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Microbial Fuel Cells using Mixed Cultures of Wastewater for Electricity Generation

(Sel Bahan Api Mikrob Menggunakan Air Sisa Kultur Bercampur untuk Penjanaan Tenaga Elektrik)

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ABSTRACT

Fossil fuels (petroleum, natural gas and coal) are the main resources for generating electricity. However, they have been major contributors to environmental problems. One potential alternative to explore is the use of microbial fuel cells (MFCs), which generate electricity using microorganisms. MFCs uses catalytic reactions activated by microorganisms to convert energy preserved in the chemical bonds between organic molecules into electrical energy. MFC has the ability to generate electricity during the wastewater treatment process while simultaneously treating the pollutants. This study investigated the potential of using different types of mixed cultures (raw sewage, mixed liquor from the aeration tank & return waste activated sludge) from an activated sludge treatment plant in MFCs for electricity generation and pollutant removals (COD & total kjeldahl nitrogen, TKN). The MFC in this study was designed as a dual-chambered system, in which the chambers were separated by a Nafion™ membrane using a mixed culture of wastewater as a biocatalyst. The maximum power density generated using activated sludge was 9.053 mW/cm², with 26.8% COD removal and 40% TKN removal. It is demonstrated that MFC offers great potential to optimize power generation using mixed cultures of wastewater.

Keywords: Dual-chambered system; electricity; microbial fuel cell (MFC); mixed cultures; wastewater

ABSTRAK

Bahan api fosil (petroleum, gas asli dan arang batu) merupakan sumber utama untuk menghasilkan tenaga elektrik pada masa kini. Walau bagaimanapun, bahan api ini merupakan penyumbang utama kepada masalah pencemaran alam sekitar. Salah satu pendekatan yang dilihat berpotensi untuk dikembangkan ialah penggunaan sel bahan api mikrob (MFC) untuk menghasilkan tenaga elektrik menggunakan mikroorganisma. MFC merupakan satu tindak balas katalisis mikroorganisma untuk menukarkan tenaga yang disimpan di dalam ikatan kimia organik kepada tenaga elektrik. Sel bahan api mikrob berupaya untuk menghasilkan tenaga elektrik dan pada masa yang sama dapat menyingkirkan bahan pencemar. Kajian ini adalah untuk menentukan potensi penggunaan kultur bercampur yang berbeza (kumbahan mentah, likuor campuran tangki pengudaraan dan enap cemar kumbahan yang dikitar semula) dari loji rawatan enap cemar teraktif di dalam MFC untuk menjana tenaga elektrik dan menyingkirkan bahan pencemar (COD & jumlah kjeldahl nitrogen, TKN). Di dalam kajian ini, MFC direkabentuk sebagai sistem dua kebuk dan dipisahkan oleh membran Nafion™ menggunakan air sisa kultur bercampur sebagai biokatalis. Ketumpatan tenaga maksimum yang diperoleh adalah 9.053 mW/cm² menggunakan enap cemar teraktif dengan penyingkiran COD sebanyak 26.8% dan TKN sebanyak 40%. Ini menunjukkan MFC berpotensi untuk dioptimumkan penjanaan tenaga menggunakan kultur bercampur.

Kata kunci: Air sisa; kultur bercampur; sel bahan api mikrob; sistem dua kebuk; tenaga elektrik

INTRODUCTION

The high utilization of energy around the world has contributed significantly to the energy crisis, especially from the environmental perspective. Populations have become too dependent on conventional energy sources such as coal and oil which have led to the accumulation of harmful gaseous emissions in the atmosphere. The high demand on fuels has led scientists and researchers to open a new area of research and development of renewable fuels from alternative sources. The application of microbial fuel cells (MFCs) represents a completely new approach to wastewater treatment processes while simultaneously producing sustainable clean energy.

