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Low Cost Cathode Performance of Microbial Fuel Cell for Treating Food Wastewater

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ABSTRACT

Aluminium mesh is a cheap option for oxygen reduction in microbial fuel cells (MFCs), but there is a need for improving its power production and longevity. This study showed the effect of aluminium mesh as cathode in a MFC system for wastewater derived from food sources. Maximum dissolved solutes removal was around 58%, which was initially 570±20 mg/L and decreased to 360±5 mg/L within ten days of operation. Open circuit voltage (OCV) was around 520 ± 30 mV and decreased in the next five days of operation. Graphene (active surface area of 8.5 cm^2) was used as the anode owing to its good conductivity; reactor housing was an inexpensive polyethylene terephthalate (PET) system. These results show that aluminium mesh can be a simple and effective material to improve cathode performance. Power density calculations have been normalized by the anode surface area, further improvement in performance would be a key to low cost MFC markets.

INTRODUCTION

Increasing demand for natural resources by various power sectors has led to a growing concern since these resources are limited (Ono & Tsunemi 2017). Energy crisis brings out the mandatory requirement for major changes in the energy consumption pattern. Alternate and renewable energy sources must be brought into picture, to fill the role of limited natural resources which would eventually run out (Bose & Bose 2017). The major challenge faced by industries includes the identification of possible ways for controlling and harnessing the energy by ensuring its commercial availability and viability. Almost 80% of the current energy needs are met by fossil fuels and also its demand is expected to increase by half in the coming decades.

Extraction of energy by burning of fossil fuel emits carbon dioxide to the atmosphere, which is one of the major reasons for increase in the global temperature (Cardoen et al. 2015). Carbon dioxide emissions can be reduced by either reducing the amount of its generation in production activities or by the application of techniques for carbon capture and storage (CCS). Reducing carbon dioxide emissions in the production activities is considered as suitable option since the CCS techniques are still in research phase and also are not economical in current scenario (Herrero-Hernández et al. 2013). Studies conducted by environmental protection agency (McPartland et al. 2015, Bows-Larkin 2015) have shown that there is an increasing trend in carbon emissions globally since 1900 and the contribution of various sectors in the emission of greenhouse gases are as shown in Fig. 1.

Carbon dioxide emissions from the production activities can be reduced only by introducing severe changes in the current power generation technologies (Kapoor et al. 2017). Alternate energy sources like solar, wind, tidal and fuel cells are found to be promising candidates for reducing these emissions to have a control over the climate change and also for eventual replacement of fossil fuels.

Microbial Fuel Cell (MFC) systems can address the issue of reducing carbon footprint and support the water infrastructure. Wastewater generated in large volumes from both urban and rural areas require the use of expensive chemicals for treatment (Zhang et al. 2015). MFCs can reduce the chemical load on these wastewater streams and also produce utilizable electricity from it. Much of the work in MFC system and architecture is based around carbon based materials for both the anode and the cathode (Bose et al. 2018).

Present work explores a membrane-less MFC with a relatively inexpensive aluminium mesh as the cathode. The system was able to generate electrical power, the study was discontinued after ten days of operations, and such systems represent a challenge and a business opportunity.

MATERIALS AND METHODS

The electrodes in the system were a graphene disc (1 cm × 8.5 cm) and aluminium mesh (5 cm × 5 cm) housed in a circular system as shown in Fig. 2. The reactor surface area is 1045 cm^2 with a working volume of 2268 cm^3, this being a relatively inexpensive standard polyethylene terephthalate (PET) system.

