Economic Feasibility Evaluation of Simultaneous Electricity Generation and Leachate Treatment with Single-Chamber Microbial Fuel Cell

V Sawasdee

1 Lecturer of Innovation of Environmental Management, Valaya Alongkorn Rajabhat University under The Royal Patronage, Pathum Thani, Thailand
E-mail: s.vanatpornratt@gmail.com

Abstract. Bio-electrochemical technology in form of single chamber microbial fuel cell was used to simultaneous reduce organic pollutants and electricity generation under anoxic condition. Reactor was fixed working volume 1 liters. Single chamber microbial fuel cell was started with open circuit that inoculates to biofilm on anode chamber and microorganisms can be adjusted to single chamber microbial fuel cell condition. Close circuit was started with 1,000 Ω. Initial COD was converted to 5,109 mg L⁻¹ that obtained current density per area 154 mA m⁻², maximum power density per area 152 mW m⁻² and COD removal efficiency was 70%, respectively. Moreover, the economic feasibility was evaluated in term of net present value (NPV) was 1,746.20, payback period (PBP) was obtained 1 year 4 months, respectively. Therefore, single chamber microbial fuel cell is technology that suitable for simultaneous reduce organic pollutants and electricity generation.

1. Introduction
Nowadays, there are many open dumping areas in Thailand such as Sai noi and Nongkem that effect to leachate increasing. Leachate is one critical problem that cannot solve efficiently. Generally, stabilization pond or oxidation pond are solution that leachate treatment in open dumping area. The suitable technology is microbial fuel cell (MFC). MFC is bio-electrochemical technology that can be simultaneous electricity and wastewater treatment. It can be converting various of wastewater directly into electricity with exo-electrogenic bacteria [1]. MFCs system can be operated with low energy input and less excess sludge when compared to traditional technology [2]. Traditional wastewater treatment was required large investment and more excess sludge. In addition, during treatment process the greenhouse gases (CO₂, N₂O, and other volatile substances) are released into atmosphere [3]. MFCs technology has many unique advantages that sustainable pattern in wastewater treatment. MFCs are considered energy saving and environmentally friendly because it needless of maintain aeration and temperature. The treatment wastewater with MFC can be occurred in efficiently. Moreover, the operational cost was low. Therefore, these are results that MFC is suitable technology for simultaneous electricity and wastewater treatment [4].

This study aimed to evaluate the simultaneous electricity and leachate treatment with single chamber microbial fuel cell. Moreover, the economic feasibility was evaluated. The single chamber microbial fuel cell was constructed for this study. However, leachate contains not only simple substrate but also complex substrate that need to hydrolyzed and fermented. Therefore, acclimation in microbial fuel cell is important to developing microbial community that effectively electricity production from complex substrate [5].
2. Material and methods

2.1. Single chamber microbial fuel cell
This study was used single chamber microbial fuel cell of a 1 L volume (Figure 1). This model was modified from Logan [6]. Nafion 117 was used as a proton exchange membrane with effective area 0.00636 m². Proton exchange membrane is membrane that allow only proton through from anode to cathode chamber. In term of anode and cathode were made from carbon cloth [7]. Single chamber microbial fuel cell was operated with room temperature. It was operated with open circuit for acclimation and then switch to close circuit with external resistance 1,000 $\Omega$ to electricity generation and wastewater treatment.

![Figure 1. Illustration of single chamber microbial fuel cell.](image)

2.2. Leachate and inoculum
Leachate was obtained from stabilization pond, open dumping area, Sainoi Nonthaburi Province, Thailand. Leachate was used without sterilization and stored at 4 °C. Initial leachate pH was 6.5 and COD 5,109 mg L⁻¹. Inoculum was obtained from full scale up flow anaerobic sludge blanket (UASB) [8] of cassava starch, Eiamburapa Group, Sakaew Province, Thailand. Inoculum was washed with tap water and sieving by coarse mater > 0.5mm.

