Electricity generation from dairy milk factory wastewater using single chamber microbial fuel cell.

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Abstract— **The efficiency of wastewater treatment of a dairy milk industry wastewater using single chamber microbial fuel cell was examined here in terms of maximum power densities and chemical oxygen demand (COD) removal as a function of the cathode compartment aeration rate, space between anode and cathode and a hydraulic retention time (HRT). Increasing the aeration rate from 0.0 ml/min to 50 ml/min improved the maximum power density from 12.97 mW/m^2 to 25.32 mW/m^2.While decreasing the space between electrodes from 40.0 cm. to 32.5 cm. increased the maximum power density from 22.46 mW/m^2 to 27.25 mW/m^2. The COD removal efficiency decreasing from 82% to 79% as the HRT was reduced from 12.5 days to 10 days.**

Keywords: ***single chamber microbial fuel cell, electricity generation, dairy milk industry, power density***

I. INTRODUCTION

Nowadays it is recognized that the tradition dependence on fossil fuel for energy extracts a heavy cost on environment. The role of renewable energy will have significant effects on the mitigation of global environment problems. Microbial fuel cell (MFC) which is one of green technologies holds a great promise as a sustainable biotechnological solution to future energy needs and wastewater treatment [1]. By using microorganisms as a catalyst to directly generate electricity from the oxidation of organic matters or various substrates in wastewater, clean electricity and wastewater treatment can be accomplished simultaneously[2]. Waste treatment would benefit greatly if an efficient, industrial scale MFC design could be implemented for waste water treatment. This would reduce energy demands on treatment plants in addition to reducing the amount of unusable sludge produced by current anaerobic production. In general 50-90% of energy available from the oxidation of organic load in wastewater is converted to electricity in term of columbic efficiency while the remaining energy used for microbial growth [3,4,7]. Various wastewaters from different sources such as domestic wastewater [15], food processing process wastewater, agricultural wastewater, hospital wastewater , animal farm wastewater and brewery wastewater [5,6,8,10,11] have already been used successfully as substrates or fuels for MFCs.

The amount of organic load in a dairy milk industry wastewater is relatively high especially the COD which can be as high as the COD in the beer brewery wastewater [10], not only that the volume of wastewater can be as high as 2.5 times the volume of dairy milk produced. Since a dairy milk industry wastewater contains high concentrations of organic matter, it can cause considerable environmental problems if discharged without effective treatment. Over the past decades, several economically viable technological solutions have been utilized for the treatment of a dairy milk industry wastewater, including simple skimming devices, land disposal, chemical coagulation and flotation, ultra-filtration, aerobic and anaerobic biological processes and other specialized treatments. From all of these, anaerobic biological processes are most widely used because of their particular advantages, such as energy efficiency, low biomass yield, low nutrient requirement, and high volumetric organic loading. High-rate anaerobic reactors such as the up-flow anaerobic sludge blanket presently play an important role in wastewater treatment. However if the biogas produced by anaerobic reactors is not utilized but is directly discharged to the atmosphere, the greenhouse effect is likely to be exacerbated [12,13].

The large amount of organic load in a dairy milk industry wastewater makes it suitable as a fuel for the MFC. As far as simultaneously electricity generation and wastewater treatment is concerned the membrane-less MFC has a great economic potential, by eliminating an expensive membrane the overall cost of the industrial side MFC is greatly reduced. However, the major drawback of membrane-less MFC is that it can lead to a reduction of electron recovery. As the anode and the cathode sections of a membrane-less MFC act as anaerobic and aerobic reactors connected in series with no separator between them [13], membrane-less operation of MFC can cause an increased contact between oxygen from the cathode chamber and organic material in the anode chamber by diffusion. In the case of an up-flow MFC where the air is usually supplied beneath the cathode to facilitate the oxidation at the cathode however some of the oxygen in the air will diffuse down to the anode, higher the air flow rate greater the oxygen diffusion which will lead to direct aerobic conversion of the organic material. This organic material is lost and cannot be used by the electrochemically active microorganisms for current generation. The simplest method to reduce the effect of oxygen diffusion from the cathode to the anode is to increase the distance between cathode and anode. However the greater the distance between cathode and anode will increase the internal resistance of the MFC which results in the reduction of the potential output of the MFC. In order to be practical the MFC needs to be able to generate sufficient electrical power to drive the load [14,16,17,18].

