

# Electricity Generation and Community Wastewater Treatment by Microbial Fuel Cells (MFCs)

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**Abstract.** The attractive solution to the pressing issues of energy production and community wastewater treatment was using of Microbial Fuel Cells (MFCs). The objective of this research was to study the efficiency of electricity generation and community wastewater treatment of MFCs. This study used an experimental method completely randomized design (CRD), which consisted of two treatment factors (4x5 factorial design). The first factor was different solution containing organic matter (T) and consisting of 4 level factors including T<sub>1</sub> (tap water), T<sub>2</sub> (tap water with soil), T<sub>3</sub> (50 % V/V community wastewater with soil), and T<sub>4</sub> (100% community wastewater with soil). The second factor was the time (t), consisting of 5 level factors t<sub>1</sub> (day 1), t<sub>2</sub> (day 2), t<sub>3</sub> (day 3), t<sub>4</sub> (day 4), and t<sub>5</sub> (day 5). There were 4 experimental models depending on containing organic matter (T<sub>1</sub>-T<sub>4</sub>). The parameter measured consisted of Open Circuit Voltage (OCV), Chemical Oxygen Demand (COD), Total Dissolve Solid (TDS), acidity (pH), Electric Conductivity (EC) and number of bacteria. Data were analysed by ANOVA, followed by Duncan test. The results of this study showed that, the T<sub>3</sub> was the highest voltage at 0.816 V (P<0.05) and T<sub>4</sub>, T<sub>2</sub>, and T<sub>1</sub> were 0.800, 0.797 and 0.747 V, respectively. The T<sub>3</sub> was the lowest COD at 24.120 mg/L and T<sub>4</sub> was 38.067 mg/L (P<0.05). The best model for electricity generation and community wastewater treatment by Microbial Fuel Cells was T<sub>3</sub>. This model generated highest voltage at 0.816 V, and reduction of COD at 46.215%.

## 1. Introduction

Increasing scarcity of water and decreasing energy sources have been regular phenomenon in recent days [1]. Both water quantity and quality are the biggest environmental problems. Rapid population increased in urban areas and industrialization has raised the concern about appropriate wastewater management practices [2]. Surface waters are being polluted by means of wastes or effluent discharge from the industries, domestic sewage, and municipal wastes etc. Further, land application of wastewaters is now becoming one of the most economically and ecologically viable method of disposal of this water. With rapid expansion of cities and domestic water supply, quantity of grey/wastewater is increasing in the same proportion. Overall analysis of water resource indicates that in coming years, these will be a twin edged problem to deal with deduced fresh water availability and increased wastewater generation. Like water problem, energy source scarcity is serious problem. Because the world's known oil and gas reserves are not infinite, it is necessary to evaluated alternative and renewable energy sources such as wind, solar and hydropower [3]. Energy efficiency and demand-side management—doing more with less, reducing energy consumption by substituting fuels and technologies and altering consumer behaviour is clearly the most environmentally being way to



address increases in demand for energy services. Energy efficiency can include practices as diverse as switching from conventional coal power plants to combined heat and power units, lowering thermostats, better maintaining industrial boilers, and walking or cycling instead of driving. These actions not only involve very little damage to the environment [4]. Energy conservation seems to be the most effective method to mitigate both air pollution and greenhouse gases. Energy conservation measures such as demand side management have been attempted at national level. However, management development, transfers of better energy conservation technologies are still needed for further control of energy consumption and emission. Because of both serious environmental problems, microbial fuel cell (MFC) is the best optimization way for water and energy management. Microbial fuel cells provide a method of adding wastewater to the list of renew energy source. Microbial fuel cells (MFCs) provide new opportunities for the sustainable production of energy from biodegradable, reduced compounds. MFCs functions on different carbohydrates but also on complex substrates present in wastewaters [5]. As yet there is limited information available about the energy metabolism and nature of the bacteria using the anode as electron acceptor; few electron transfer mechanisms have been established unequivocally [6]. To optimize and develop energy production by MFCs fully this knowledge is essential. Depending on the operational parameters of the MFCs, different metabolic pathways are used by the bacteria. This determines the selection and performance of specific organisms. The MFCs technology is evaluated relative to current alternatives for energy generation. The objective of the research is to study the efficiency of electricity generation and community wastewater treatment of MFCs.

