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ENERGY HARVESTING WITH ESTUARINE SEDIMENT MICROBIAL FUEL CELL

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Abstract – Electricity can be produced using Sediment Microbial Fuel Cell (SMFC). The existence of microbes in the sediment was able to transform organic matter to produce electrons. This study was started from November to April 2017 at the Laboratory of Microbiology Research in the Biology Department, P3IN Laboratory of Soil Science, Andalas University. The objectives of the study were to determine the characteristics of estuarine sediments from Muaro Padang, West Sumatra, calculate the production of electric current that can be generated through SMFC, determine the sediment characteristics as SMFC substrate. Characteristics of Muaro Padang sediments were black mud soil, organic carbon 3.9%, total nitrogen 0.17% and phosphorus 82.075 ppm. Electrical current production peaked on the 20th day with a value of 432.69 mA/m^2. The SMFC substrate changed color to brownish on the surface with 1.65% organic carbon, 0.25% total nitrogen and 53.881 ppm phosphorus.

INTRODUCTION

The increase in population is accompanied by the increasing need for energy to carry out activities in the industrial sector, households, businesses and others, draining the energy supply. Currently there is a dependence on fossil fuel-derived energy with limited supplies and causing pollution (Franks and Nevin, 2010).Various human activities produce organic and inorganic wastes, which in turn will be a carbon input to aquatic ecosystems. The estuary is a hydraulic water system that holds organic material in it to run the biogeochemical cycle (Zhang *et al*., 2009). Excessive accumulation of organic matter will make the assimilation capacity exceeded, and cause turbidity and reduce oxygen level, which of course will disrupt the life of the biota in it. The role of microorganisms here is necessary especially in terms of enzymatic decomposition of organic matter. Bacteria are microorganisms that carry out decomposition and oxidation of organic matter, and it is well known that bacteria are able to produce electric current from metabolic process (Potter, 1911). Therefore pollution of organic in waters and the need for new alternative energy became a problem which at the same time also a solution for electrical energy production.

Microbial Fuel Cell (MFC) is a technology to actualize renewable energy, by utilizing bacteria and organic matter in sediments, electric energy can be produced. Chemical energy is converted through active catalytic and electrochemical reactions with two electrodes to oxidate organic matter (anode) and to reduce oxygen (cathode) (Hong *et al*., 2010). The generated electrical energy comes from the oxidation of complex organic matter by microbes in sediments. Complex organic matter such as glucose and amino acid are converted into fatty acids, acetates, minor fermentation products and aromatic compounds to be oxidized to produce CO_2, H^+, and electrons (Lovley, 2006). Electron as a product of microbial metabolism can be transferred to the anode through the cells outer membrane, mediators and through bacterial nanowires (Lovley, 2012). Then the electrons are flowed to the cathode through an external electrical circuit (Rabaey and Verstraete, 2005). The oxidized proton moves to the cathode as a reduction in oxygen and forms water because of the consumption of protons and electrons (Hong *et al*., 2010).

Exoelectrogenic bacteriahave the capability to transfer electrons out of cells, such as the family of Geobacteraceae and Desulfobulbaceae which are found in several varieties of aquatic sediments

(Holmes *et al*., 2004). Alternative energy sources using sediment as a substrate or identified as Sediment Microbial Fuel Cell (SMFC) have been studied previously, including sediment from river that produce an electric current of 20.2mA/m² (Seok Won Hong *et al*., 2010). Previously Holmes *et al.* (2004) used sea sediment as its substrate, produced a maximum electric current of 30mA/m². Utilization of sediments has a positive impact in reducing the content of organic matter in water. Hong, *et al*. (2008) reported the organic matter of Ilgam Lake Seoul sediments decreased from 3.52% to 2.37% after being used for bioelectrical production. Hong *et al*. (2009) also reported a decrease in the organic matter of Lake Sihwa Korea from 6.4% to 4.20%. The purpose of this study was to determine the potential of SMFCs in electricity production, and remediation of organic material pollution in estuarine sediments.