The aim of this research is to investigate the effects of the air supplied flow-rates or the cathode compartment aeration rate and space between anode and cathode, hence internal resistance on power production of the MFC. Their performances were monitored at different cathode compartment aeration rate by carrying out polarization experiments, which enabled the quantification of the internal resistance under those conditions.

II. MATERIALS AND METHODS

A . Wastewater and inoculation.

Wastewater used in this study was collected from wastewater treatment pond of dairy milk factory in Khon Kean, Thailand. Anaerobic digestion and activated sludge taken from the sewage treatment plant of the factory were used as inoculums in the anode chamber of the MFC and was fed a dairy milk wastewater which has characteristics as followed: pH = 6.7$\pm$0.1, average COD = 716$\pm$51 mg /l (with standard deviation of 25.85), suspended solids (SS) 650 $\pm$28 mg/l. The wastewater supplied flow rate was fixed at 0.3 ml/min. which gives a hydraulic retention time (HRT) constant at about 13 days when configured as 5.6 liter chamber. The MFC was operated in continuous flow at room temperature (29$\pm$2.0 ^{o}C).

B. MFC construction & Operation.

A single-chamber MFC has been built from a 52cm. acrylic tube with inside diameter of 12.4 cm. and has a maximum chamber capacity of 5.6 liter during the operating. The anode is made of a 10cm.x 125cm. rectangular graphite felt of 5 mm. thick with the projected surface area of 1,250 cm^2 rolled into a solid cylinder and placed at the bottom of the acrylic tube. On top of anode is layer of glass wood and glass beads with diameter of 1 cm. to form the layer of 5 cm thickness. The cathode is made of a 5 mm. thick graphite felt disk having diameter 12 cm. The distance between the anode and cathode can be adjusted within the range of 32.5 cm. to 40 cm. The chamber capacity of the MFC is reduced to 4.7 liter when operated at the minimum electrode gap of 32.5 cm. The fuel (the wastewater) was supplied to the bottom of the anode at flow rate which can be controlled to be between 0 to 1.2 ml/min. and the effluent left through the cathode compartment at the top. The cathode compartment was aerated at the rate between 0 to 90 ml/min for the cathode reaction. The electrodes were connected to the external load and the data logger was used to record voltage, current and running time. Figure 1 shown the details of the membrane-less MFC system.

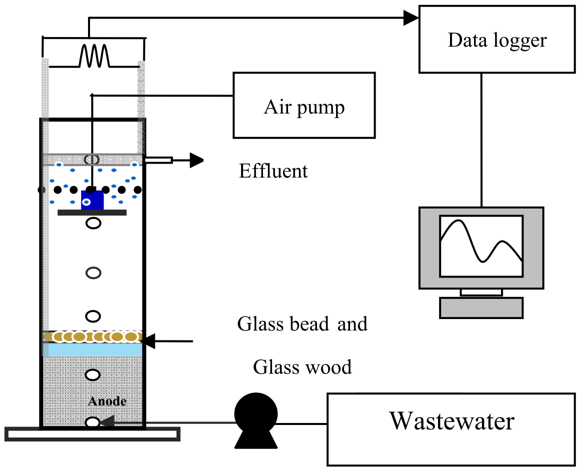

Figure 1. The Membrane-less Microbial fuel cell system

C. Analyses and calculations

The potential and current were measured using a digital multimeter with data logger and converted to power according to P = IV, where P = power (W), I = current (A), and V = voltage (V). Power density was calculated by normalizing power with respect to projected anode area (1,250 cm2). Polarization studies were carried out by varying the external resistances from 10 to 15,000 Ω. The open-circuit voltage (OCV) and short-circuit current (SCC) were also measured. The linear slopes of curve of voltage as a function of current represented the internal resistances of the MFC were determined directly from polarization curves.