The use of bacteria for electricity generation has been addressed by Rabaey and Verstraete (2005) who used bacteria as an electron acceptor (anode). Different metabolic pathways were used to determine the selection and performance of specific organisms. Bullen et al. (2006) extensively reviewed biofuel cells and their development. They also highlighted the application of biofuel cells in sewage treatment processes. It was noted that sewage-digesting bacteria capable of generating electricity, and the biological oxygen demand of the fuel itself could serve to maintain the system in an anaerobic state, but the levels of power for a practical system have not yet been demonstrated. The advantages of using mixed cultures in an MFC include no requirement for sterilization and the possibility of using MFC in a continuous process.

MFCs consist of three basic components, anode and cathode chambers separated by a proton exchange membrane (PEM). The anode chamber provides a sufficient medium for the growth of microorganisms, which oxidize organic matter and release electrons to the anode and protons to the cathode through metabolic reactions. The dissolved oxygen in the cathode chamber enables reactions of electrons and protons, thereby producing electricity through a wire completing the system circuit. Figure 1 shows a schematic diagram of the MFC components. The objective of this study was to investigate the performance of MFCs using different types of mixed cultures of wastewater. The performance of the MFCs was evaluated based on fuel cell power output and the removal of carbon (chemical oxygen demand, COD) and nitrogen (total kjeldahl nitrogen, TKN).

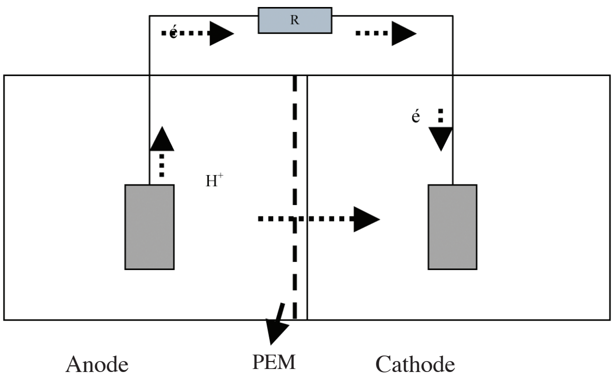

FIGURE 1. Schematic diagram of MFC components

MATERIALS AND METHOD

EXPERIMENTAL SETUP

The MFC reactor was designed and fabricated from acrylic material and consisted of two chambers (1 liter each) housing the anode and cathode compartments separated by Nafion™ membrane (D=3.6 cm). The Nafion™ sheet (Alfa Aesar, USA) was pretreated by boiling it in sequence of 30% H_2O_2, deionized water (pH 7.0), 0.5 M H_2SO_4 and again in deionized water for one hour. This process was to increase the porosity of the membrane (Mohan et al. 2008). The anode and cathode were each a single piece of carbon paper (0.5 mm thickness; Advent Research Material, England) with a surface area of 25.75 cm^2. Electrodes were placed at a distance of 7 cm and connected with copper wire. Electrodes were soaked in deionized water for a period of 24 h prior to use. The cathode chamber of the MFC was filled with phosphate buffer (50 mM, pH 7.5) as a catholyte and was continuously aerated to supply oxygen. The anode chamber was fed with a mixed culture of wastewater.

MIXED CULTURE OF WASTEWATER

The mixed culture of wastewater was collected from three different locations in an activated sludge treatment plant (raw sewage, mixed liquor from the aeration tank & return waste activated sludge). The wastewater samples had pHs ranging from 7.1 to 7.6 and CODs of 80 mg/L to 3600 mg/L. The experiments were conducted at a room temperature (30°C) in duplicate.

ANALYSES

The voltage and current were measured using a digital multimeter (BK Precision 5491A). Power density, P (W/m^2) was calculated by $P = iV/A$, where A is a surface area of the anode electrode (m), i is current (A) and V is voltage (V). Parameters such as COD, pH, suspended solids (SS) and total Kjeldahl nitrogen (TKN) were measured before and after the MFC operation according to the APHA (1998).

