ISSN: 2278-4632
Vol-10 Issue-1 January 2020

MEMBRANE-LESS MICROBIAL FUEL FOR WASTEWATER TREATMENT AND ENERGY GENERATION

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Abstract: The membrane-less microbial fuel cell (ML-MFC) is one of the appealing methods for generating power and treating wastewater at the same time. The continuous mode of ML-MFC energy generation has been examined in this research. To maximise performance, a number of studies were conducted to examine the influence of aeration in the cathode compartment, sludge concentration, initial substrate concentration, and the ML-capacity MFC's to remove COD. With a current density of 34.02 mA/m2, a maximum power density of 8.98 mW/m2 was noted. In all experiment, COD elimination was detailed between 44% and 54%.

Keywords: microbial fuel cell; MFC; COD; wastewater treatment

1 Introduction

In recent years, the globe has begun to seriously consider different alternative energy sources due to the rising energy demand, diminishing fossil fuel resources, and rising environmental degradation. Renewable energy sources could play a crucial part in the energy mix. An appealing alternative energy source is the microbial fuel cell (MFC), which converts wastewater-derived materials into power (Gil et al., 2003; Bond and Lovley, 2003; Logan et al., 2006). It would be advantageous to use this kind of fuel cell to utilise common waste materials and the chemical energy they contain. Direct power recovery is achievable during the oxidation of the organic pollutants present in wastewater in MFC type fuel cells. As a result, it is possible to treat wastewater while also recovering electricity. Also, compared to typical aerobic wastewater treatment, excess sludge production is extremely minimal in MFC, which lowers the expense of additional sludge management.

This kind of fuel cell would have several advantages since it could be used to harness the chemical energy contained in everyday waste items. The organic pollutants in wastewater are oxidised in MFC-type fuel cells, and direct electricity recovery is possible during this process. As a result, it is possible to cleanse wastewater and collect electricity at the same time. Also, compared to typical aerobic wastewater treatment, the amount of surplus sludge produced by MFC is quite low, which lowers the expense of further sludge management. In the anodic chamber, microorganisms develop by oxidising a substrate that serves as an electron donor. Protons are internally conveyed through the membrane while external circuitry is used to transfer the electrons gathered on the anode to the cathode (You et al., 2007; Fan et al., 2007). Due to different liquid solutions, potential difference is therefore created between the anode and cathode chambers. Using oxygen from water, electrons and protons are consumed in the cathode compartment.

MFC's use in large-scale wastewater treatment that involves suspended solids, however, may be constrained by its high initial cost and membrane fouling that necessitates replacement. The acceptability of MFC for wastewater treatment would rise if the usage of membranes was discontinued. Jang et al. (2004) and Liu et al. (2005) employed a membrane-less microbial fuel cell (ML-MFC) to turn organic pollutants from synthetic wastewater into power. A membrane-free MFC can increase acceptability and economic viability. Thus, the following were the study's goals:

1 to fabricate an inexpensive configuration of ML-MFC

2 to evaluate the capability of mediator-less microbial fuel cell as combined wastewater treatment and electricity production unit under various operating conditions.

2 Methods

ML-MFC construction

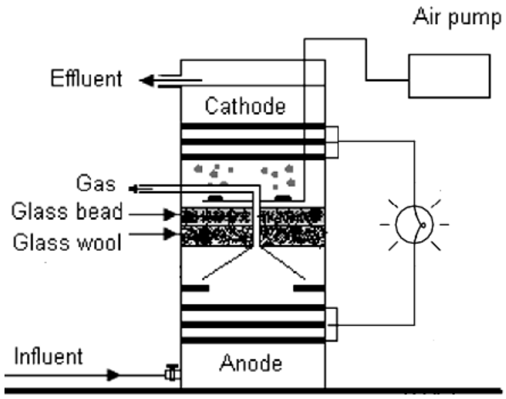
The ML-MFC was designed and fabricated in the laboratory using locally available materials. The schematic diagram and fabricated ML-MFC with the auxiliary equipment's are shown in Figure 1. The ML-MFC was made up of PVC cylinder having the effective height of 20 cm and internal diameter of 5 cm. A sieve plastic plate is placed for support the glass wool and glass beads. Anode compartment (depth 8 cm) was placed at bottom, and cathode compartment (depth 8 cm) was at top. Glass wool (2 cm depth) and glass bead (2 cm depth) were placed at the upper portion of the anode compartment separating anode and cathode. Graphite rods obtained from a local dry cell factory were placed in both anode and cathode compartment to be used as electrodes. The total apparent surface area of the two anode electrodes was 50.27 cm^2. The MFC was provided with an inlet and an outlet port. Besides this, another port was provided for aeration by the aquarium pump. The fuel (wastewater) was supplied from the bottom of the anode chamber and the effluent was discharged through the cathode chamber at top. The electrodes were connected with copper wire through the external resistance, ranging from 1.6 Ω to 152 KΩ, including the resistance of copper wire and multi-meter.