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Effect of the rate of the cathode compartment aeration

In this experiment the gap between the electrodes was kept constant at 38.5 cm. at this configuration the effective volume of the MFC is 5.4 liter. The feeding rate of wastewater in this study was set to 0.3ml/min. The aeration of cathode compartment was studied at four different rates which were 0, 40, 50 and 90 ml/min. The MFC was allowed to run until reach steady state (the open circuit voltage (OCV) remained constant) before the external loads were applied and the polarization curves obtained. Figure 2 shown the polarization curves, and their corresponding power curves were shown in Figure 3 below.

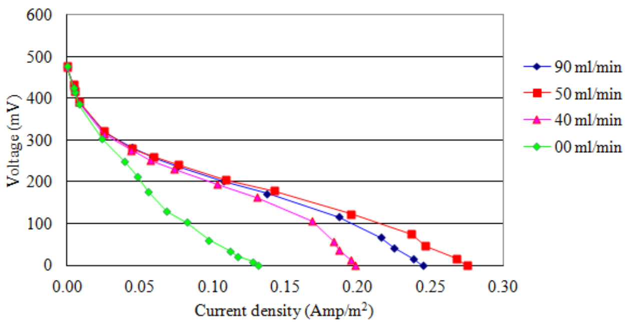

Figure 2. Polarization curves (Open circuit voltage against Intensity) and with different flow rate

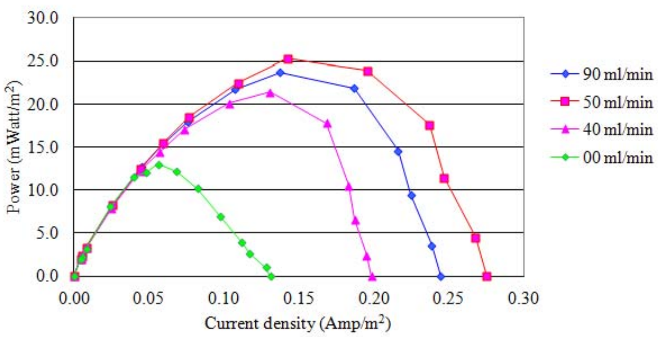

Figure 3. Power density curves with different flow rate

It can be seen from Figure 2 that the rates of the cathode compartment aeration have negligible effects on the OCV which are in the range of 474-478 mV. At the low current density (lower than 0.03 Amp/m^2) activation losses are a major contribution of the voltage potential loss. The cathode compartment aeration rate has very small effect on the polarization curve in this region this implied that most of the activation losses occur at the anode. However in the case of no cathode compartment aeration the activation losses effected the whole range of the polarization curve more strongly which can be seen from the characteristic concave of the V-I curve, in contrast to the cases where the aeration were employed in which at the intermediate current density (between 0.05-0.18 Amp/m^2) the Ohmic losses are more dominate (the linear portion of V-I curve). Since the linear slope of polarization curves represents the internal resistance of the MFC, from the slope the internal resistances of the MFC were estimated to be 14,328Ω, 8,971Ω, 7,470Ω, and 7892Ω for the cathode aeration rate of 0, 40, 50 and 90 ml/min respectively. It is worth noting that as the cathode aeration rate was increasing the internal resistance was reduced to as low as 7,470Ω at 50 ml/min cathode aeration rate before increasing to reach 7,892Ω at the 90 ml/min aeration rate. The increasing of the internal resistance at the high cathode aeration rate may result from the forming of air bubble carpet under the cathode when aeration rate is too high. The internal resistance has a direct effect on the peak power of the MFC, the experimental results show that the peak power obtained for a given aeration rate are 12.97, 21.36, 25.32 and 23.66 mW/m^2 for the aeration rate of 0, 40, 50, and 90 ml/min respectively. The reduction of internal resistance from 14,328 Ω to 7,470 Ω resulted to the increasing of the peak power from 12.97 mW/m^2 to 25.32 mW/m^2 as shown in Figure 3.

B. Effect of space between anode and cathode on the internal resistance of the MFC

The effect of space between electrodes were investigated at four different electrode gaps which were 32.5, 35.5, 38.5 and 40.0 cm. The corresponding effective capacity of the MFC were 4.7, 5.0, 5.4 and 5.6 liter respectively when configured the each electrode gap. The feeding rate of wastewater in this study was set to 0.3ml/min. as in the previous study and the cathode compartment aeration rate was kept constant at 50ml/min.

