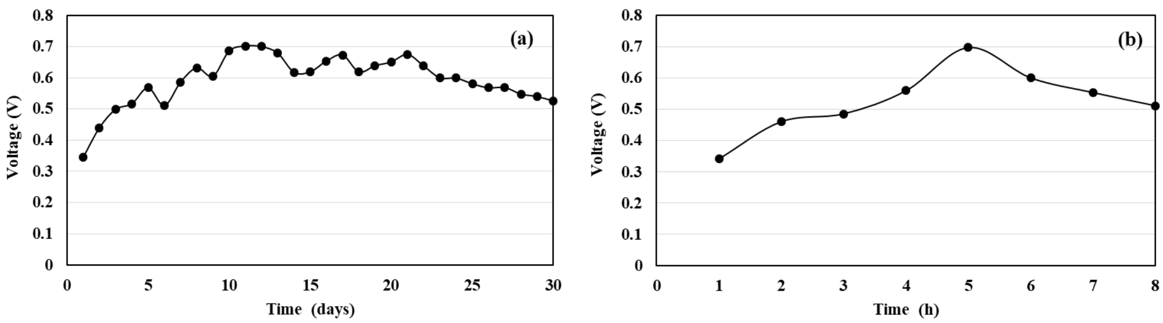


Fig. 4. Voltage characteristics of MFC with 0.5 kg of food waste, (a) for 30 days, (b) for 8 h

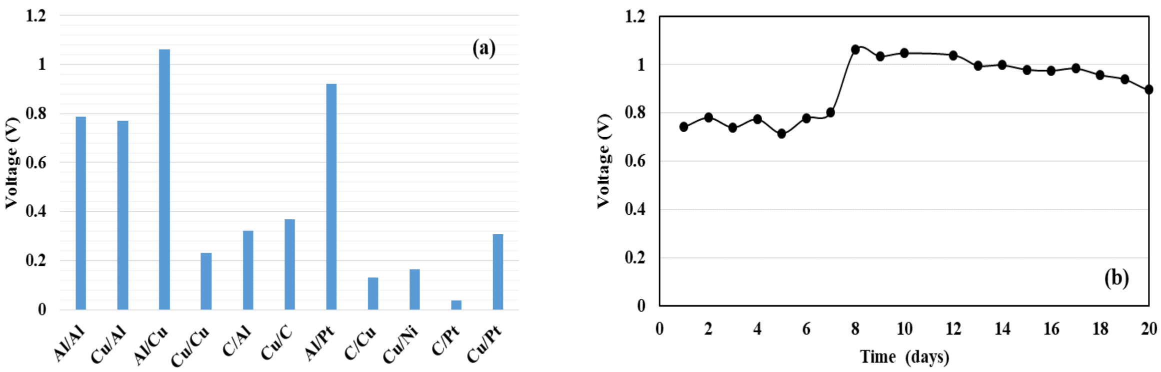
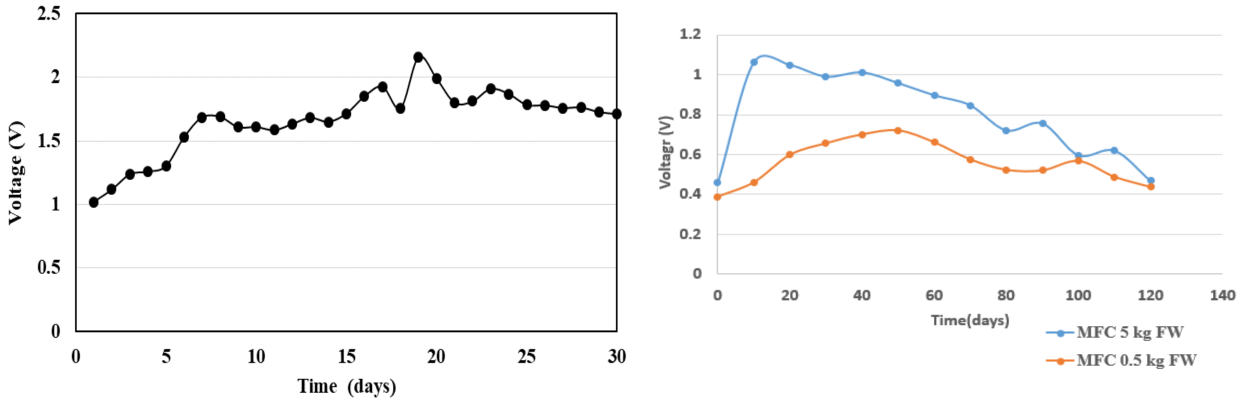


Fig. 5. Voltage characteristics of MFC with 5 kg of food waste, (a) different electrode materials (b) day wise voltage monitoring of MFC with Cu as anode and Al as cathode

The voltage characteristics for the different electrode materials were measured for the large-scale MFC in which 5 Kg of food waste was taken. The maximum voltage value of 1.061 V was observed for the aluminium and copper electrode combination. Same combination was maintained in the large scale MFC.

