Journal of Bioprocessing & Biotechniques

Dhaka and Joshi, J Bioprocess Biotech 2015, 5:11
DOI: 10.4172/2155-9821.1000261

Review Article Open Access

Neutral Red Immobilized Graphite Felt Anodic Microbial Fuel Cell for Wastewater Treatment and Generation of Electricity

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Abstract

Microbial Fuel Cell (MFC) can be a great demand for waste water treatment in future. Alternatively, the increasing demand of energy can be fulfilled by this technique in the future if the performance of MFC is improved. In this paper, a MFC was constructed by using graphite felt immobilized with neutral red as anode and a platinum coated platinum wire as cathode. Analyte used was municipal wastewater and catholyte was phosphate buffer of pH 7. The wastewater contained 1.457 mg/l of Ammonical Nitrogen, 33.363 mg/l of COD, 0.537 mg/l of total Phosphorus, 0.105 mg/l of reducing sugar and 0.139 mg/l of Nitrite nitrogen. The mixed culture of organism dominantly present in the wastewater was used in MFC. The result was found to be effective when cellulose acetate was used as membrane compared to the Nafion membrane. The COD of wastewater was reduced by 69.96% when MFC was run for five days with cellulose acetate membrane. The maximum power generated was 24.45 W/m^3 when 1% H_2O_2 was supplied as a source of oxygen in the cathode compartment. The result indicates microbial fuel cell technology to be a new approach for wastewater treatment as it produces sustainable clean energy by minimizing COD level.

Keywords: Microbial fuel cell; Wastewater treatment; Electricity generation; Mixed microbial culture

Introduction

A Microbial Fuel Cell (MFC) is a system that converts the energy stored in organic chemicals directly into current through microorganism under anaerobic conditions [1]. MFC is developed as a new method for both renewable energy production and as a method of wastewater treatment. The enriched microbial culture in these MFCs have capabilities to use organic matter present in the wastewater as energy source and produce electrons and protons through which electricity can be generated. MFCs offer high conversion efficiency due to their ability of direct conversion of substrate's chemical energy to electricity. MFCs exhibit safe and quiet performance [2]. MFCs operate efficiently at ambient temperature. Electricity obtained from MFC is sustainable and the fuel to electricity conversion by MFC is not limited by the Carnot cycle as chemical energy from the oxidization of fuel molecules is converted directly into electricity instead of incurring partial heat losses. MFC is capable of energy efficiency far beyond 50% [3].

Municipal waste water holds high energy density, theoretically higher than necessary for disposal; the development of techniques for capturing the energy contained in this biomass would provide a new source of electrical power that would also avoid the consumption of energy for wastewater treatment. In past two decades, high rate anaerobic processes such as MFC are finding increasing application for the treatment of domestic as well as industrial wastewaters. This paper deals a new idea to treat wastewater and generate electricity.

Materials and Methodology

Collection of sample

The effluent water sample was collected from Bishnumati River, near Kalanki, Kathmandu, Nepal.

Environmental analysis of water

The wastewater was analyzed to determine the concentration of Ammonical-Nitrogen, Chemical Oxygen Demand, total phosphorus, reducing sugar and nitrite nitrogen respectively using standard protocol [4].

Isolation and identification of bacteria

The nutrient agar medium was used for isolation of bacteria from wastewater with dilution 10^{-1} to 10^{-6}. From the consequent dilution 0.1 ml suspension was plated on agar medium and plates were incubated at 37°C for 18-24 hr and isolated colonies were subcultured. Bacterial isolates were subjected to test for gram staining. Methyl red, voges-proskauer, catalase test were also performed for biochemical analysis.

MFC setup

A MFC was constructed by joining two plastic bottles of 500 ml capacity connected via a wide mouthed glass tube with the help of a rubber gasket (Figure 1). Nafion (117) membrane (Dupant, Sigma) and cellulose acetate membrane (Sigma) were used as proton exchange membrane. The experiment was carried out by using cellulose acetate and Nafion membrane as proton exchange membrane separately. Graphite felt was used as anode and the platinum coated platinum wire was used as cathode in the MFC. Anode compartment was filled with 300 ml of wastewater whereas the cathode compartment was filled with 0.1M Phosphate buffer pH 7. Open circuit voltage was observed by using multimeter (FLUKA). External resistance of 500 Ω was applied to the system to generate power curve and study the efficiency of MFC (Figure 2).

Results and Discussion

Table 1 above shows the contaminants present in wastewater. The wastewater collected was not that much polluted as described in Water Quality Parameter of the Baghmati River at Sundarighat which was

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Received November 03, 2015; **Accepted** November 20, 2015; **Published** November 24, 2015

Citation: Dhakal B, Joshi J (2015) Neutral Red Immobilized Graphite Felt Anodic Microbial Fuel Cell for Wastewater Treatment and Generation of Electricity. J Bioprocess Biotech 5: 261 doi:10.4172/2155-9821.1000261

found to be up to 255 mg/L COD [5]. This may be because the water is flowing water from less polluted area (Figure 3).

