

Tofu wastewater treatment by sediment microbial fuel cells

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Abstract. This research aimed to measure power density generated by sediment microbial fuel cells (SMFCs) by varying anode position and wastewater concentration. Anode position was varied at 2 cm and 4 cm under the surface of sediment, while wastewater concentration varied into 25%, 50%, 75% and 100%. The electrodes employed was stainless steel mesh, while the organic substrate source was taken from wastewater of soybean washing and boiling process. The sediment was taken from the Lamnyong River around the outlet of tofu industry wastewater. SMFCs was run until the power density was relatively small. The produced electricity represented in power density. The results of this research showed that power density was decreased over time. Generated power density by varying 2 cm and 4 cm position of anode under the sediment surface was not significantly different, while the lowest wastewater concentration, 25%, gave the highest power density.

1. Introduction

The volume of wastewater from 8400 tofu industries across Indonesia in 2010 reached the number of 20 million m³^[2]. Most tofu industries in Indonesia are home scale industries which have minimum wastewater treatment installation. They usually let the wastewater flow into the river.

Table 1. Tofu industry wastewater parameters and quality standards.

Parameters	Concentration (mg/L)	
	Tofu industry in Banda Aceh ^[2]	Quality standards ^[3]
BOD	4415.5	150
COD	8500	300
TSS	841	200

With the BOD, COD and TSS levels above the quality standard as be shown in Table 1, the tofu wastewater can potentially pollute the environment and harm people's health. Tofu wastewater comes from boiling, filtering, pressing, and washing process of soybean. The wastewater contains organic compounds such as protein, carbohydrate and fat^[4,5].

The most appropriate wastewater treatment installation to most tofu industries in Indonesia is the most convenient and cost effective method. The conventional methods of tofu wastewater treatment utilized are aerobic^[6] and anaerobic^[1] processes. Both of those processes are giving side effects;

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aerobic process requires wide pond area and energy to run aeration pump, while anaerobic process produces methane that will pollute environment. By those considerations, the previous methods are ineffective. Microbial fuel cells (MFCs) is a new technology that can provide solution for wastewater treatment problem of tofu industry in Indonesia, as this process requires small area, no energy input, no by side product, and another advantage is MFCs can produces electrical energy.

SMFCs is one type of MFCs that takes advantage of metabolic activity of bacteria present in sediment to develop energy while degrading organic compound. According to current SMFCs researches, the primary focus of the study is to obtain higher energy, but not many of them take SMFCs application to treat wastewater as center of interest[14]. By advocating SMFCs method to treat tofu wastewater, not only it will reduce the pollution, but also it will produce electricity as well.

Several factors affecting SMFCs performance are materials and arrangement of electrodes[8]. Carbon and stainless steel are the most common materials used, whether use in one or both electrodes[9]. Stainless steel that is more robust and relatively cheaper than carbon is more applicative to be used in SMFCs to treat wastewater of home scale tofu industry. Stainless steel mesh (SSM) size chosen is 40 mesh type 304 which is the alloy of 18% chromium and 8% nickel. This choice is based on the result of research done by Zhang et al.[9], where the highest power density obtained is from SSM size of 30 mesh, small difference from 50 mesh, and the power density is linearly decreasing as the SSM size is smaller (70 mesh, 90 mesh and 120 mesh).

Based on Huang et al.[11], the most suitable internal resistor will give the highest power. Thus, in this research, the selection of the optimum internal resistance is completed using potentiometric test, where it will give the highest electric power.

High substrate concentration is also adequate to increase electric power in certain condition, that is because higher concentration will facilitate proton transfer to cathode surface[12]. High concentration also means more organic material to be degraded by microbial activity, thus more electric potential can be obtained[13].

Therefore, the objective of this study is to learn the effectivity of SMFCs in treating wastewater of tofu industry, SMFCs performance in decreasing COD level of wastewater, and the effect of anode position and wastewater concentration in developing power density obtained.

2. Materials and method

2.1. Preparation of SMFCs reactor

SMFCs reactor consisted of easily obtained materials, glass jar with volume of 0.5 L and 5 cm x 5 cm stainless steel wire 40 mesh as the electrodes. Electrodes consisted of anode and cathode. While anode was put in the sediment, cathode was put in the wastewater. Both electrodes were connected by electrical wire to facilitate electron transfer. The sediment was collected near the wastewater outlet on Lamnyong River where tofu industries flow their wastewater into. The first pretreatment was sieving the sediment using 5mm-opening wire to separate gravel and rubbish. It was then left for 24 hours to minimize water content. Then, the treated sediment was put into the jar.