RESULTS AND DISCUSSION

ELECTRICITY GENERATION AND MFC PERFORMANCE

The performance of the MFC was evaluated using voltage and current production. The MFC was operated using three different substrates from raw sewage, mixed liquor from the aeration tank and return waste activated sludge. All operations were done under batch mode conditions. After inoculation, the MFC took an average of two days to reach a stable condition, with a rapid increase thereafter. A stable condition was achieved when the bacterial community found the necessary conditions to enrich and produce electricity. This occurred when biofilms accumulated at the anode surface. The maximum voltage production was achieved by the return activated sludge sample (0.63 V, 120th h), followed by the sample from the aeration tank sample (0.59 V, 264th h) and raw sewage (0.24 V, 168th h) (Figure 2). Voltage production varied with different types of samples. Those samples from the return waste activated sludge sample produced higher voltage than any other samples. Voltage generation depends on factors such as mass transfer, temperature and internal resistance (Mohan et al. 2007), with low internal resistance resulting in higher voltage generation.

Figure 3 shows that current generation increased slowly during the experiment. The peak was measured on the 12^{th} day for both samples from the aeration tank sample and return activated sludge. Raw sewage on the other hand produced a stable current ranging from 0.02 mA to 0.025 mA. This was due to the fact that electrochemically active bacteria were more dominant than methanogenic bacteria. The current decreased likely due to conditions favorable to methanogenic bacteria, namely the ranging from pH 6.8-7.2 and temperature above 20°C. Current output decreased while COD removal increased was reported by Jadhav and Ghangrekar (2009).

Referring to Figures 2, 3 and 4, return activated sludge shows better performance compared to the sample from the aeration tank and raw sewage. Therefore, the mixed culture from activated sludge offers a good substrate to explore for electricity generation even though at maximum voltage, activated sludge showed lower power density than the aeration tank sample (Table 1). Given the current profile, return activated sludge demonstrated a better performance and recorded a maximum power density of 9.053 mW/cm^2 (10th day), followed by 8.958 mW/cm^2 for the aeration tank sample (11th day). A high power density of 3986.72 mW/m^2 was previously report by You et al. (2006).

CARBON AND NITROGEN REMOVAL EFFICIENCY

Table 2 shows the results of COD and TKN removals. The data for pH and SS were also monitored before and after the MFC process. The COD removal efficiency was 26.8%, 45.8% and 50% for return activated sludge, mixed liquor from aeration tank and raw sewage, respectively. Although activated sludge can generate high power density, its ability to remove COD was lower compared to the other samples. This observable between carbon removal and electricity generation requires more study. Higher COD removal of 80% to 90% has been reported previously using single chamber and dual chambered MFC (Jadhav & Ghangrekar 2009; Liu et al. 2004). For the aeration tank sample, the effluent COD concentration was 1950 mg/L with an SS concentration of 2.18 g/L. For activated sludge, the effluent COD concentration was 1009 mg/L with an SS concentration of 4.26 g/L. For raw sewage, the effluent COD concentration was 40 mg/L with an SS concentration of 0.02 g/L. The MFC efficiency of nitrogen removal was 37.5%, 40% to 54.5% for the aeration sample, activated sludge and raw sewage, respectively. Further study is needed to increase the performance of the MFC.