## **2. Materials and methods**

### *2.1. Construction and designs*

The sixty microbial fuel cell (MFC) was single chamber cell and were based on anode and cathode compartment. The chamber was a glass test tube (25 x 150 mm). The anode electrode was a copper plate felt on the bottom (1x7 cm), and connected with a 20 cm copper wire that used for voltage measurement. The cathode electrode was zinc plate with 1 x7 cm. The end of zinc plate was dipped in the liquid and the other side was connected with the top of the chamber.

### *2.2. Experimental design*

The experiment was conducted using two factorials completely randomize design with three replications. The 1<sup>st</sup> factor was different solution containing organic matter (T), consisted of 4 levels, the 2<sup>nd</sup> was the time, and consisted of 5 levels sampling time, namely: Factor ( $t_1$ : day 1), ( $t_2$ : day 2), ( $t_3$ : day 3), ( $t_4$ : day 4), and ( $t_5$ : day 5). All of MFCs were tested in the same environment and were filled with different solution. The whole treatment consisted in:

2.2.1. ( $T_1$ ): 55 ml of tap water

2.2.2. ( $T_2$ ): 45 ml of tap water + 20 grams of soil

2.2.3. ( $T_3$ ): 45 ml of 50% v/v community wastewater + 20 grams of soil

2.2.4. ( $T_4$ ): 45 ml of 100% v/v community wastewater + 20 grams of soil

### *2.3. Parameter measurement and statistical analysis*

Parameter measured consisted of Open Circuit Voltage (OCV), Chemical Oxygen Demand (COD), acidity (pH), Electrical Conductivity (EC) and Total Dissolve Solid (TDS). The experimental data obtained and analysed by using analysis of variance (ANOVA). If there was a real effect then continued with multiple range test (Duncan) with a significance level of 0.05.

## **3. Results and discussion**

### 3.1. Soil properties.

Ampawa soil series from Samut Songkram province, Thailand, was used in this experiment due to properties of soil. The outstanding characteristic of this soil was silty clay loam (SiCL) that suitable for anaerobic bacteria activity. Initial properties of the soil were analyzed before the initiation of the experiment and were presented in Table 1.

**Table 1.** Soil properties.

Soil properties	Unit
Soil texture	silly clay loam (SiCL)
Sand (%)	16
Silt (%)	45
Clay (%)	39
pH	7.6
Organic matters (mg/L)	2.4
Phosphorus (mg/kg)	86.9
Potassium (mg/kg)	10.1
Calcium (mg/kg)	417.3
Magnesium (mg/kg)	29.5

Table 1 shown that soil particle of this experiment was silty clay loam (sand: silt: clay = 16:45:39). They were high phosphorus and organic matters, moderate calcium and low magnesium and potassium.

### 3.2 Community wastewater

Water from Saen Seab Canal, Thailand, was represented community wastewater in this study due to water quality analysis. The pollution control department of Thailand insisted that people should not use this water for drinking without high standard treatment process and treatment for drinking or bathing was worthless. The same water qualities were shown in Table 2.

**Table 2.** Community wastewater quality.

Parameters	Unit
Temperature (C)	28
pH	7.2
EC (uS/cm)	288
TDS (mg/L)	142
COD (mg/L)	36

### 3.3 Production of voltage

Data was collected from MFCs after one day of bacterial growth. A multi-meter was connected to each MFC and the initial voltage and current reading were taken.

**Table 3.** Duncan's multiple rang test of production of voltage over time

Design Number	Voltage (V)					
	day 1	day 2	day 3	day 4	day 5	Mean
T <sub>1</sub>	0.929	0.936	0.645	0.613	0.615	0.747 <sup>b</sup>
T <sub>2</sub>	0.886	0.785	0.760	0.801	0.757	0.797 <sup>a</sup>

T <sub>3</sub>	0.891	0.838	0.816	0.817	0.717	0.816 <sup>a</sup>
T <sub>4</sub>	0.776	0.821	0.811	0.811	0.780	0.800 <sup>a</sup>
Mean	0.870 <sup>a</sup>	0.845 <sup>b</sup>	0.758 <sup>c</sup>	0.760 <sup>c</sup>	0.717 <sup>d</sup>	

Note: Difference letters indicate there are significant differences

T<sub>1</sub>: MFC with 55 ml of tap water

T<sub>2</sub>: MFC with 45 ml of tap water + 20 grams of soil

T<sub>3</sub>: MFC with 45 ml of 50% v/v community wastewater + 20 grams of soil

T<sub>4</sub>: MFC with 45 ml of community wastewater + 20 grams of soil

The Table 3 showed that, the average cell voltage of day 1 was significantly higher than day 2, 3, 4 and 5 ( $P < 0.05$ ) at 0.870, 0.845, 0.758, 0.760 and 0.717 V, respectively because of microbial activity. This showed that microorganism could degrade organic matter in the community wastewater into CO<sub>2</sub>, H<sub>2</sub>O and also electron [7]. Electrons produced by bacteria from substrates are transferred to the anode and flow to the cathode to produce electricity. Bacteria need energy source for growing and increasing then over time, the nutrient is reduced [8]. Therefore, it can be conducted that increasing time can reduce amount of voltage.