Wastewater was collected from soybean boiling water and washing process in tofu industry around Lamnyong River. Collected wastewater was then varied into several concentrations and poured into each jar.

2.2. Tofu wastewater treatment using SMFCs

In this study, the thickness of sediment was set to 4 cm from the bottom of the reactor, while the height of wastewater was 4 cm from top of the sediment. To learn the effect of anode position in degrading COD and producing electric power, the anode position was varied on 2 cm and 4 cm from top of sediment. On the other side, cathode position was fixed on 2 cm from wastewater surface. This point will give the maximum power, as the dissolved oxygen level is stable to accommodate reaction at cathode surface. This is because when cathode too close to wastewater surface or too deep the

SMFCs performance will be affected by dissolved oxygen deficiency due to evaporation and depth factor [14].

The effect of wastewater concentration was studied by varying the concentration into 25%, 50%, 75% and 100%. After electrodes, sediment and wastewater were set, cables from anode and cathode were attached with 50k Ω resistor and datalogger DATAQ DI-710 to record electricity generated over time.

Efficiency of SMFCs is determined from COD removal in wastewater. COD was analyzed using titrimetric method. The COD removal efficiency is calculated using Equation 1.

$$\text{COD removal} = \frac{\text{COD}_{\text{initial}} - \text{COD}_{\text{final}}}{\text{COD}_{\text{initial}}} \times 100\% \quad (1)$$

To compare SMFCs performance, control reactor was used for each variation. The control reactor use the same equipment but electrodes, thus in terms of reducing wastewater, the process was conducted aerobically and anaerobically. Data recorded by data logger are voltage (E_{cell}) produced. The electric power (P) is then calculated using equation 2.

$$P = IE_{\text{cell}} \quad (2)$$

where I is electric current. As the Ohm law stated $E_{\text{cell}} = IR_{\text{ext}}$, then

$$P = \frac{E_{\text{cell}}^2}{R_{\text{ext}}} \quad (3)$$

with R_{ext} is the external resistance used during this research.

Power density indicated electric power obtained per electrode surface area, but it is often expressed per anode surface area (A_{anode}). The calculation is using Equation 4 [8]:

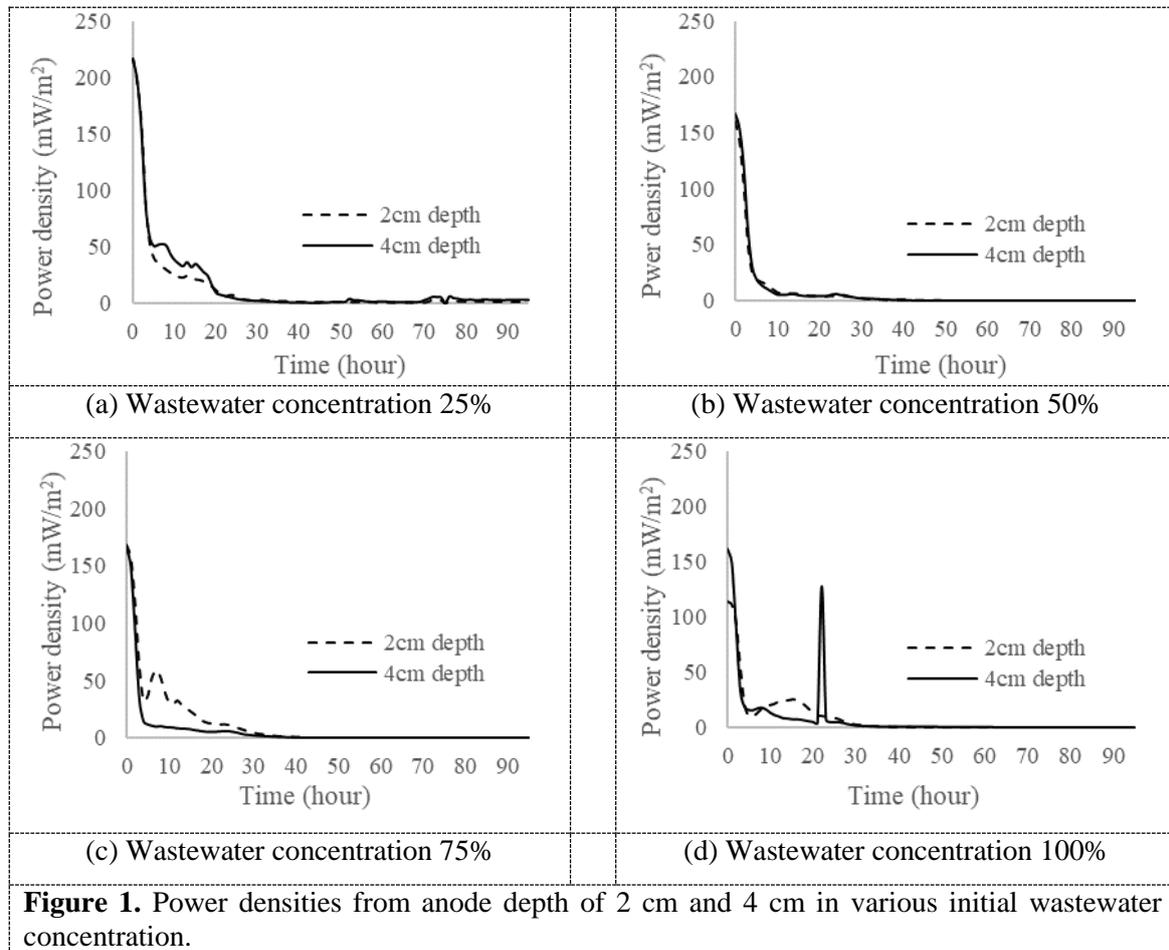
$$P = \frac{E_{\text{cell}}^2}{A_{\text{anode}} R_{\text{ext}}} \quad (4)$$

3. Result and discussion

3.1 Effect of anode depth to power density

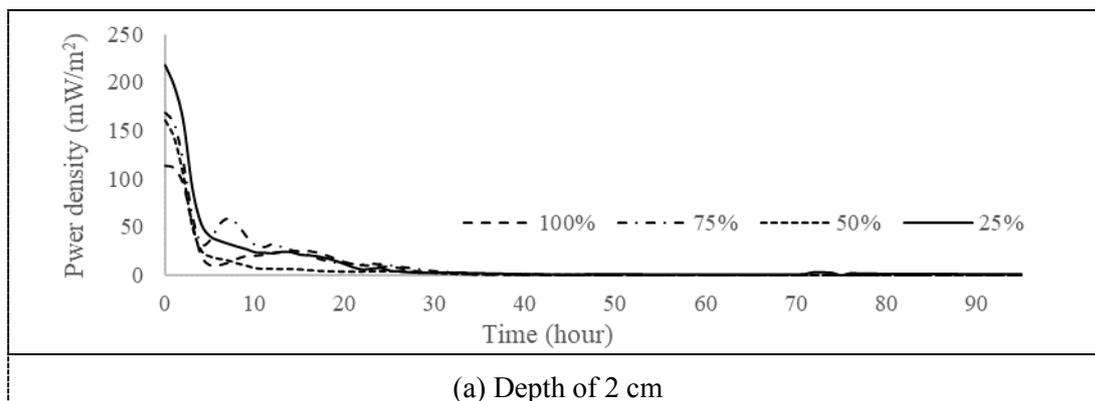
With relatively small depth variation, Figure 1 shows that power densities was not significantly affected by anode position. In initial wastewater concentration of 25%, reactor with 4 cm anode depth produced power density of 215.954 mW/m², while 2 cm-deep anode yielded 217.142 mW/m² after one hour. The amount of power generated decreased with time due to the formation of thin biofilm on wastewater surface which inhibit oxygen transfer into cathode chamber.

These results were different from research conducted by Lehman et al. [16], who varying spacing between anode and cathode, ~3cm (reactor 1) and ~10.5cm (reactor 2). Lehman's research showed that highest power density developed in reactor after 60 days operation. It is due to sediment which is closer to the surface contains more dissolved oxygen [17], therefore major bacteria, heterotrophic bacteria, existed in that position will consume more substrate compared to electron donor bacteria (anodophile and electrodophile) presented in deeper sediment. This deviation is caused by variable difference of anode spacing is too small.