After the MFC was reaching steady state the polarization curve was obtained for each electrode gap. Figure 4 and Figure 5 shown the polarization curves of 4 different electrode gaps and their corresponding power curves respectively.

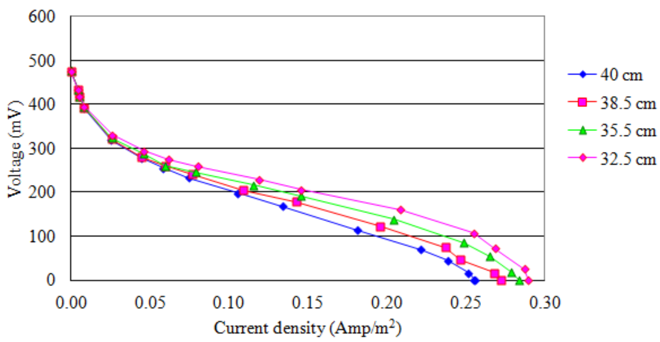

Figure 4. Polarization curves and with different electrode gap

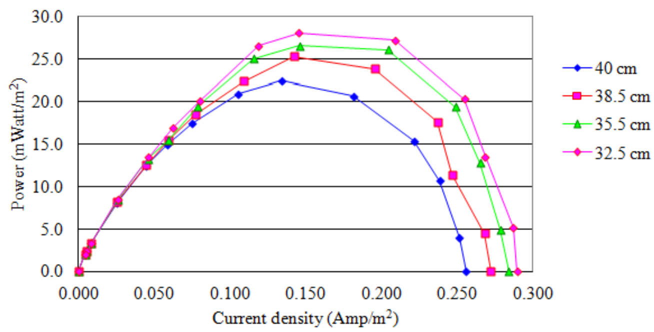

Figure 5 Power density curves with different flow rate

From the polarization curves as shown in Figure 4 ones can see that by adjusting the electrode gaps between 32.5 to 40.0 cm. in this particular design MFC did not change the characteristics of the polarization curves. All four curves show the domination of activation losses at low current density followed by Ohmic losses at the intermediate current density and at high current density the mass transport-related losses dominate. As expected the internal resistance of the MFC reduced as the electrode gaps reduced. The internal resistances were estimated to be 5,855Ω, 6,498Ω, 7,470Ω, and 8,582Ω for the electrode gaps of 32.5, 35.5, 38.5 and 40.0 cm. respectively. Since the minimum electrode gap that can be set is 32.5 cm. for this particular MFC which was relatively wide in comparison with the internal diameter of the reactor chamber of 12.4cm.no effect of oxygen diffusion from cathode to anode in the term of the reduction of peak power was detected in this study. The mass transport-relate losses as shown in the high current density portion of polarization curves (the convex portion of the curve) implied that closer the electrode gap the higher the mass transport-relate losses. However the predominant of this mass transport-relate losses may due to the reduction of the volume of the MFC chamber which reduce from 5.6 liter to 4.7 liter (16% reduction) when configured with 32.5 cm electrode gap.

In general the Ohmic resistance normalized by the active cell area (in this particular case, the projected anode area) is a function of the cell design, material choice, manufacturing technique, the electrolyte (the wastewater used) and operating conditions. As far as the peak power generation is concerned the Ohmic resistance often play a major role because the peak power usually occur at the center portion of polarization where Ohmic losses dominate. The peak power of each case is 27.25, 26.10, 25.32, and 22.46 mW/m^2 for the electrode gap of 32.5, 35.5, 38.5 and 40.0 cm respectively. From the experimental data, it was apparent that the internal resistance plays an important role in the performance of the MFC. Decreasing the internal resistance can improve the power output substantially.

