Evaluation of viable anode material for bioelectricity production in Microbial Fuel Cell

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Abstract - Microbial Fuel Cell (MFC) technology is based on bioelectrochemical system, extract power from organic load of the wastes to produce bio-electricity. The present study have evaluated the effect of the different electrode materials in two sets of mediator-less H- type double chambered MFC operated at 30 ± 2 °C in a batch mode. In MFC_{GG}, graphite rods (G) and in MFC_{CBG} carbon brush (CB) and graphite rod (G) were used as anode and cathode electrode respectively. The both MFC were fed with distillery spent wash as a substrate with HRT of 21 days. The maximum COD removal of 61.07 % and 67.17 %; open circuit voltage (OCV) of 565 and 735 mV were achieved in MFC_{GG} and MFC_{CBG} respectively. The peak power densities of 3.19 W/m^2 and 5.4 W/m^2 were recorded in MFC_{GG} and MFC_{CBG}. These results suggest the efficacy of carbon brush anode in MFC_{CBG} compared to graphite rod as an anode material in MFC for bioelectricity production.

Keywords: BioElectricity, Microbial Fuel Cell, Distillery Spent Wash, Open Circuit Voltage (OCV), Anode material

1. Introduction

To address the depleting fossil fuels and to control the associated air pollution new genera of energy carriers are sought (Nayak et al., 2018). These energy sources should be safe, sustainable and environmentally friendly. The renewable energy from waste can serve the purpose as energy derivation from waste materials can solve the problem of the waste generation and energy scarcity simultaneously (Sonawane et al., 2017). Microbial fuel cells (MFC) have received concentration for wastewater treatment and contaminant removal. The MFC generally consists of two an anodic chamber and a cathodic chamber separated by a proton exchange membrane (PEM) (Nayak & Ghosh, 2019; Ucar et al., 2017).
The Microbial Fuel Cell, a type of Bio-electrochemical systems, is capable of producing electricity by utilisation of waste (Zhang et al., 2011). A wide range of substrate can be utilized in MFC, e.g. wastewater, food waste, agricultural waste, sludge, swine slurry etc. MFCs can exploit pure as well as complex substrates ranging from carbohydrates, proteins, fats, to alcohols (Pandey et al., 2016). The two chambered MFC is most widely studied in comparisoon to other reactor configurations. The mixed culture has diverse range of microbes are more suited for bio-electricity generation (Gezginci & Uysal, 2016). The bacterial consortia in anodic chmaber harbours the biofilm forming microorganisms (Venkata Mohan et al., 2014). These microbes in biofilm oxidise the organic content of the feed and release electrons and protons. The electrons travel down via external circuit to cathode and to maintain charge neutrality protons diffuse to cathode through the cation exchange membrane, where they combine together with oxygen to produce molecular water (Cerrillo et al., 2016).
In MFCs, substrate, electrode material, microorganisms etc are the most influeincing factors for MFC performance (Gezginci & Uysal, 2016).
The present study aims to evaluate the viable anode materials for biofilm formation thus bio-electricity production in dual chambered H type MFC. Two different sets of electrodes i.e. Set I - graphite rods (GG) and Set II Carbon brush and graphite rod were used in diffrent batch modedMFCs to evaluate the performance.

2. Materials and methods

2.1. Experimental set-up

The two H type identical acrylic sheet derived MFCs were constructed in which both the anode and cathode compartments with working volume of 700 mL each were made in a cube shape with side of 10 cm and each chamber was separated by Nafion-117 from Dupont as proton exchange membrane. In MFC – I, labelled as MFC_{GG}, both electrodes were graphite rods (G) of surface area approximately 10 cm^2, while MFC – II, labelled as MFC_{CBG} had carbon brush (CB) as anode and graphite rod (10 cm^2) as cathode. The two electrodes were connected with copper wire and an external resistance of 100 Ω was connected in series. The anodic chamber was fed with distillery spent wash while cathodic chamber was fed with distilled water. All electrodes were acid treated and then subjected to heat to remove impurities.

2.2 MFC inoculation and operation

The inoculum for both the MFCs were taken from 3 month old MFCs operated on anaerobic sludge. The reactors were purged by N_2 gas to maintain anaerobic conditions in anodic chambers.The inoculum was added in a ratio of 1:3 to the substrate. The electrodes were kept in inoculums to form biofilm on the surface of anodes. The distillery spent wash was kept at 4 °C to avoid any degradation and prior to fed to anodic chambers it was bought to room temperature *(30 ± 2 °C)*. The HRT of 21 days was maintained to assess the performance of MFCs. The Open Circuit Voltage was measured by multimeter.