Wastewater composition and inoculation of ML-MFC

The synthetic wastewater used as fuel was supplied at a rate of 10 L/d to ML-MFC, which containing sucrose as a carbon source was used in the study. The composition of waste water was 300–900 mg/L of glucose, 500 mg/L of sodium hydrogen carbonate, 97.7 mg/L of ammonium chloride, 142 mg/L of K_2HPO_4, 8.7 mg/L of KH_2PO_4, 74.3 mg/L of calcium chloride and 23.2 mg/L of $MgSO_4.7H_2O$. The cathode compartment was aerated at rate of 60mL/min by an aquarium pump at an air pressure of 122 kPa. The ML–MFC was inoculated with anaerobic sludge collected from the local residential areas waste water drainage system. The inoculum sludge was sieved through 1mm opening sieve and heated at 100°C for 15min to suppress the methanogens, cooled at room temperature. No microbial addition was carried out in the cathode compartment. The ML–MFC was operated at room temperature ranging from 29°C to 33°C.

Figure 1 Schematic diagram of ML-MFC

ISSN: 2278-4632
Vol-10 Issue-1 January 2020



2.3 Analytics and calculations

Current (I) and potential (V) measurements were recorded using digital multimeter (FL-9205A, SHEN-ZHENXL electronic co. Ltd china) by connecting with 10 Ω external circuit. Power (W) was calculated using relation P = IV, where I, V represents current (A) and voltage (V), respectively. Current density (A/m^2) was calculated by dividing the obtained power current by the anode surface area (m^2). COD and pH were monitored in the anodic chamber of MFC during operation according to the standard methods.

3 Result discussions

Effect of aeration in the cathode chamber in membrane less MFC

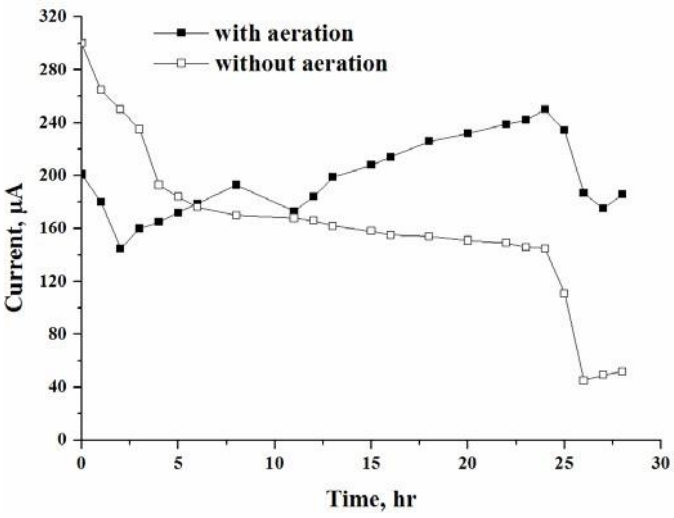
To explore the effect of aeration in the cathode chamber on current generation, two sets of ML-MFC reactor were operated under different operating conditions. The second set was subjected to aeration in its cathode chamber with the same feed compositions. The glucose and sludge concentrations were also fixed at 600 mL/L and 150 mL/L with the influent average flow rate of 10 L/d.