Isolation and identification of bacteria

From the waste water sample, 6 different bacteria were isolated based on their morphology using 10^{-6} and 10^{-5} dilution. The isolates were named as BT1, BT2, BT3, BT4, BT5 and BT6. Table 2 shows the biochemical analysis for BT1, BT2, BT3, BT4, BT5 and BT6. Based on the staining and the biochemical tests, the bacterial isolates were identified (Table 3; Figure 4).

Enterobacter spp, *Staphylococcus* spp, *Pseudomonas* spp, *Escherichia* coli, *Klebsiella* spp and *Salmonella* spp are the predominant species recorded in waste water. Park et al. [6] also reported the predominance of *Pseudomonas* species in waste water. According to Rabaey et al. [2] *Pseudomonas* spp, *Escherichia coli* are good microbes for electricity generation in microbial fuel cell (Figure 5; Table 4).

Figure 1: Microbial Fuel Cell.

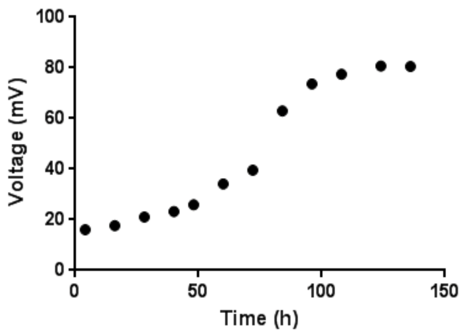

Figure 2: Voltage generated by MFC at different time interval using cellulose acetate membrane.

Analytical parameters of water	Concentration(mg/l)
Ammonia- Nitrogen	1.457 ± 0.392
Chemical Oxygen Demand	33.363 ± 0.76
Total phosphorus	0.537 ± 0.023
Reducing sugar	0.105 ± 0.033
Nitrite Nitrogen	0.139 ± 0.107
pH	6.96 ± 0.2

Table 1: Environmental analysis of water.

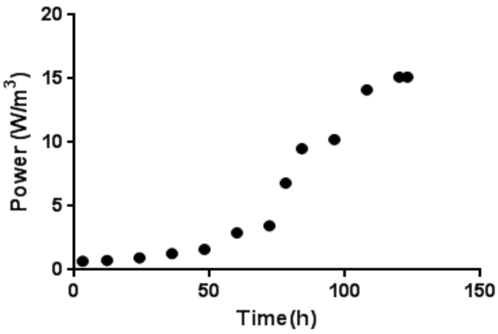

Figure 3: Power generation in MFC at different time interval using cellulose acetate membrane.

Character	BT1	BT2	BT3	BT4	BT5	BT6
Morphology	Gram negative, motile	Gram positive, non-motile	Gram negative, motile	Gram negative, motile	Gram negative, non-motile	Gram negative, motile
Catalase test	+ve	+ve	+ve	+ve	+ve	+ve
Methyl red test	-ve	+ve	-ve	+ve	-ve	+ve
Voges-Proskaur	+ve	+ve	-ve	-ve	+ve	-ve
Indole test	+ve	-ve	+ve	+ve	-ve	-ve
Citrate test	_ve	_ve	+ve	_ve	+ve	+ve
Nitrate test	+ve	+ve	+ve	+ve	_ve	+ve
Urease test	_ve	+ve	_ve	_ve	+ve	_ve

Table 2: Morphological and biochemical characteristics of the isolates BT1, BT2, BT3, BT4, BT5, BT6.

Strains	Identified bacterial isolates
BT1	*Enterobacter* spp
BT2	*Staphylococcus* spp
BT3	*Pseudomonas* spp
BT4	*Escherichia* coli
BT5	*Klebsiella* spp
BT6	*Salmonella* spp

Table 3: Identification of bacterial isolates.

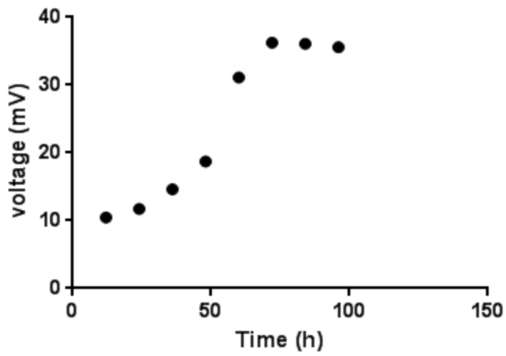

Figure 4: Variation of voltage with time using Nafion membrane.

