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ScienceDirect

Energy Procedia 79 (2015) 646 – 650

Energy Procedia

2015 International Conference on Alternative Energy in Developing Countries and Emerging Economies

Performance of A Membrane-Less Air-Cathode Single Chamber Microbial Fuel Cell in Electricity Generation from Distillery Wastewater

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Abstract

Distillery wastewater contains high organic compounds and nutrients suitable for microorganisms in biological processes such as microbial fuel cell (MFC) which converts the chemical energy contained in organic matter into electricity by microorganisms. The bioelectricity production during the treatment of the distillery wastewater was studied using the air-cathode SCMFCs. The distillery wastewater varied concentrations in the range of 125 to 3,000 mg COD L^{-1} and operated in fed batch mode at 37°C. The results shows that the voltage and current outputs increased with increases in distillery wastewater concentration (0.005-0.055 mA). Greater soluble chemical oxygen demand (COD_S) removal (29.5-56.7%) and total solids reduction was obtained up 35%. Indicated that the distillery wastewater can produced bioelectricity and can be treated using the membrane-less, air-cathode SCMFCs.

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE

Keywords: microbial fuel cell; membrane-less; bioelectricity; distillery wastewater; wastewater treatment

1. Introduction

Microbial fuel cells (MFC) have been developed and can generate electricity directly from almost renewable material or wastewater by using microorganisms through anaerobic condition [1]. However, the

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Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE
doi:10.1016/j.egypro.2015.11.548

amounts of current generation are depending on the types of MFCs and the sources of the substrates [2]. The air-cathode, single-chamber MFC without membrane has been developed to increase mass transfer to the cathode versus a two-chamber, reduced operating costs, and a simplified design [3, 4]. However, membrane-less air-cathode SCMFC was increased oxygen diffusion into the anode chamber, but an aerobic biofilm on the cathode surface can be help removes any oxygen that diffuses into the chamber [4].

Previous studies have focused on the MFCs to generate electricity couple with treating wastewaters, such as food processing [2], swine [5], paper recycling [6], and starch processing [3]. Thailand is the largest source of industrial and agricultural waste and wastewaters which are different characteristics and compositions. The molasses from distillery wastewater in Thailand has been rapidly expanded, and thus generates a large amount of highly polluting. The raw distillery wastewater has very high levels of chemical oxygen demand (COD) [7]. However, for the high level of COD in distillery wastewater which can be used as a source of energy for the bioelectricity production. This study focused on current generation and the treatment of distillery wastewater in membrane-less, air-cathode SCMFCs under batch mode. In addition, the work was evaluated the relationship between distillery wastewater concentrations with the current output from air-cathode SCMFC.

2. Methodology

2.1. Microbial fuel cells

Membrane-less, air-cathode, single-chamber MFCs were made of acrylic cylindrical chamber (4 cm long, 3 cm diameter and 28 mL working volume) [8]. The anode (without wet proofing; E-Tek) and the cathode (30% wet proofed; E-Tek) were made of carbon cloth (surface area = 7 cm^2) and titanium wire was connected the electrodes. The air-cathode was coating with the gas diffusion layer on the air side of the cathode and the catalyst layer on the solution side of the cathode. The catalyst layer was prepared by mixing the catalysts powder (20% of Pt/C, E-Tek, USA) loading is 0.4 mg cm^{-2} in 5 wt% Nafion solution, water and iso-propanol [8]. The air-cathode SCMFCs were enriched with the heat pretreated seed as an inoculums and the synthetic wastewater after one month in batch mode.

2.2. Distillery wastewater

The raw distillery wastewater was collected from the primary clarifier effluent of alcohol production which sugar cane molasses was used as the raw material. The characteristics of the raw distillery wastewater has very high levels of COD_T (135,000 mg L^{-1}), COD_S (131,000 mg L^{-1}), biochemical oxygen demand (70,000 mg L^{-1}), reducing sugar (16,200 mg L^{-1}), total kjeldahl nitrogen (800 mg L^{-1}), total solids (128,800 mg L^{-1}), low pH (4.35) and high temperature (70-80°C). The raw distillery wastewater was kept in a refrigerator at 4°C before use. The raw distillery wastewater was diluted to the given concentrations from 125 to 3,000 mg COD L^{-1} and the pH of the dilution was adjusted to 7.0 by using 50 mM phosphate buffer solution before being fed into the air-cathode SCMFCs. The air-cathode SCMFCs were operated at mesophilic condition (37°C) and fix external resistance 50Ω in batch mode.

2.3. Operations

The distillery wastewater was diluted to the given concentrations from 125 to 3,000 mg COD L^{-1} and the pH of the dilution was adjusted to 7.0 by using phosphate buffer solution before being fed into the air-cathode SCMFCs without additions of any other nutrient or trace metal. The air-cathode SCMFCs were operated at mesophilic condition (37°C) and fix external resistance 50Ω in fed batch mode. The liquid samples were collected at the end of each batch concentration to analyze for pH, ORP, COD_T, COD_S, reducing sugar and total solid (TS) according to the Standard Methods [9]. The volatile fatty acids (VFAs) was measured by using gas chromatography (GC).

2.4. Analytical

The voltage output was automatically recorded by a multimeter every 10 min. The current (I) was calculated using the Ohms law; $I = V / R$, the power (P) was calculated from $P = IV$, current density (mA m^{-2}) was calculated with the function of anode surface area. Volumetric power production (mW m^{-3}) was calculated based on the liquid volume of the air-cathode SCMFC. The coulombic efficiency (CE) was calculated based on current generation over time and the change in substrate concentration during a SCMFC operation (COD_S removal), so that for batch mode was calculated from $CE = \left(C_P / C_T\right) \times 100\%$ as previously reported [10].