Figure 2 clearly shows that, aeration in the cathode chamber has a great effect on current generation. It displayed a decreasing trend for the cell operating without aeration in the cathode chamber. Maximum electricity of 250 µA was recorded for the cell operated with aeration. There might be two potential reasons for the enhanced current production activities, reflecting an increase in the rate of bio electrochemical reaction, include:

1 the presence of oxygen led to more biomass formation

2 the presence of oxygen changed metabolic reaction patterns, enhancing the electronflux to the electrode.

Figure 2 Effect of the aeration in the cathode chamber



Effect of sludge concentration in membrane less MFC

To investigate the effect of sludge concentration in the current production of ML-MFC, two sets of reactors were operated with varying sludge concentrations. The sludge concentrations were 50 mL/L and 100 mL/L, respectively. Substrate concentration was fixed at 600 mg/L. All the sets were aerated in the cathode chamber with an aquarium pump at an air pressure of 122 kPa.

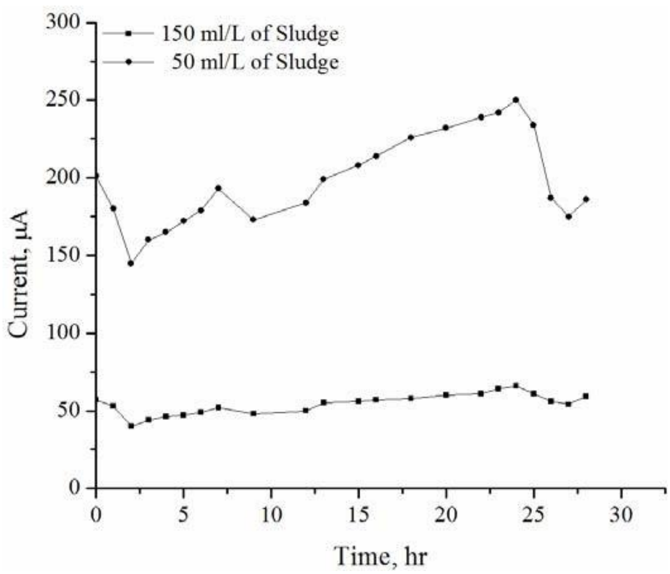


Figure 3 Effect of the sludge concentration on the ML-MFC

Figure 3 illustrates that, the cell using 150 mL/L sludge at the influent showed better current production. The current generation for feed rate of 150 mL/min was fluctuated slightly throughout the operation and reached a maximum value of 250 µA after 24 h of operation. The cell using 50 mL/L sludge at the influent gave the initial current of 52 µA which was much lower than the other. But current was stable compared to previous cell. After the 28 hrs operation, the readings were 186 µA and 59 µA respectively in two reactors. The results suggest that for a fixed amount of substrate

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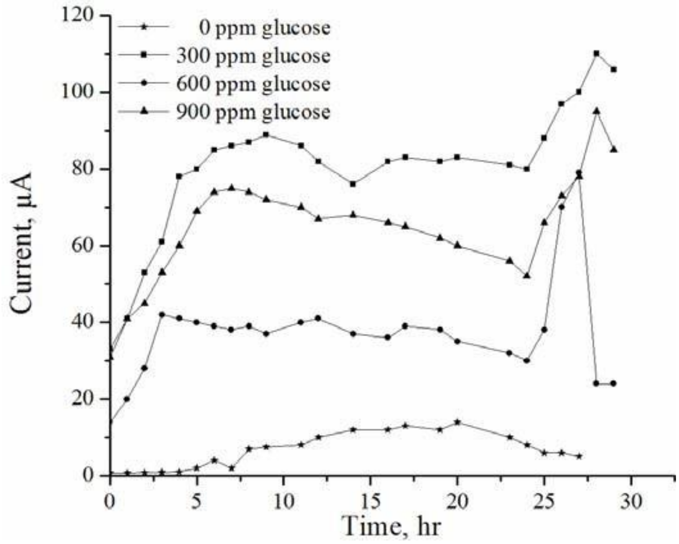
and salt, current generation increases with increasing the sludge concentration. This result indicates that more sludge may contain the higher electricity generating microorganism.