2.3. Chemical analysis, electrochemical and calculation
Single chamber microbial fuel cell was monitored voltage with digital multimeter (Keithley Instruments, Cleveland, OH). Current density and power density were calculated with equation (1) and (2), respectively [6].

$$I \ (m A \ m^{-2}) = \frac{V}{A \times R} \quad (1)$$

$$P \ (W \ m^{-2}) = \frac{IV}{A} \quad (2)$$

Cyclic voltammogram was measured the redox potential on electrode surface. The scanning rate for cyclic voltammetry was 20 mV s⁻¹ with three electrodes consist of working electrode, counter electrode and reference electrode [9]. COD was measures with standard method [10] using spectrophotometer. Then, COD removal efficiency was calculated.

2.4. Economic feasibility and calculation
The economic feasibility was identifying and forecasting costs and benefits in project. The consideration of costs and benefits can be showed project was interested or not. The criteria economic calculation includes net present value (NPV), benefit to cost ratio (B/C ratio), and payback period (PBP). Equation of NPV and B/C ratio were calculated with equation (3) and (4), respectively. B/C ratio is considered when B/C ratio value more than 1: project is suitable investment but value less than 1: project is not suitable investment [11].
\[ NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+i)^t} \]  
\[ \frac{B}{C} \text{ Ratio} = \frac{\text{Present value benefit}}{\text{Present value cost}} \]

In term of payback period was calculated by cumulative net present value and positive net present value. PBP is time to require the amount invested in asset to be repaid by net cash flow generated by asset.

3. Results and discussions

3.1. Electricity generation and leachate treatment

Figure 2 was showed the values of current density and power density. Before close circuit was operated that open circuit operation for developing microbial community (exo-electrogenic bacteria). Exoelectrogens mechanism is electron transfer through electrode that can be electricity generation. The maximum current and power density were 154 mA m \(^{-2}\) and 152 mW m \(^{-2}\) with COD concentration 5,109 mg L \(^{-1}\), while Wang et al [12] found that municipal wastewater can be current density production 0.06 mA m \(^{-2}\) with COD concentration 600 mg L \(^{-1}\). The inlet COD concentration should be less than 10,000 mg COD L \(^{-1}\) because exo-electrogenic bacteria can be more effective with this concentration [2]. The COD removal from leachate achieved 70% while Santos et al [13] found that vinasses wastewater can achieved COD removal efficiency 49% with microbial fuel cell. Moreover, color of leachate can be removed with single chamber microbial fuel cell.

\[ 0 \quad 20 \quad 40 \quad 60 \quad 80 \quad 100 \quad 120 \quad 140 \quad 160 \quad 180 \]
\[ 0 \quad 20 \quad 40 \quad 60 \quad 80 \quad 100 \quad 120 \quad 140 \quad 160 \quad 180 \]

**Figure 2.** Electricity generation from leachate with COD 5,109 mg L \(^{-1}\).

3.2. Cyclic Voltammetry (CV)

Cyclic Voltammetry was described electron transfer interactions between exo-electrogenic bacteria on anode that important for performance of microbial fuel cell [14]. It was identifying the activities and redox potential on anode. The growth of exo-electrogenic bacteria resulted in larger peak currents in cyclic voltammetry (Figure 3). Cyclic voltammogram peak between oxidation and reduction indicative of reversible homogeneous electrochemical reaction [1]. Therefore, cyclic voltammogram was showed a released or accumulation of electroactive material to solution that can readily oxidation on anode with exo-electrogenic bacteria.
Figure 3. Cyclic voltammogram of biofilm developed with leachate COD concentration 5,109 mg L\(^{-1}\). Anode was working electrode, cathode was counter electrode and Ag/AgCl (3M KCl) was reference electrode.