Wastewater was collected from the university cafeteria (pH = 8.2), analysis were made based on system open circuit voltage (OCV), which is the maximum possible voltage for any given system. Total dissolved solutes (TDS) in the wastewater was continuously monitored for contaminant removal efficiency. An external resistance of 100 Ω was used in the system to study the effectiveness of chemical removal along with the characterization of the voltage and current produced. For calculating current, the multimeter shown in Fig. 2 is replaced with a resistor, voltage drop measured across the resistor, gives the current using Ohm's law.

$$E_{MFC} = I\,R_{ext} \qquad ...(1)$$

Where, E_{MFC} is the cell voltage (in volts), I is the current produced (in ampere), and R_{ext} is the external resistance (in ohms).

Further the power production is measured by taking the product of cell voltage and the current produced.

$$P_{MFC} = E_{MFC}\,I \qquad ...(2)$$

The power density from the system as characterized by normalizing to anode surface area, is given by

$$P_{An} = \frac{E_{MFC}^2}{A_{an}\,R_{ext}} \qquad ...(3)$$

Where, P_{An} is the normalized power production by the surface area of the anode, E_{MFC} is the cell voltage, A_{An} is the anode surface area, and R_{ext} is the external resistance (load) on the system.

RESULTS AND DISCUSSION

System OCV stabilized near 520 mV around tenth day, after which the voltage started decreasing rapidly. As shown in Fig. 3, this shows relatively inexpensive materials can be used to facilitate tri-phase reaction of the proton, electron and oxygen at the cathode.

Further, a characterization of the dissolved solutes was studied as a function of increasing voltage, the TDS value dropped from around 580 mg/L to around 367 mg/L as shown in Fig. 4, giving an overall TDS removal efficiency of around 58%.

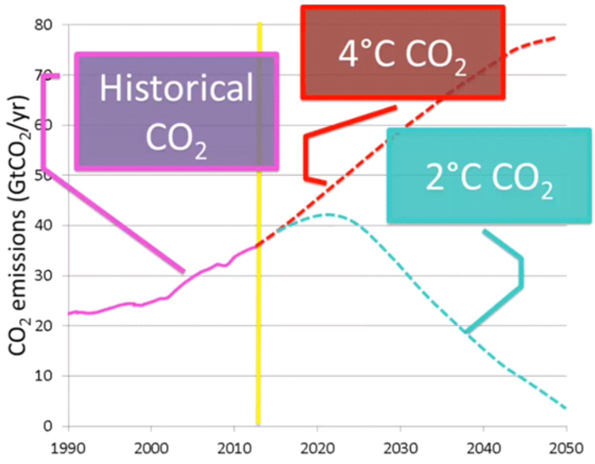

Fig. 1: The blue line represents the target of all nations to mitigate surface temperature rise below 2°C, as per the Paris Agreement (COP 21). This represents a global consensus to produce reduced net CO_2 emissions based technology, which, if not followed will result in a 4 °C temperature rise which can be a cause of major environmental disturbances.

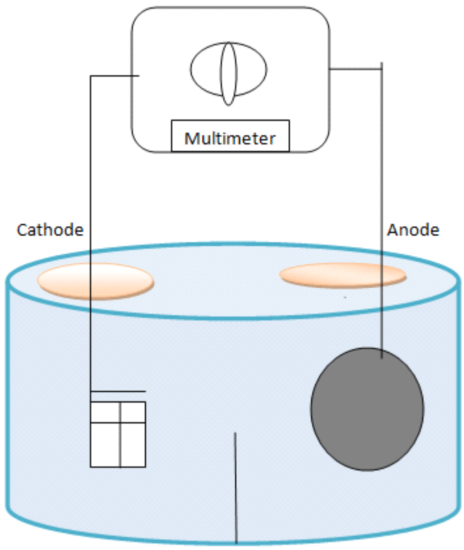

Fig. 2: For open circuit voltage measurement, cathode and the anode are directly plugged to a multimeter; this can be connected to a data acquisition system for consistent readings.

After the OCV studies, external resistance was connected to the system, which showed the voltage drop peak around 14 mV, as shown in Fig. 5. This showed that such systems with, though limited output, can produce electrical power.