Effect of initial glucose concentration in membrane less MFC

To scrutinise the effect of initial substrate concentration in the current production of two ML-MFC were operated under fixed concentration of salts and variable substrate concentrations. Glucose concentrations were varied to 0 mg/L – 900 mg/L. The target of this experiment was to find a trend to describe effect of initial substrate concentration. The influent was feed at an average flow rate of 10 L/d.

As the glucose concentration increased from 0 to 300mg/L, the current density increased from 12 µA to 110µA after 28 h of operation, with the further increase in glucose concentration from 300 to 900 mg/L the current density decreased from 110 µA to 25 µA (Figure 4). Very poor current generation was obtained for the cell operating without substrate.

Figure 4 Effect of the initial substrate concentration on the ML-MFC



Microorganisms generate electricity due to the consumption of glucose in the aerobic conditions, where they produce carbon dioxide and water. However, when oxygen is not present they produce carbon dioxide, protons and electrons as described below (Logan et al., 2006)

$C_6H_{12}O_6$ □ $6H_2O$ □ $6CO_2$ □ $24H^+$ □ $24e$□

According to Hideki and Takaaki (2009) the current increased with the increase in the glucose concentration. However, for the higher glucose concentration this may cause the increase of the proton concentration within the immobilised layer by the following glucose oxidation reaction which leads to suppression of the enzymatic activities.

Glucose □ Gluconolactone □ $2H$□ □ e□

In comparison with various glucose concentrations in the anode, higher glucose concentration exhibited lower current generation. As a result, to achieve the maximum electricity generation, MFC should be operated with the optimum concentration level.

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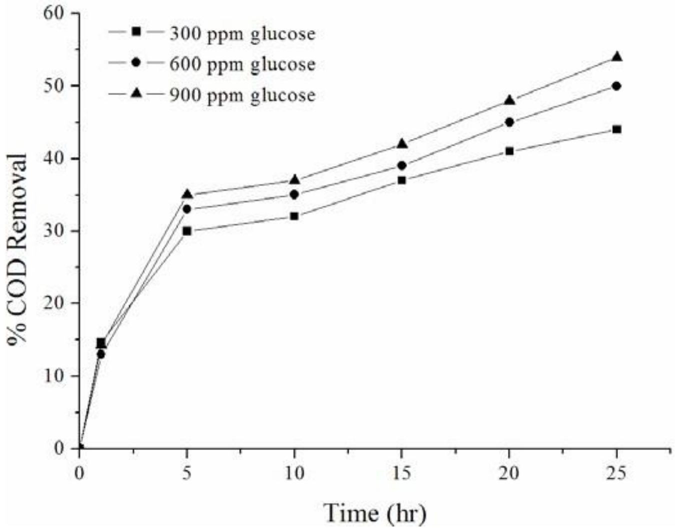
Removal of COD from influent to effluent

It has been reported that microorganisms can convert organic matter into electricity using MFCs while simultaneously accomplishing wastewater treatment. ML-MFC was also continuously monitored for the COD removal efficiency. The following figure shows the waste water treatment potential of ML-MFC used in this paper. Throughout the experiments, three ML-MFCs (containing variable glucose concentration of 300 mg/L, 600 mg/L and 900 mg/L) were showed a similar trend.

Figure 5 Percentage of COD in terms of time for three cells of ML-MFC



After 29hr of operation, COD removal were 44%, 50% and 54% respectively for the cell containing 300 ppm, 600 ppm and 900 ppm glucose and fixed amount of sludge. From the curve it is clear that the COD removal efficiency dose not depends on glucose concentration, but it depends on time.

Polarisation power curve

The performance of the anode, cathode cell was analysed by polarisation curves (*E-j* curves). The polarisation curve characterises the cell voltage as a function of current.

The current depends on the size of the electrical load placed across the fuel cell. In essence the polarisation curve shows the electrochemical efficiency of the fuel cell at any operating current. Since fuel cell's polarisation curve indicated the relationship between voltage current at all operating conditions, it can be used to derive a corresponding power curve. At any point along the curve the instantaneous power is represented graphically as the rectangular area that just touches the curve. At the peak point of the power curve, the internal resistance of the cell is equal to the electrical resistance of the external circuit. Electrodes potential were measured at various current densities to investigate the effect ofpolarisation on MFC operation.