3.3. Economic feasibility

Single chamber microbial fuel cell can be electricity generation and pollution treatment. It was suggested for pilot scale microbial fuel cell. The economic feasibility was calculated in term of wastewater treatment from single chamber microbial fuel cell. The investment of single chamber microbial fuel cell was 36.50 $. Net present value (NPV) in this project is 1,746.20. Payback period (PBP) was obtained 1.4 that was 1 year 4 months. B/C ratio is greater than suggested that the single chamber microbial fuel cell is suitable investment. Therefore, the economic evaluation suggested that this project is suitable investment for energy production and leachate treatment.

4. References

[1] Friman H, Schechter A, Loffe Y, Nitzan Y, and Cahan R 2013 Current Production in a Microbial Fuel Cell using a Pure Culture of Cupriavidus basilensis Growing in Acetate or Phenol as a Carbon Source (Microbial Biotechnology) pp 1-10

[2] Sawasdee V, and Pisutpaisal N 2016 Simultaneous Pollution Treatment and Electricity Generation of Tannery Wastewater in Air-cathode Single Chamber MFC (International Journal of Hydrogen Energy vol 41) pp 15632-15637

[3] Gude VG 2016 Wastewater Treatment in Microbial Fuel Cells-An Overview (Journal of Cleaner Production) pp 287-307

[4] Liu WF, and Cheng Sa 2014 Microbial Fuel Cells for Energy Production from Wastewaters: The Way Toward Practical Application (Appl Phys & Eng vol 11) pp 841-861

[5] Park Y, Cho H, Yu J, Min B, Kim HS, Kim BG, and Lee T 2017 Response of Microbial Community Structure to Pre-Acclimation Strategies in Microbial Fuel Cells for Domestic Wastewater Treatment (Bioresource Technology vol 233) pp 176-183

[6] Logan BE 2008 Microbial Fuel Cells (The Pennsylvania State University A John Wiley & Sons, Inc Publication) New Jersey

[7] Palanisamy G, Jung HY, Sadhasivam T, Kurkuri MD, Kim SC, and Roh SH 2019 A Comprehensive Review on Microbial Fuel Cell Technologies: Processes, Utilization, and Advanced Developments in Electrodes and Membranes (Journal of Cleaner Production vol 221) pp 598-621

[8] Sawasdee V, Boonyawanich S, and Pisutpaisal N 2015 Simultaneous Treatment of Nitrogen-Rich Wastewater and Electricity Generation using Single-Chamber Microbial Fuel Cells (Energy Procedia vol 79) pp 624-628
[9] Park, Hyun D, Park YK, and So CE 2004 Application of Single-Compartment Bacteria Fuel Cell (SCBFC) Using Modified Electrode with Metal Ion to Wastewater Treatment Reactor (Journal of Microbiology and Biotechnology vol 14) pp 1120-1128

[10] APHA Standard Methods for the Examination of Waste and Wastewater 21st ed Washington DC USA: American Public Health Association, American Water Works Association, Water Environment Federation: 2005

[11] Sawasdee V, and Pisutpaisal N 2015 Economic Feasible Evaluation of Biogas Production from Napier Grass (Research Journal of Biotechnology vol 10) pp 94-98

[12] Wang X, Feng Y, Wang H, Qu Y, Yu Y, Ren N, Li N, Wang E, Lee H, Logan BE 2009 Bioaugmentation for electricity generation from corn stover biomass using microbial fuel cells (Environ. Sci. Technol. Vol 43) pp 6088–6093

[13] Santos MLV, Valadez FJR, Solis VM, Nava CG, Martell AJC, and Hensel O 2017 Performance of Microbial Fuel Cell Operated with Vinasses using Different COD Concentrations (Rev. Int. Contam. Ambie vol 33) pp 521-528

[14] Fricke K, Harnisch F and Schroder U 2008 On the Use of Cyclic Voltammetry for the Study of Anode Electron Transfer in Microbial Fuel Cell (Energy Environ Sci vol 1) pp144-147

Acknowledgments
This research was financially supported by Valaya Alongkorn Rajabhat University under The Royal Patronage, Thailand (Contract no. 03/2562).