C. COD removal efficiency

The MFC ability to remove the COD was investigated by setting space between anode and cathode to be 38.5 cm. at this setting the effect volume of the chamber is 5.4 liter. The chamber was filled with 5.4 liter of fresh dairy milk industry wastewater while the extra 500 ml. was filled into the influent tank, from this thank the influent was pump into the MFC at the rate of 0.3 ml/min. (432 ml/day) and the effluent was allowed to over flow in to the effluent tank. This gives a hydraulic retention time (HRT) constant at about 12.5 days. The influent was replenished by 432 ml. daily collected wastewater every morning during the period studied. The COD of both influent and effluent were measured daily.

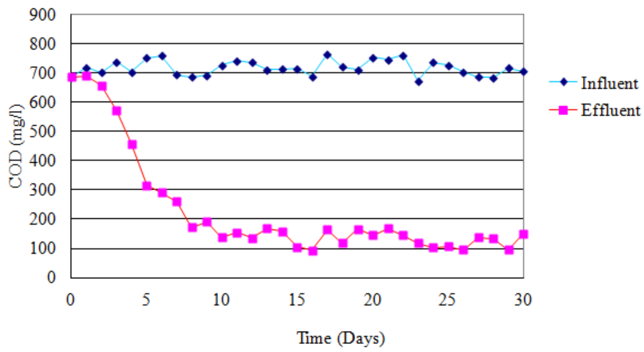

Figure 6. COD from Influent and Effluent

During the operation the aeration of cathode compartment was kept constant at 50 ml/min. And the resistance of 100Ω was connected to the MFC as the electrical external load. Fig. 6. shown the COD of both the influent and the effluent during the 30 days test period. The results showed that the COD removal of the MFC was closely related with HRT. The MFC operated at the period which is longer than the HRT (12.5 days) achieved higher and more stable COD removal efficiency compared with those operated at period shorter than the HRT. During the period of 16th to 30th day the average COD of the influent was 719.39 ml/liter while the average COD of the effluent was 129.42 ml/liter, which corresponding to the COD removal of 82%. The average voltage potential across the 100Ω external load was found to be 122 mV and the average current density was 0.20 Amp/m^2 corresponding to the average power density of 24.4 mW/m^2. However when the experiment was repeated with the setting space between anode and cathode to be 32.5 cm. which results the effect volume of the chamber was reduced to 4.7 liter. The HRT of this configuration was 10 day. The average COD of the influent was 716.57 ml/liter during the period of 16th to 30th day and the average COD of the effluent was found to be 150.48 ml/liter indicated the 79% removal of COD with average voltage, average current density and average power density of 139 mV, 0.20 Amp/m^2 and 27.2 mW/m^2 respectively. For the operation period which was longer than the HRT then the COD removal efficiency was depending upon the HRT as shown from the experimental results, by increasing the HRT from 10 days to 12.5 days the COD removal efficiency increased from 79% to 82%. Nevertheless, the increasing of HRT by keeping the influent feeding rate constant at 0.3 ml/liter involving the widering the space between electrodes in this particular designed MFC which resulted the increasing the internal resistance of the MFC and hence lower the power density of the MFC.

IV. CONCLUSION

It has shown that the Microbial fuel cell using membrane-less can produce electricity by using waste water as fuel, thus allowing energy production from abundant and inexpensive sources. However to increase the power output for applications, many technological improvement are needed. In this study the effect of the internal resistance on the performance of MFC from continuous dairy milk wastewater was demonstrated. Both distance between electrodes and the cathode compartment aerated rate have an effect on the electrochemical performance of the single chamber MFC. The result of this study reveals that:

1 The rate of the cathode compartment aeration in the single chamber membrane-less MFC is importance, and can effected the performance of the MFC.

2 The space between electrodes has influence on the internal resistance of the MFC.

3 The COD removal efficiency of the MFC depends on the HRT.

4 The dairy milk wastewater can be treated and used as fuel for the MFC.

And it showed that implementation of MFC is feasible and sustainable in nature because of the utilization of raw wastewater as substrate for in situ power generation apart from treatment

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REFERENCES

[1] S. T. Oh, J. R. Kim. G. C. Premier, T. H. Lee, C. Kim, W. T. Sloan, "Sustainable wastewater treatment: How might microbial fuel cells contribute," Biotechnology Advances, Vol. 28 (6), 2010, pp. 871-881.