Figures 6–7 shows the polarisation curve and power curve for ML-MFC having the variable substrate concentration (300 mg/L, 600 mg/L and 900 ppm glucose).

From the Figure 6 it is observed that, the current density of the cell increased whenthe cell potential decreased. The maximum potential was recorded 0.43 V at the cell containing 300 glucose.

Figure 6 Polarisation curve for MFC having the variable substrate concentration

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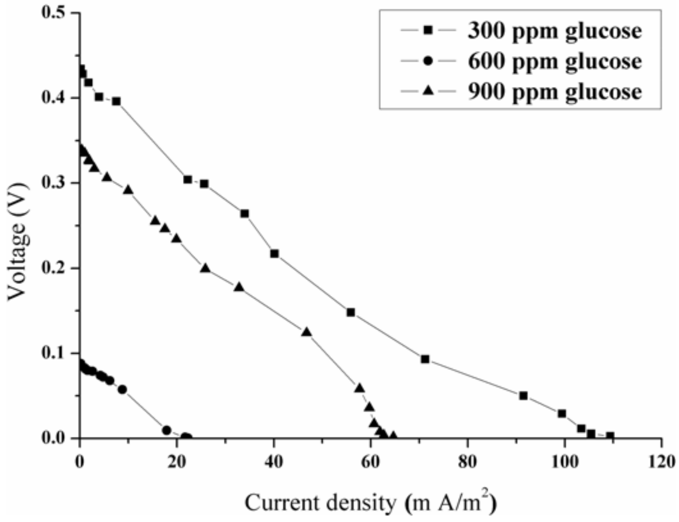
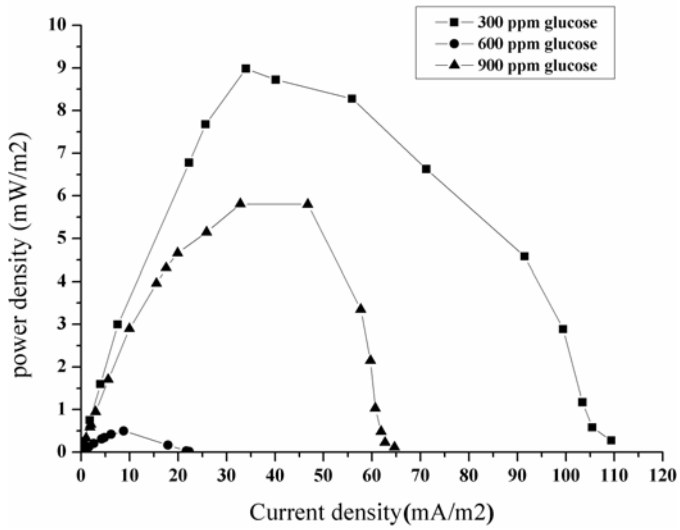


Figure 7 displayed the maximum power density of 8.98 mW/m^2, for the cell operating with 300mg/L glucose at the anode chamber. For all cases, power densities showed an incremental trend with increasing external resistance and reaches to a peak value. After that, the power densities begin to fall down with increasing resistance and current density. Current generation showed decreasing trend with the increase in resistance is consistent with the reported literature by Venkata Mohan et al. (2008), which indicated a typical fuel cell behaviour. At higher resistance used, relatively less power density was observed.

From all the polarisation curves, it can be noted that, the losses of potential is mainly due to the ohmic polarisation which was expected for this kind of fuel cells. The loss due to concentration polarisation and activation polarisation is negligible.

Figure 7 Power curve for MFC having the variable substrate concentration



4 Conclusions

The ML-MFC, inoculated with mixed anaerobic sludge demonstrated its effectiveness as a wastewater treatment process along with electricity production, without incorporating any costly component, such as mediator and membrane. Maximum

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power density was recorded 8.98 mW/m^2 at the current density of 34.02 mA/m^2 for the cell containing
300 mg/L of glucose substrate. Further studies would be necessary to optimise the electricity production from this ML–MFC. Performance of ML-MFC should be observed for long times in continuous mode. With further improvements and optimisation, it could be possible to increase power generation. Thus, the combination of wastewater treatment along with electricity production might help in compensating the cost of wastewater treatment.

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