MFC for wastewater treatment

Efficiency of MFC was studied with 500 Ω external load and operated for five days. The COD of wastewater was found to be reduced from 33.363 mg/l to 10.019 mg/l on the fifth day when cellulose acetate membrane was used. Similarly the consumption of reducing sugar also lowered from 0.105 mg/l to 0.014 mg/l on the fifth day. The result indicates the utilization of sugar present in the wastewater. Although the concentration of reducing sugar was very low in the sample it was able to produce considerable power showing that other organic matter in the wastewater has equal contribution in the production of electricity. This result is in favor of the paper reported by Youngho et al. [7] that total nitrogen was not effectively removed in continuous mode MFCs when the reactors were operated under high organic loading rates while total nitrogen removal were high in elongated fed batch mode (Figure 6).

Microbial fuel cell for power generation

Cellulose acetate membrane was found to be best in microbial fuel cell for power generation than Nafion membrane (Figures 3 and 5). The former generated power of 15.13 W/m^3 whereas Nafion membrane generated 6.25 W/m^3 only. Nafion membrane is not suitable for neutral pH and in the presence of cation species such as Na^+, K^+, and NH_4^+ (when 10^5 times higher than H^+ concentrations and are predominant in waste water) [8,9]. These species have more potential to transfer through the membrane rather than protons. This process causes pH increase in the cathode chamber. High cost of Nafion owing to the complexity of fluorine chemical structure, physical instability at the temperatures higher than 100°C are the other challenge in using Nafion as membrane material. When 1 ml/min 1% H_2O_2 was supplied in cathode with cellulose acetate membrane, power generation drastically increased [10,11]. Power reached to 24.45 W/m^3 during 24 h (Figure 7) and gradually decreased. The maximum power generated is very high comparing to the power reported by Youngho et al. [7]. The increase in power may be due to good redox activity of H_2O_2. However, the decrease in power after 24 hrs. may be due to the intolerance of microbes with H_2O_2. This study reveals to choose a new oxygen generating or redox species which help to increase power generation [12].

Conclusion

Neutral red immobilized anodic microbial fuel cell with cellulose acetate as proton transfer membrane can be a good alternative for waste water treatment and generation of power. Hydrogen peroxide has the capability of enhancing power generation. However power generation decreased after one day as it is toxic in nature. With the addition of good redox species which can be reduced easily in cathode enhances the generation of electricity. Alternatively, use of a low cost cathode electrode could be a better option for minimizing the cost of MFC.

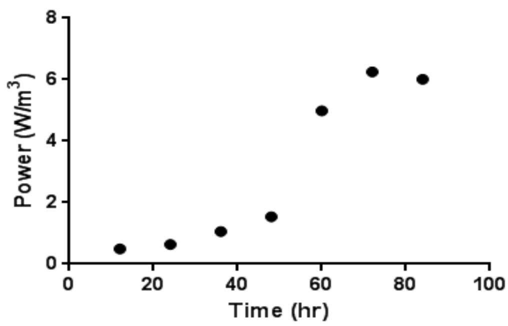

Figure 5: Power generation in MFC at different time interval using Nafion membrane.

Membrane	Maximum current(mA)	Maximum voltage(mV)	Maximum power (W/m^3)
Cellulose acetate	0.075 (5th day)	80.74 (5th day)	15.13(5th day)
Nafion membrane	0.069 (3rd day)	36.26(3rd day)	6.25(3rd day)
Cellulose acetate on addition of 1% H_2O_2	0.146 (1st day)	67.0(1st day)	24.45(1st day)

Table 4: Relative power generated by Biofuel cell at different conditions.

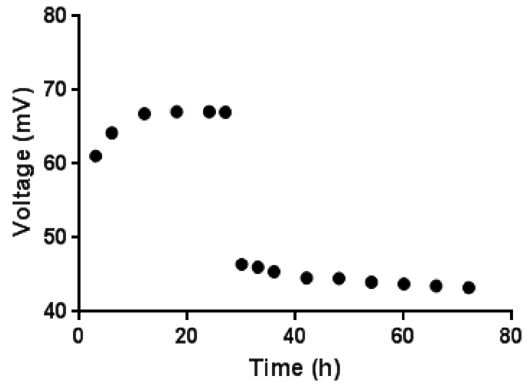

Figure 6: Variation of voltage with time using cellulose acetate membrane with 1 l/min 1% H_2O_2.

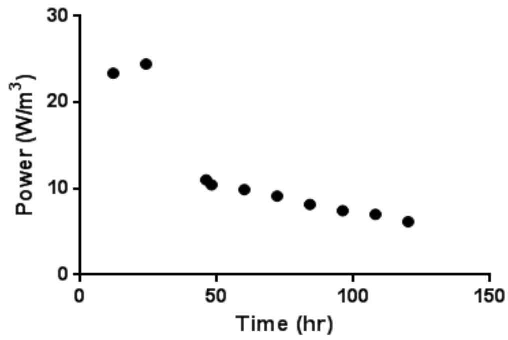

Figure 7: Power generation by MFC using cellulose acetate membrane with 1 l/min 1% H_2O_2.

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