Based on the voltage drop recorded, the current generation was calculated, which peaked around 0.15 μA as shown in Fig. 6. This highlights the low Coulombic efficiency in terms of electron transfer, and also represents an opportunity to develop more relatively inexpensive electrodes with appropriate binders.

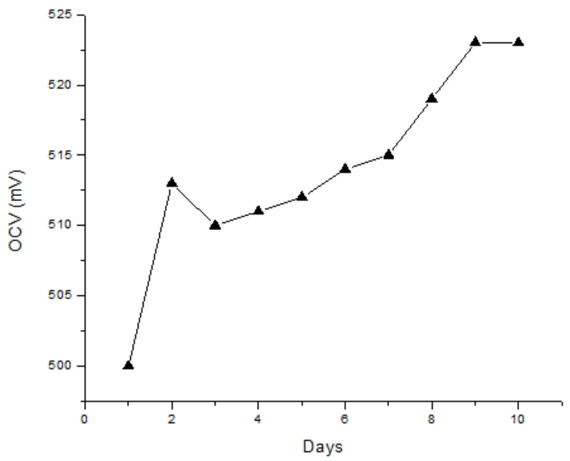

Fig. 3: The theoretical voltage generated with infinite resistance vs days of operation.

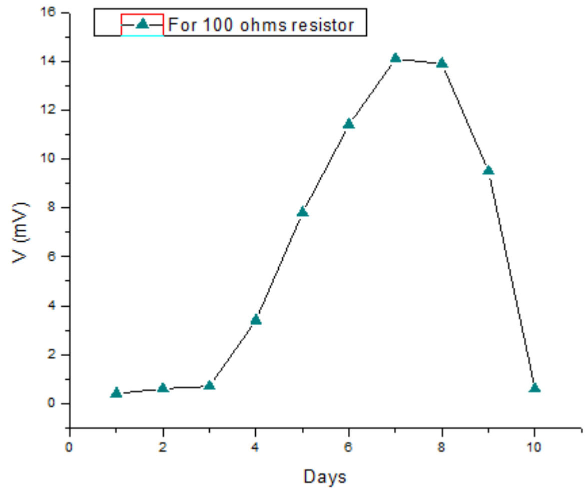

Fig. 5: The characteristic curve for voltage drop being monitored through the external load for the MFC system.

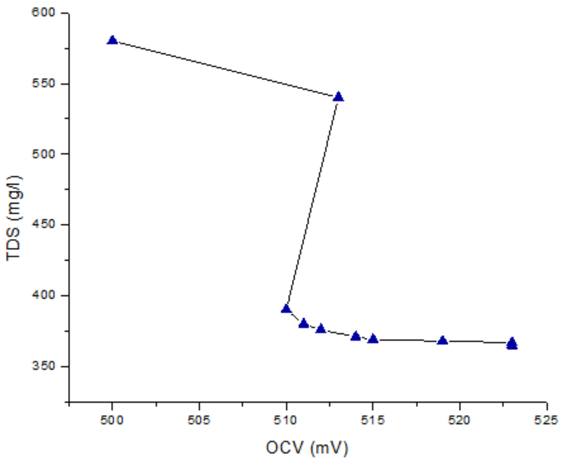

Fig. 4: Characterization curve for the drop in TDS with increasing voltage.

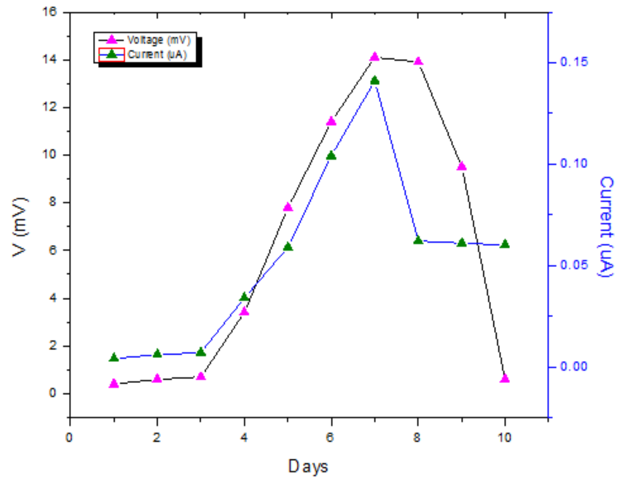

Fig. 6: Current generation curve characterized with the voltage generation as a function of days of operation.