The average cell voltage of T<sub>3</sub>, T<sub>4</sub> and T<sub>2</sub> were significantly higher than T<sub>1</sub> ( $P < 0.05$ ) at 0.816, 0.800, 0.797 and 0.747 V, respectively, because of soil property. This showed that soil structure include minerals and nutrients that support microbial activity. Microorganisms oxidize the organic matter in wastewater and transfer the electrons to the anode [9]. The hydrogen ions produced by the oxidation half reaction pass through the cathode compartment where they reduced oxygen to water (the reduction half reaction). As a result of these two half reaction, a potential difference develops between the anode and the cathode and current flows in the external circuit [10]. Therefore, it can be conducted that soil component can effected amount of voltage.

### 3.4 Community wastewater improvement

The chemical oxygen demand (COD) was determined by open flux method as described by Tendon. The total dissolve solid (TDS), Electricity Conductivity (EC) and acidity (pH) of water were analysed immediately after bringing the samples to the laboratory and the results as showed in Table 4.

**Table 4.** Duncan' s multiple rang test of water quality over time

Design Number	Chemical Oxygen Demand (mg/L)						Percentage decline in the value
	day 1	day 2	day 3	day 4	day 5	Mean	
T <sub>1</sub>	0.000	0.000	0.000	0.000	0.000	0.000 <sup>a</sup>	0.000
T <sub>2</sub>	0.000	0.000	0.000	0.000	0.000	0.000 <sup>a</sup>	0.000
T <sub>3</sub>	35.267	20.800	22.933	20.800	20.800	24.120 <sup>b</sup>	41.000
T <sub>4</sub>	42.533	38.933	36.800	36.800	35.267	38.067 <sup>c</sup>	17.000
Mean	19.450 <sup>b</sup>	14.933 <sup>a</sup>	14.933 <sup>a</sup>	14.400 <sup>a</sup>	14.017 <sup>a</sup>		
Design Number	Total Dissolve Solid (TDS (mg/L))						Percentage decline in the value
	day 1	day 2	day 3	day 4	day 5	Mean	
T <sub>1</sub>	52.667	48.000	10.667	10.333	12.333	26.800 <sup>d</sup>	
T <sub>2</sub>	39.000	62.000	78.000	95.333	116.333	78.133 <sup>c</sup>	
T <sub>3</sub>	184.000	197.667	213.667	214.667	229.000	207.800 <sup>b</sup>	
T <sub>4</sub>	207.333	205.667	233.000	247.667	251.333	229.000 <sup>a</sup>	
Mean	120.750 <sup>e</sup>	128.333 <sup>d</sup>	133.833 <sup>c</sup>	142.000 <sup>b</sup>	152.250 <sup>a</sup>		
Design Number	Electric Conductivity (EC (mS/cm))						Percentage decline in the value
	day 1	day 2	day 3	day 4	day 5	Mean	
T <sub>1</sub>	106.667	96.000	21.333	21.333	24.667	54.000 <sup>d</sup>	
T <sub>2</sub>	78.000	124.000	156.000	190.000	232.667	156.133 <sup>c</sup>	
T <sub>3</sub>	368.000	392.000	427.333	430.000	456.667	414.800 <sup>b</sup>	
T <sub>4</sub>	414.667	413.333	466.000	492.667	502.667	457.867 <sup>a</sup>	
Mean	241.833 <sup>e</sup>	256.333 <sup>d</sup>	267.667 <sup>c</sup>	283.500 <sup>b</sup>	304.167 <sup>a</sup>		
Design Number	pH						Percentage decline in the value
	day 1	day 2	day 3	day 4	day 5	Mean	
T <sub>1</sub>	7.523	7.550	8.300	8.467	9.100	8.188 <sup>a</sup>	
T <sub>2</sub>	7.683	7.480	7.647	7.997	8.187	7.799 <sup>b</sup>	
T <sub>3</sub>	7.380	7.350	7.707	7.833	8.033	7.661 <sup>c</sup>	
T <sub>4</sub>	7.523	7.637	7.797	7.643	8.047	7.729 <sup>b</sup>	
Mean	7.528 <sup>d</sup>	7.504 <sup>d</sup>	7.862 <sup>c</sup>	7.985 <sup>b</sup>	8.342 <sup>a</sup>		