[3] H. Liu, R. Ramnarayanan, and B. E. Logan, "Production of electricity during wastewater treatment using a single chamber microbial fuel," Water Sci. and Technol. Vol.38 (7), 004, pp. 2281-2285.

[4] K. Rabaey, P. Clauwaert, P. Aelterman. and W. Verstraete, "Tubular microbial fuel cell for efficient electricity generation," ,Env. Sci. and Technol., Vol. 39. 2005b, pp. 8077-8082.

[5] K. Rabaey and W.Verstraete "Microbial fuel cells: novel biotechnology for energy generation," Trends in Biotechnology, Vol. 23 (6).2005a, pp. 291-298.

[6] K. Rabaey, W. Ossieur, M. Verhaege and W. Verstraete, "Continuous microbial fuel cell convert carbohydrate to electricity," Water Sci. and Technol. Vol. 52, 2005c, pp. 515-523.

[7] D. Jiang and B. Li "Granular activated carbon single-chamber microbial fuel cells (GAC-SCMFCs): A design suitable for large-scale wastewater treatment processes," Biochemical Engineering Journal, Vol. 47 (1-3): 2009, pp. 31–37.

[8] B. Min, J. Kim, S-E Oh, J. M. Regan and B. E. Logan. "Electricity generation from swine wastewater using microbial fuel cells," Water Research, Vol.39(20), 2005, pp. 4961-4968.

[9] R.C. Wagner, J. M. Regan, S-E Oh, Y. Zuo, B. E. Logan. "Hydrogen and methane production from swine wastewater using microbial electrolysis cells," Water Research, Vol.43 (5), 2009, pp. 1480-1488.

[10] X. Wang, Y. J. Feng, H. Lee, "Electricity production from beer brewery wastewater using single chamber microbial fuel cell." Water Sci Technol. Vol. 57(7), 2008, pp.1117-1121.

[11] Q. Wen, Y. Wu, D. Cao, L. Zhao, Q. Sun, "Electricity generation and modeling of microbial fuel cell from continuous beer brewery wastewater," Bioresource Technology, Vol. 100 (18), 2009, pp. 4171-4175.

[12] Nam J.Y., Kim H.W., Lim K.H., Shin H.S. "Effects of organic loading rates on the continuous electricity generation from fermented wastewater using a single-chamber microbial fuel cell," Bioresource Technology, Vol.101(1), 2010, S33-S37.

[13] K. Holasut, K. Ngamsai, S. Wareesongnoen and K. Kumwachara, "Electricity generation from wastewater by using membrane-less single chamber microbial fuel cell," Technology and Innovation for Sustainable Development Conference (TISD 2008, at Sofitel Raja Orchid, Khon Kaen, Faculty of Engineering, Khon Kaen University, 29-28, Jan. 2008.

[14] S. Cheng, H. Liu, and B. E. Logan, "Increased Power Generation in a Continuous Flow MFC with Advective Flow through the Porous Anode and Reduced Electrode Spacing." Environmental Science & Technology, Vol. 40, 2006, pp. 2426 – 2432.

[15] Y. Ahn and B. E. Logan, "Effectiveness of domestic wastewater treatment using microbial fuel cells at ambient and mesophilic temperatures," Bioresource Technology, Vol.101, pp. 469-475, 2009.

[16] P. Aelterman, K. Rabaey, T. H. Pham, N. Boon, W. Verstraete, "Continuous electricity generation at high voltages and currents using stacked microbial fuel cells," Environ. Sci. Technol., Vol. 40, pp. 3388-3394, 2009.

[17] B. E. Logan, J. M. Regan, "Electricity-producing bacterial communities in microbial fuel cells" Trends in Microbiology, Vol.14(12), 2006, pp. 512-518.

[18] T. H. Pham, N. Boon, P. Aelterman, P. Clauwaert, L. De Schamphelaire, P. Oostreldt, K. Verbeken, W. Verstraete and K. Rabaey, "The performance of anodophilic microbial consortium in a microbial fuel cell," Microbial Biotechnology, Vol.1, 2008, pp. 487-497.