Further, a characterization was made for power density as a function of anode surface area, as knowing how much power is generated by an MFC is not sufficient to describe how efficiently that power is generated by the specific system architecture. The anode surface area provides a context to available area for the microbes to grow on, which has an effect on overall power generated. Fig. 7, shows the graphical representation for the same.

This study showed that it is possible to use relatively inexpensive material without any catalyst as cathode, while research is needed to improve power production and also for low cost binders and suitable substitute for expensive catalysts (such as platinum). This represents a limitation and a market opportunity (Kim et al. 2016). Such systems can be used with the modules of a conventional treatment plant to replace the biological treatment unit, and the process would yield effective COD removal and bioelectricity production, and the left-over sludge can be used as an organic fertilizer. However, a secondary treatment facility would be required as power production is low below the 150 mg/L organic load. Other processes can be used with reduced aeration requirement compared to those needed without the MFC pretreatment (Logan & Rabaey 2012). A critical obstacle for the further development of MFCs is the capacity to produce cost effective reactor cathodes. The present work has shown that it is possible to develop such with locally available cheaper materials; however, the fact that current production is limited with such systems, represents both a production challenge and a business opportunity.

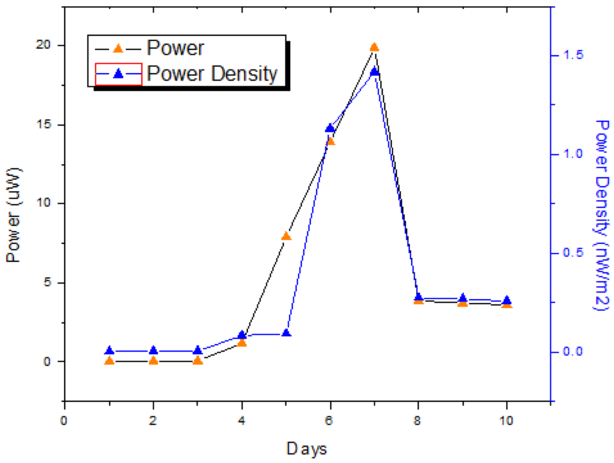

Fig. 7: Power density as a function of anode surface area (A_{An} = 56.74 cm^2) and external resistance (R_{Ext} = 100Ω) for. The circuit resistance was chosen so that it did not limit power output.

MFCs can play a vital role in powering the energy infrastructure with sustainable energy solutions. This would require the trust, support and encouragement at the local, national and indeed international level. For this to work at the commercial level, support of customers, policy makers, power utilities, suppliers and local communities will be pivotal.

CONCLUSION

The method for evaluation of inexpensive cathodes can be extended to other test conditions, such as different reactors, electrode spacing, and studies with pure cultures. This method is convenient for initial screening of MFC performance without actual measurement of recovered ions, especially in conjunction with the use of small scale reactors and provides a basis for further detailed analysis, which includes the complete energy balance. In hindsight, the most likely application of MFCs will be wastewater treatment in large scale as these systems lack expensive membranes and can achieve organic matter removal without aeration. Scaling up these systems successfully will depend on high cathode specific surface area and its material conductivity to maximize power production and organic matter utilization rates. Further, on successful commercialization it might be possible to develop similar electrochemical systems, which work on bacterial interactions, and might aid the development of other renewable energy technology particularly those based on salinity gradient and exploration of waste heat.

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