Note: Difference letters indicate there are significant differences

T<sub>1</sub>: MFC with 55 ml of tap water

T<sub>2</sub>: MFC with 45 ml of tap water + 20 grams of soil

T<sub>3</sub>: MFC with 45 ml of 50% v/v community wastewater + 20 grams of soil

T<sub>4</sub>: MFC with 45 ml of community wastewater + 20 grams of soil

Based on Table 4, the chemical oxygen demand of day 5, 4, 3 and day 2 were non significance but they were significantly lower than day1 (P<0.05). The COD of day 1 was the highest at 19.450 mg/L then reducing steadily to 14.933, 14.933, 14.400 and 14.017 mg/L, respectively, due to limiting of microbial degradation [11]. Because the microbial fuel cell generated electricity by anaerobic process, microorganism in this experiment is anaerobic or facultative aerobic bacteria. Both types of bacteria are not potential to oxidize organic compounds chemically that concentration in community

wastewater [12]. Therefore, it can be conducted that increasing experimental time cannot reduce value of COD.

The COD level observation of  $T_4$  was significantly higher than  $T_3$  ( $P < 0.05$ ) at 38.067 and 24.120 mg/L, respectively, due to initiative substrate concentration [13]. The  $T_3$  was able to reduce the COD level high at 41% followed by  $T_4$  which was able to reduce at 17%.

The Total Dissolves Solid value of day 5 was significantly higher than day 4, 3, 2 and 1 ( $P < 0.05$ ) at 152.250, 142.000, 133.833, 128.333 and 120.750 mg/L, respectively, because of zinc corrosion. The TDS value increased steadily overtime because zinc ion passes through the anode compartment. The anode compartment contain high dissolve solid [14]. Therefore, it can be conducted that increased experimental time can affect the TDS value.

The TDS value of  $T_4$  was significantly higher than  $T_3$ ,  $T_2$  and  $T_1$  at 299.000, 207.800, 78.133 and 26.800 mg/L ( $P < 0.05$ ), respectively, due to soil property [15]. There are a lot of not only positive charges such as potassium, sodium, hydrogen, calcium and magnesium but also negative charges such as nitrate and sulfate in soil. Both ions suspend in compartment that cause all treatment with soil was high TDS value.

The Electric Conductivity value of day 5 was significantly higher than day 4, 3, 2 and 1 ( $P < 0.05$ ) at 304.167, 283.500, 267.667, 256.333 and 241.833 mg/L, respectively, due to zinc corrosion [16]. As same as TDS value, the EC value increased steadily overtime because zinc ion passes through the anode compartment. The anode compartment contain with high ion and increasing EC value [14].

The EC value of  $T_4$  was significantly higher than  $T_3$ ,  $T_2$  and  $T_1$  ( $P < 0.05$ ) at 457.867, 414.800, 156.133 and 54.000 mg/L, respectively, because of ion absorption [17]. The soil particle due to the presence of charges absorbs and exchange ions in solution. When zinc ion is added to water, by corrosion, it is adsorbed on the charge of soil particle. Therefore, it can be conducted that soil was important effect on EC value [18].

The pH value of day 5 was significantly higher than day 4, 3, 2 and 1 ( $P < 0.05$ ) at 8.642, 7.985, 7.863, 7.504 and 7.528, respectively, due to microbial activity [15]. Anaerobic bacteria break down organic matter in community wastewater and produce proton, electrons, alcohol and carbon dioxide. The anaerobic products are used to convert to carbonate compound such as calcium carbonate, zinc carbonate that increasing pH value [19].

The pH value of  $T_1$  was significantly higher than  $T_2$ ,  $T_4$  and  $T_3$ , ( $P < 0.05$ ) at 8.188, 7.799, 7.729 and 7.661, respectively, due to soil property. Like TDS and EC, dissolve cations organic matter were absorbed by soil particle. Because of pH buffer of soil property, the pH value of  $T_2$ ,  $T_4$  and  $T_3$  which contain soil in anode chamber were slightly changed [20].