Table 1. Physico-chemical parameters pre and post treatment

	pH	COD (g/L)	TS (g/L)	TSS (g/L)	VSS (g/L)
Influents					
MFC-I	6.2	26.2	14.8	8.9	7.2
MFC-II	6.2	26.2	14.8	8.9	7.2
Effluents					
MFC-I	6.9	10.2	11.2	6.8	5.6
MFC-II	6.6	8.6	10.2	6.5	5.1

2.3 *Analytical methods and calculations*

The performance of the MFC_{GG} and MFC_{CBG} were evaluated on the maximum voltage generated by the degradation of the feed. This voltage was used to calculate the Current densities and Power densities. The percentage COD removal of the feed is an indicator of the efficiency of the microbial consortia to oxidise the feed.

$$\textbf{Power Density} = \frac{V*V}{R*A} \qquad \textbf{Eq. 1}$$

Where
V = Voltage in V
R = resistance in Ω
A = area in m^2

$$\%\ \textbf{COD Removal} = \frac{(CODi - CODf)}{CODi} * 100 \qquad \textbf{Eq. 2}$$

Where
COD_i – Initial COD concentration
COD_f – Final COD concentration

3 Results and Discussion

3.1 *Bio-electricity generation in terms of Voltage*

The OCV was monitored and recorded continuously for both the MFCs. Initially, increase in voltage was not steady attributed to lag phase of the microbial consortia. In the log phase, voltage was increased in a linear manner, reaching to the highest value of 565 mV and 735 mV for MFC_{GG} and MFC_{CBG} respectively. The decrease in voltage was recorded after 11^{th} and 15^{th} day of the cylcle for MFC_{GG} and MFC_{CBG} respectively. The decreasing voltage indicated the exhaustion of the organic matter of the feed. The higher voltage obtained in Carbon brush anode (MFC_{CBG}) had suggested the more efficient biofilm formation on the anode (Fig. 1).

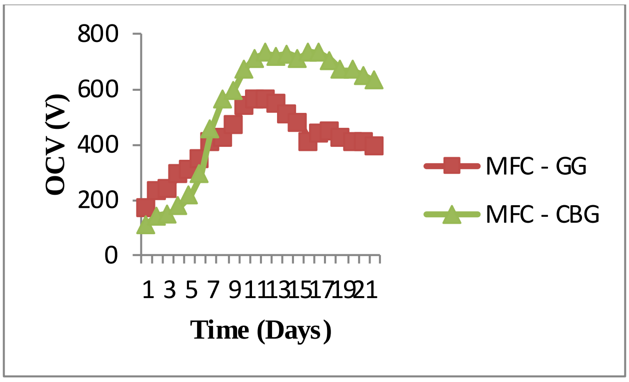

Figure 1. Variation of OCV with time

3.2 *Power Density*

The power density is one of the major criteria to evaluate the MFC performance. The OCV was used to calculate the power densities for both the MFCs. The lag phase of growth cycle resulted in smaller values of power densities, but as the voltage increased in the log phase the power densities also reached to the maximum values. The maximum power density of 3.19 W/m^2 and 5.4 W/m^2 were obtained for MFC_{GG} and MFC_{CBG} respectively (Fig. 2).