The three MFC cells were connected in series to improve the power output. During the initial day's low voltage output was recorded and then there is an increase in the trend and again it dropped down slowly. The maximum voltage obtained from the series connection was 2.16 V on the 19th day (Figure 6a). The voltage was measured for a period of 30 days, and it was given in the range of 1.5 V. The current from the series setup was found to be 10 mA.

Single MFCs were allowed to function continuously for 4 months, open circuit voltage was monitored (Figure 6b). MFC with 0.5 kg food waste and salt bridge showed 37% depletion in voltage. MFC with 5 kg food waste and Nafion membrane showed 58% depletion in voltage. This can be due to the higher internal resistance in MFC with 5 kg



food waste.

Fig. 6: Voltage characteristics (a) MFCs connected in series, (b) Working of single MFC for 4 months.

Conclusions

MFC serves as an alternating energy source to solve the energy crisis and environmental pollution. The performance of the MFC mainly depends on the kinetics of the electrode reactions. Many different combinations of electrode materials have been tested to enhance the performance of MFC. The aluminium and copper combination showed a good result which can be used for anode and cathode construction. The maximum voltage and current output of 786 mV and 200 μA were obtained respectively on the 11th and 12th day for the MFC with 0.5 kg food waste. The MFC with 5 kg waste yielded a maximum voltage of 1.061 V on the 10th day with a current of 20 μA. The series connected MFC increased the cell voltage compared to individually operated cells. Voltage was above 1.5 V throughout 30 days in the series connection and a maximum of 2.16 V was obtained on the 19th day of operation. MFC could work efficiently over two months with a 15% decrease in voltage. After 8 months of working, the degradation of potential was around 80%. The voltage variation depends on the type of food waste used, salt bridge composition and electrode size.

WHAT IS THE INNOVATION IN THE PROJECT?

Algae-assisted microbial fuel (MFC) is a technique that uses microorganisms to digest organic materials to produce electricity while simultaneously assisting algae in lowering their carbon footprint. MFC provides a sustainable and eco-friendly solution for power generation and it can also be used as a method for bioremediation. We have developed MFC with low-cost eco-friendly components to treat food waste. Simultaneously microalgae are grown in the cathode to supply oxygen which is capable of carbon capture from the environment. This type of MFC can be easily scaled up and domesticized due to the readily available components. The sludge from the used MFC can also be reused as manure and the anode chamber can be integrated with a biogas collection unit. This mainly emphasises the recycling of food waste which has grown to become crucial in order to bring it for a functional purpose and also make it more sustainable than regular microbial fuel cells that need oxygen supply. MFC can be the best solution for decentralized zero-waste management.

SCOPE FOR FUTURE WORK

Microbial fuel cells may be linked to municipal waste streams or sources of agricultural and animal waste, providing a sustainable system for waste treatment and energy production.

MFCs are far from making an industrial debut soon, but better research can definitely speed up the process. The lifetime of these MFCs are longer as they are fuel cells, and can continuously generate electricity. It can also be made to store energy by coupling with a supercapacitor, as this MFC depends on sunlight exposure. The algae in the cathode can also account for carbon dioxide capture, being reliant on photosynthesis. Algal biomass grown at the cathode can also be utilized for biofuel production or animal feed. At the anode chamber, biogas can be collected and an integrated biogas MFC can be constructed. It can be scaled up or can be connected in series to maximize the output power, it can be incorporated into houses or at large-scale levels for agricultural waste and wastewater treatment.

REFERENCE

1. Palanisamy, G., Jung, H., Sadhasivam, T., Kurkuri, M.D., Kim, S.D, Roh, S.H.: A comprehensive review on microbial fuel cell technologies: Processes, utilization, and advanced developments in electrodes and membranes. J. of Cleaner Production, 221, 598-621 (2019)
2. Sinha, S., Tripathi, P.: Trends and challenges in valorisation of food waste in developing economies: A case study of India. Case Studies in Chem. and Environ. Engg., 4, 100162 (2021)
3. Xin, X., Ma, Y., Liu, Y.: Electric energy production from food waste: Microbial fuel cells versus anaerobic digestion.
4. Bioresource Technology, 255, 281-287 (2018)Katz, E.: Implantable Biofuel Cells Operating In Vivo—Potential Power Sources for Bioelectronic Devices. Bioelectronic Medicine, 21-12 (2015).
5. Wang, F., Gu, Y., O'Brien, J. P., Yi, S. M., Yalcin, S. E., Srikanth, V., Shen, C., Vu, D., Ing, N. L., Hochbaum, A. I., Egelman, E. H., & Malvankar, N. S., : Structure of Microbial Nanowires Reveals Stacked Hemes that Transport Electrons over Micrometers. Cell, 177, 361-369 (2019).
6. Carvalho, A., Costa, R., Neves, S., Oliveira, C.M.: Determination of dissolved oxygen in water by the

7. Winkler method: Performance modelling and optimisation for environmental analysis (2021).
8. Yaqoob, A.A., Ibrahim, M.N.M, Umar, K.: Electrode Material as Anode for Improving the Electrochemical Performance of Microbial Fuel Cells, Energy Storage Battery Systems, (2021).