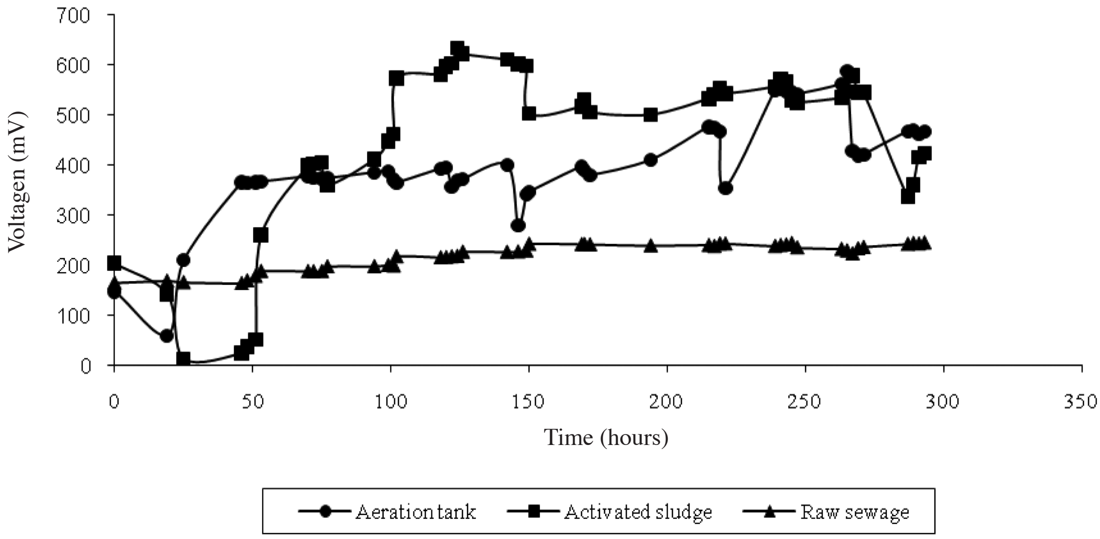

FIGURE 2. Voltage performance for different types of samples

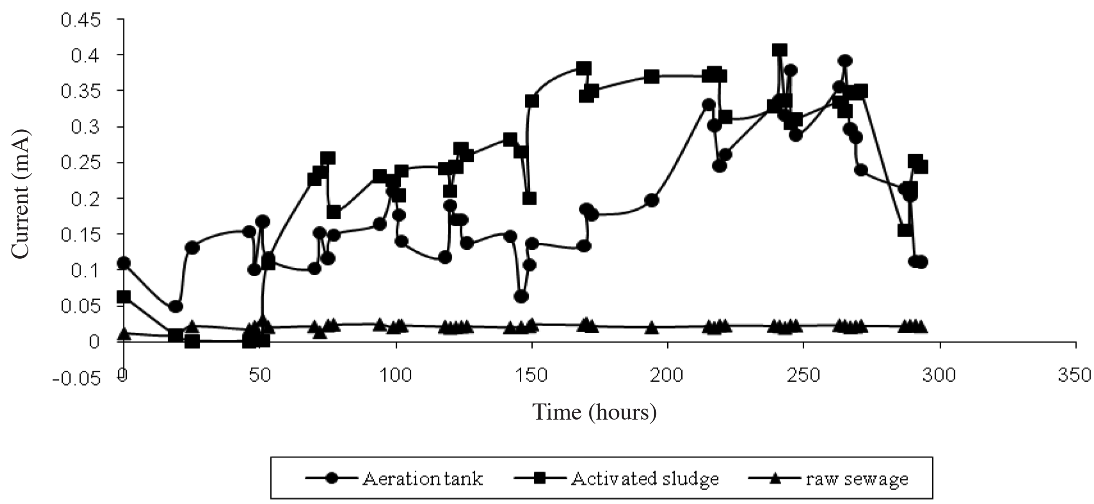

FIGURE 3. Current production for different types of samples

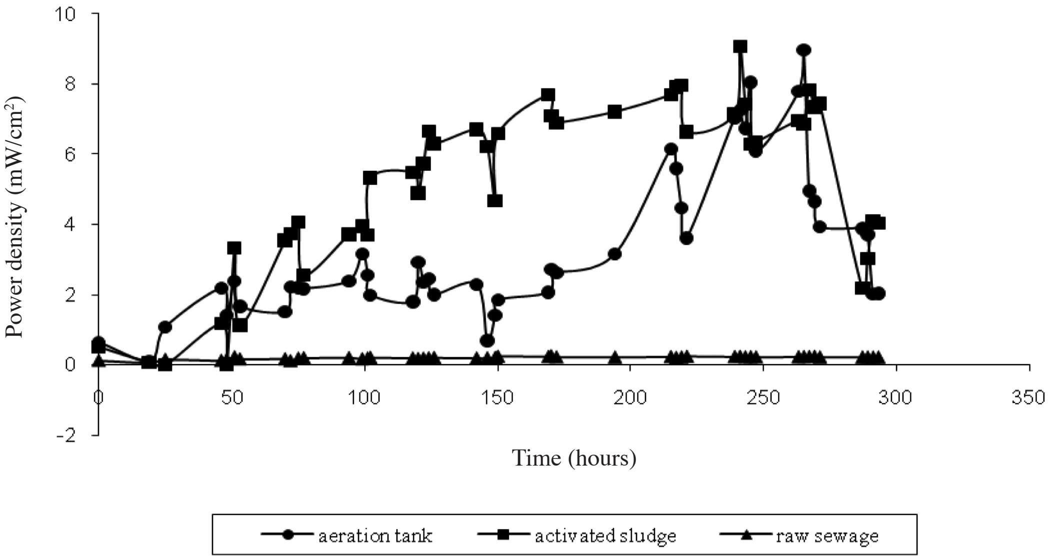

FIGURE 4. Power density profile for different types of samples

TABLE 1. MFC performance profile with respect to various parameters

Sample	pH	SS inlet (g/L)	SS outlet (g/L)	COD inlet (mg/L)	COD outlet (mg/L)	% COD removal	TKN inlet (mg/L)	TKN outlet (mg/L)	% Nitrogen removal
Mixed liquor from aeration tank	7.08-7.13	3.54	2.18	3600	1950	45.8	4.48	2.80	37.5
Return Activated sludge	6.12-6.44	6.33	4.26	1377.6	1009	26.8	5.60	3.36	40.0
Raw sewage	7.10-7.30	0.065	0.02	80	40	50.0	3.08	1.40	54.5

TABLE 2. MFC performance in the removal of COD, TKN and SS

	Sample		
	Mixed liquor from aeration tank	Return Activated sludge	Raw sewage
V_{max}(V)	0.59	0.63	0.24
Current at V_{max}	0.392	0.270	0.026
P_{max}(mW)	230.69	170.96	6.338
Powerdensity (mW/cm^2)	8.958	6.639	0.246
Current density (mA/cm^2)	0.02	0.01	0.001

CONCLUSIONS

The MFC process can stimulate the bacterial community in mixed cultures of wastewater to generate electricity. Mixed cultures from return activated sludge performed better compared to samples from an aeration tank and raw sewage. MFCs offer a promising prospect in wastewater treatment; however improvements and optimization are needed to achieve better results for electricity generation and pollutant removal.