3. Results and discussion

3.1. Influent of the distillery wastewater

The air-cathode SCMFCs were operated with varying the distillery wastewater concentrations in the batch mode. The results showed the maximum current outputs were increased in the proportion to different distillery wastewater concentration (0.005-0.055 mA) (Figure 1A). Figure 1B shows the current density and the volumetric power increased with the concentration of distillery wastewater and the maximum current density increased from 6.6-77.7 mA m^{-2}. The maximum volumetric power of 5.46 mW m^{-3} except at the highest current density. There is a good evidence for the effect of the distillery wastewater on the current generation. In addition, the calibration of maximum current outputs versus wastewater concentrations was obtained up 1,500 mg COD L^{-1} (r^2=0.99) (Figure 1A). These results are demonstrating wastewater concentration in a low ranging good correlation.

3.2. The distillery wastewater treatment

During the operation, the pH of solution decreased (6.2-6.5) from the initial pH after about 12-24 hr operation. Afterwards, the pH of solution reached to 6.7-6.9, when the voltage dropped after a long period operation. This indicated that the protons in solution were removed via the cathode reaction where they combined with oxygen from the air to produce water. The ORP values in the anode chamber were between -170 to -250 mV when the wastewater concentrations increased. The experimental showed the negative ORP values after a long period cycle operation, indicated that the system operated under anaerobic conditions. The maximum current increase when the distillery wastewater concentrations increased but the COD removal efficiency decreased. The results showed the COD_S removal efficiency was achieved at concentrations of 125-1,500 mg COD L^{-1} (30-57%). A similar trend was observed in the COD_T removal efficiency (Figure 2). However, the solids are not produced in all batches concentration tested, but the solids are reduced in all batches concentration tested (5-35%) (Figure 2). The CE increased with the wastewater concentration increase was 2.9% at the highest concentration tested. The main formic was detected in all concentrations in the range of 5-25 mmole L^{-1} and a little amount of lactic and ethanol were detected in the range of 0.6-4.5 and 0.1-0.4 mmole L^{-1}, respectively.

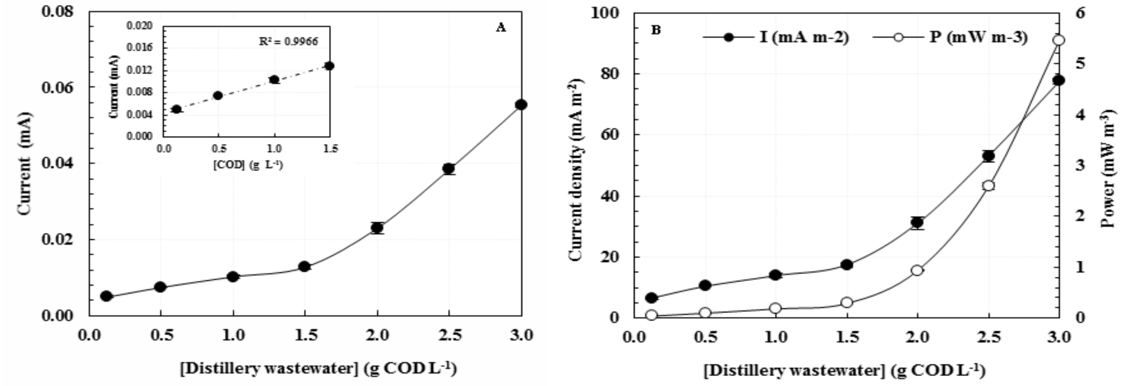

Fig. 1. Maximum current outputs (A), current density and volumetric power (B) with distillery wastewater concentrations of 125 to 3,000 mg COD L^{-1} at 50Ω. Inset: the calibration of maximum current outputs versus wastewater concentrations. The data and I-bars represent mean values and standard deviation of duplicate experiment.

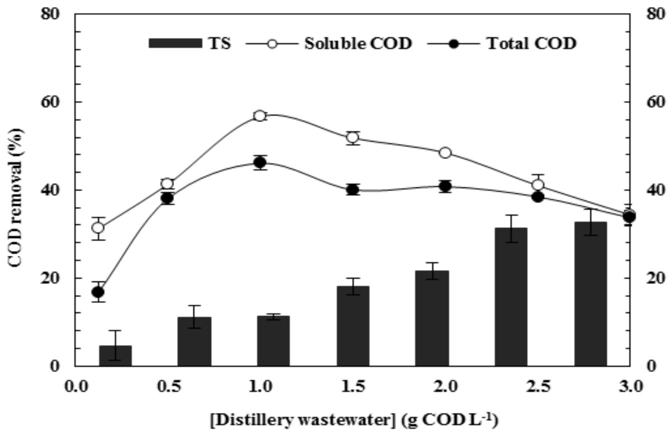

Fig. 2. The COD removal and total solids removal efficiency with distillery wastewater concentrations of 125 to 3,000 mg COD L^{-1}. The data and I-bars represent mean values and standard deviation of duplicate experiment.

4. Conclusions

The air-cathode SCMFCs using the heat pretreated seed inoculated more than one month operation were operated with the distillery wastewater showed the maximum current, volumetric power and coulombic efficiency were observed at higher distillery wastewater concentration (3,000 mg COD L^{-1}). The total and soluble COD removal efficiency were not observed and the highest COD removal efficiency efficiency at 1,000 mg COD L^{-1}.

Acknowledgements

The authors are grateful to Thailand Research Fund through the Royal Golden Jubilee Ph.D. Program (Grant No. PHD/0322/2552), Faculty of Applied Science (Grant No. 5844105), King Mongkut's University of Technology North Bangkok and the Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi for financial support.

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