#### 4. Conclusion

The objective of this research was to study the efficiency of electricity generation and water treatment of Saen Saeb Canal by Microbial Fuel Cells (MFCs). The experimental period was 4 month and collecting data in 5 days. This study used an experimental method completely randomized design (CRD), which consisted of two treatment factors (4x5 factorial design). The first factor was different solution containing organic matter (T) and consisting of 4 level factors including  $T_1$  (tap water),  $T_2$  (tap water with soil),  $T_3$  (1:1 tap water: water from Saen Saeb Canal with soil) and  $T_4$  (water from Saen Saeb Canal with soil). The second factor was the time (t), consisting of 5 level factors  $t_1$  (day 1),  $t_2$  (day 2),  $t_3$  (day 3),  $t_4$  (day 4) and  $t_5$  (day 5). There were 4 experimental models depending on containing organic matter ( $T_1$ – $T_4$ ). The parameter measured consisted of Open Circuit Voltage (OCV), Chemical Oxygen Demand (COD), Total Dissolve Solid (TDS), acidity (pH) and Electric Conductivity (EC). Data were analysed by ANOVA, followed by Duncan test. The results of this study showed that, the  $T_3$  was the highest voltage at 0.81 V and  $T_4$ ,  $T_2$  and  $T_1$  were 0.80, 0.79 and 0.74 V, respectively. The  $T_3$  was the lowest COD at 24 mg/L and  $T_4$  was 38 mg/L. The  $T_1$  was the lowest TDS at 27 mg/L and  $T_2$ ,  $T_3$  and  $T_4$  were 78, 208 and 299 mg/L, respectively. The  $T_3$  was the lowest pH value at 7.7 and  $T_4$ ,  $T_2$  and  $T_1$  were 7.7, 7.8 and 8.2, respectively. The  $T_1$  was the lowest EC value at 54  $\mu\text{S}/\text{cm}$  and  $T_2$ ,  $T_3$  and  $T_4$  were 156, 415 and 458  $\mu\text{S}/\text{cm}$ , respectively ( $P < 0.05$ ). The best model for electricity generated and water treatment of Saen Saeb Canal by Microbial Fuel was  $T_3$ . This model generated highest voltage at 0.81 V and reduction of COD at 46.215%.



## 5. Acknowledgments

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## 6. References

- [1] Jogan H and Dasog G S 2015 *Karnataka J. Agric. Sci.* 28(4) 518
- [2] Wibulswas P 2004 *Asian J. Energy Environ.* 5(4) 285
- [3] Patra A 2008 *SJWP* 1 72
- [4] Koyama K 2014 *EIIJ* 1 1
- [5] Bruce E L, Bert H, Rene R, Uwe S, Jurg K, Stefano F, Peter A, Willy V and Korneel R 2006 *Environ. Sci. Technol.* 40(17) 5181
- [6] Korneel R and Verstraete W 2005 *Trend Biotechnol* 23(6) 291
- [7] Devid P B T S, Hemelers H V M, Jan F H S and Cees J. N. B. 2008 *Int. J. Energy Res.* 32(9) 870
- [8] Zhenhua G, Wu H, Shi L, Zhang X, Sheng, Yin F and Gooneratne R 2017 *Anim. Nutri.* 3 109
- [9] Logan B E and Regan J M 2006 *Environ. Sci. Technol.* 1 5172
- [10] Nattawut K and Kanyarat H 2015 *KKU Engineering Journal* 42(1) 117
- [11] Pongludda P Weerasak S and Chanchainarong S 2012 *RMUJ* 6(1) 129
- [12] Muhammad A Abdul N and Harroon R 2016 *J. Agric. Res.* 54(1) 97
- [13] Younghyun P, Cho H, Yu J, Min B, Kim H S, Kim B G and Lee T 2017 *Bioresour. Technol.* 233 176
- [14] Hassana L M, Bruggen JJA V and Lens P N L 2015 *Ecol Eng* 84 588
- [15] Irene M U, Kennedy A C and Muzika R M 1009 *Appl. Soil Ecol* 42 1
- [16] Payel C, Uddy U S P, Mahata N, Tiwari O N, Ray R N, Bandyopdhyay T K and Bhunia B 2017 *Renew. Sustainable Energy Rev.* 79 372
- [17] Abbasi H, Salehi S, Ghorbani R, Torabi F and Amidpour M 2013 *IJEE* 4(2) 110
- [18] Irene M U, Motavalli P P and Muzika R M 2009 *Agric. Ecosyst. Environ.* 131 105
- [19] Sara M, Angelo A D, Scialdone O, Canizares P, Rodrigo M A and Morales F J F 2017 *Biochem. Eng. J.* 123 38
- [20] Zhang P, Zhang J, Pan G, Ahang X, Li L and Tippkötter R 2007 *Colloids Surf B Biointerfaces* 58 264