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REFERENCES

APHA, AWWA, WPCF. 1998. *Standard Methods for Examination of Water and Wastewater* (20th Edition). American Public Health Association, Washington, DC.

Bullen, R.A., Arnot, T.C., Lakeman, J.B. & Walsh, F.C. 2006. Biofuel cells and their development. *Biosensors & Bioelectronics* 21: 2015-2045.

Jadhav, G.S. & Ghangrekar, M.M. 2009. Performance of microbial fuel cell subjected to variation in pH, temperature, external load and substrate concentration. *Bioresource Technology* 100: 717-723.

Liu, H., Ramnarayanan, R. & Logan, B. 2004. Production of electricity during wastewater treatment using single chamber microbial fuel cell. *Environ. Sci. Technol.* 38: 2281-2285.

Mohan, S.V., Saravanan, R., Raghavulu, S.V., Mohanakrishna, G. & Sarma, P.N. 2008. Bioelectricity production from wastewater treatment in dual chambered microbial fuel cell (MFC) using selectively enriched mixed microflora: Effect of catholyte. *Bioresource Technology* 99: 596-603.

Mohan, Y., Kumar, A.M.M. & Das, D. 2007. Electricity generation using microbial fuel cells. *Int. J. Hydrogen Energy* 33(1): 423-426.

Rabaey, K. & Verstraete, W. 2005. Microbial fuel cells: novel biotechnology for energy generation. *Trends in Biotechnology* 23(6): 291-298.

You, S., Zhao, Q., Zhang, J., Jiang, J. & Zhao, S. 2006. A Microbial fuel cell using permanganate as the cathodic electron acceptor. *Journal of Power Sources* 162: 1409-1415.

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