3.2 Effect of wastewater concentration to power density

Wastewater of tofu industry used in this study contains complex mixture of organic substrates, thus this kind of wastewater is tend to form biofilm on its surface.



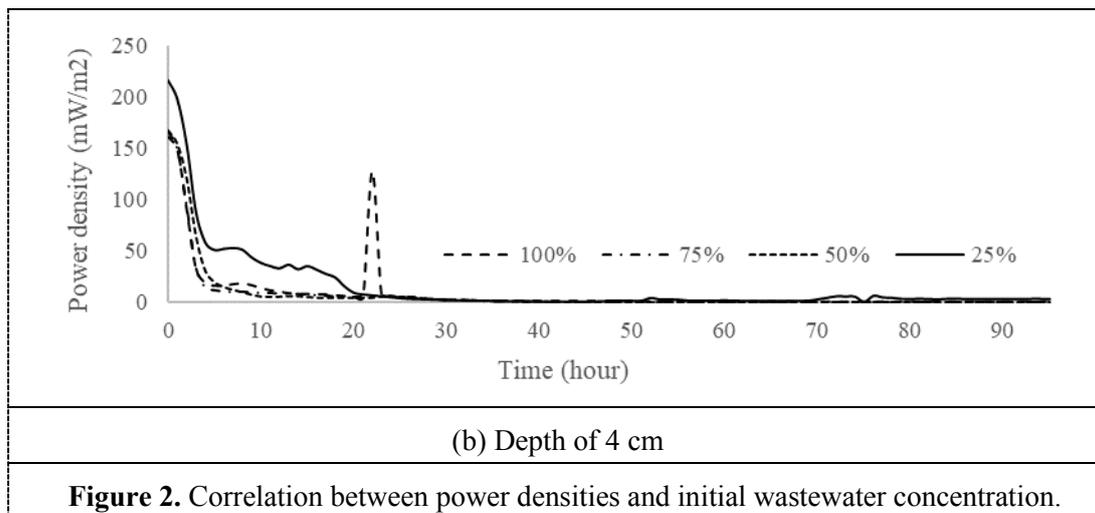


Figure 2 showed that electricity generated by SMFCs is affected by wastewater concentration. The highest power density is obtained from wastewater concentration of 25%; 217.142 mW/m² and 215.954 mW/m² for each anode depth of 2 cm and 4 cm. This is due to wastewater with higher concentration tend to form thicker biofilm layer on the wastewater and cathode surface, therefore it will deplete electric potential generated[19,20].

3.3 COD Removal using SMFC

After 95 hour operation, COD removal in control reactor, SMFCs reactor with anode position of 2 cm and SMFCs reactor with anode position of 4 cm respectively are 60%, 40% and 30%. As mentioned result, it can be seen that highest COD removal is achieved by control reactor. Similar result is also obtained by Xu et al.[7] and Liu et al.[21], where control reactor showed best performance in COD removal.

This occurred since COD removal is affected by the growth of microbes that is able to degrade organic substrates[22]. The growth process is concerned by dissolved oxygen level in substrates, while in SMFCs reactor, oxygen can also fixate electron (electron acceptor), thus dissolved oxygen content in SMFCs tend to be lower than that of control reactor. On the other side, even though the COD removal rate is low, SMFCs will give advantages as it can perform better removal of several specific compound, such as nitrate removal and decolorization[7].

4. Conclusion

Based on the research of tofu wastewater treatment using SMFCs done, it can be known that effect of anode position of 2 cm and 4 cm from sediment surface is not significant to electric power densities. This is because of small differences between the two variables. Highest power density is generated from wastewater concentration of 25%. This occurred as in lower concentration, biofilm formation that will inhibit oxygen transfer to electrode is thinner than in the higher concentration. Power densities in SMFCs is decreasing with time because of oxygen transfer to electrode decreased which mainly affected by biofilm layer formation. COD removal by SMFCs is relatively smaller than of control reactor due to lesser dissolved oxygen in SMFCs which will affect growth of degrading bacteria in wastewater. To raise power densities of SMFCs, one requires further study in resolving biofilm or thick layer formed on tofu wastewater surface or on cathode surface, optimum anode position, and other reactor operating condition.

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