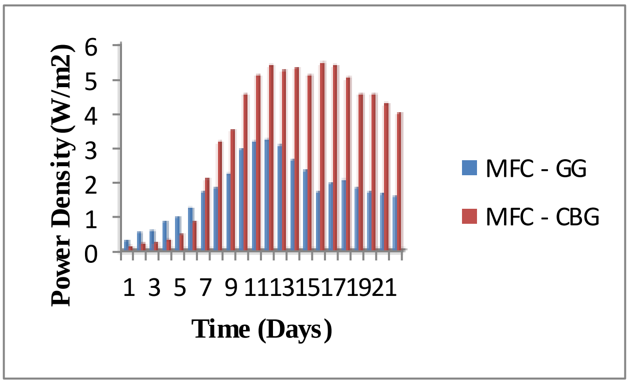

Figure 2. Variation of power density with time

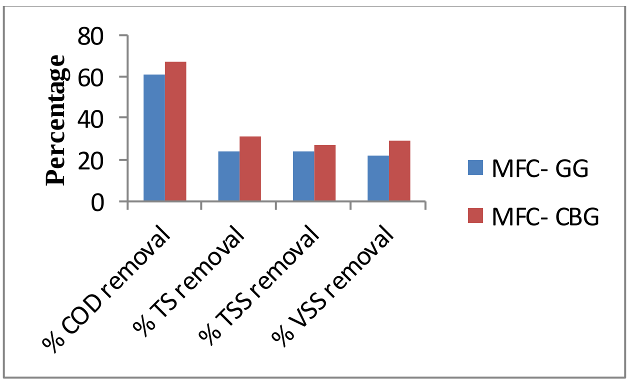

Figure 3. Percentage removal of different parameters

3.2 COD removal

The microbes in anodic chamber of MFCs, in course of voltage generation results into COD reduction. The more efficient biofilm results into higher COD removal. Among the two sets, MFC_{CBG} exibited higher COD removal thus more effcient biofilm. The MFC_{GG} and MFC_{CBG} were shown 61.06 % and 67.17 % COD removal respectively (Fig. 3). Further COD removal could have been acheived by increasing the hydraulling retenton time(HRT). Both the MFCs also resulted in the significant reduction in Total solid (TS), Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS) after HRT of 21 days.

4. Conclusion

The study has proved that the effective anode material is a critical factor for the MFC performance. The batch cycle of MECs operated on distillery spent wash had shown promising results in term of bio-electricity production. The Carbon brush anode in MFC_{CBG} has proved more biocompatabile, effective and efficient in formation of bio-film on its surface due to larger available surface area in comparison to the graphite rods in MFC_{GG}. The higher bioelectricity generation, COD removal, total solid removal etc had placed Carbon brush as better choice as anode material.

References

Cerrillo, M., Oliveras, J., Viñas, M., & Bonmatí, A. (2016). Comparative assessment of raw and digested pig slurry treatment in bioelectrochemical systems. *Bioelectrochemistry*, *110*, 69–78. https://doi.org/10.1016/j.bioelechem.2016.03.004

Gezginci, M., & Uysal, Y. (2016). The Effect of Different Substrate Sources Used in Microbial Fuel Cells on Microbial Community. *JSM Environ Sci Ecol*, *4*(3), 1035.

Nayak, J. K., Amit, & Ghosh, U. K. (2018). An innovative mixotrophic approach of distillery spent wash with sewage wastewater for biodegradation and bioelectricity generation using microbial fuel cell. *Journal of Water Process Engineering*, *23*(May), 306–313. https://doi.org/10.1016/j.jwpe.2018.04.003

Nayak, J. K., & Ghosh, U. K. (2019). Post treatment of microalgae treated pharmaceutical wastewater in photosynthetic microbial fuel cell (PMFC) and biodiesel production. In *Biomass and Bioenergy* (Vol. 131). https://doi.org/10.1016/j.biombioe.2019.105415

Pandey, P., Shinde, V. N., Deopurkar, R. L., Kale, S. P., Patil, S. A., & Pant, D. (2016). Recent advances in the use of different substrates in microbial fuel cells toward wastewater treatment and simultaneous energy recovery. *Applied Energy*, *168*, 706–723. https://doi.org/10.1016/j.apenergy.2016.01.056

Sonawane, J. M., Yadav, A., Ghosh, P. C., & Adeloju, S. B. (2017). Recent advances in the development and utilization of modern anode materials for high performance microbial fuel cells. *Biosensors and Bioelectronics*, *90*(September 2016), 558–576. https://doi.org/10.1016/j.bios.2016.10.014

Ucar, D., Zhang, Y., & Angelidaki, I. (2017). An overview of electron acceptors in microbial fuel cells. *Frontiers in Microbiology*, *8*(APR), 1–14. https://doi.org/10.3389/fmicb.2017.00643

Venkata Mohan, S., Velvizhi, G., Annie Modestra, J., & Srikanth, S. (2014). Microbial fuel cell: Critical factors regulating bio-catalyzed electrochemical process and recent advancements. *Renewable and Sustainable Energy Reviews*, *40*, 779–797. https://doi.org/10.1016/j.rser.2014.07.109

Zhang, Y., Mo, G., Li, X., Zhang, W., Zhang, J., Ye, J., Huang, X., & Yu, C. (2011). A graphene modified anode to improve the performance of microbial fuel cells. *Journal of Power Sources*, *196*(13), 5402–5407. https://doi.org/10.1016/j.jpowsour.2011.02.067