MATERIALS AND METHODS

Method

This is an experimental study carried out in several stages including the characterization of SMFC sediments and substrates, the process of SMFC sequences that refer to the research of (Holmes *et al*., 2004). The electric current was measured with a multimeter, as well as the isolation and characterization of bacteria at the anode.

Sediment Sources

The substrate used was estuary sediment from Muaro Padang, West Sumatra from the depth of 4-5 m. Sediment was taken using Ekman grab and collected in a jar and enclosed. Water at the sampling location was also taken and stored in a plastic container. All sediments and water samples were taken to the laboratory using a cool box for the SMFC series.

SMFC Series Forming

The electrodes used were made of cylindrical graphite carbon with dimensions of 58 x 8 mm. Carbon electrodes were neutralized by soaking in HCl 1 N and NaOH 1 N each for 1 day and stored in deionized water. At the end of the electrode was drilled to connect it with an open isolator single cable, and to make it waterproof, the connection was wrapped with sealtape and silicone sealant. A 1L volume glass was used as a place to form the SMFC components. Sediment was inserted up to a height of 3 cm, anode was placed on top and covered with sediment as high as 2 cm. The water at the sediment sample location was collected into a 400 mL glass and let stand for 24 hours to precipitate the sediment particles. The cathode was then placed 1 cm from the surface of the sediment. Wires from the anode and cathode were connected with 820 ± 5% Ù resistor. The lost water during the observation period due to evaporation was replaced with deionized water. SMFC was operated in a dark condition at room temperature and made in 2 pieces and also another 1 as a control (with the anode and cathode not connected).

Electrical Current Measurement

The electric current was measured with a multimeter for 40 days. The current was measured based on the pattern of changes in the current produced. Current Density conversion was calculated by dividing the amount of current produced by the anode surface area, with unit of calculation in (mA/m²).

Sediment Characterization

Sediments characterization from Muaro Padang and SMFC substrates were carried out including the analysis of organic carbon content, measurement of pH, total nitrogen (Rayment and Hingginson, 1992) and available phosphates (Watanabe and Olsen, 1965).

RESULTS AND DISCUSSION

Characteristics of Estuary Sediments

Estuary as a place of mixing of freshwater and seawater serves as a trap of nutrients such as nitrates, phosphates, and organic matter originating from the surrounding water. The characteristics of sedimentare in the form of black mud soil indicating the amount of organic matter is high compared to brown sediment (Voroney, 2007).

Table 1 showed the C-organic content in semi-closed ecosystem such as estuary has a relatively high organic carbon content up to 3.9% compared to open ecosystem with C-organic of 1.7 ± 0.2% (Hong *et al*., 2010). Meanwhile in closed ecosystem the C-organic content was 3.7% (Hong *et al*., 2009). This is due to the freshwater flow that occurs continuously from the headwaters of the river and the process of movement of water due to tides that transport minerals, organic matter, and sediment to support the productivity of waters in the estuary region.

The content of organic carbon in sediments is a

Table 1. Characteristics of Estuary Sediments

Test parameter	Research result[1]	Hong *et al.* (2010)[2]	Hong *et al.* (2009)[3]	Hong *et al.* (2008)[4]
C (%)	3.9	1.7±0.2	3.7	2.04±0.22
N (%)	0.17	-	-	-
C/N	22.9	-	-	-
P_2O_5 (ppm)	82.075	-	-	-
pH : H_2O	6.86	6.61±0.03	-	7.5
KCl	6.42	-	-	-

[1]Characteristics of sediments from Muaro Padang, West Sumatra, Indonesia
[2]Characteristics of sediments from Gongji River, Korea based on a study by Hong *et al.* (2010)
[3]Characteristics of sediments from Sihwa Lake, Korea based on a study by Hong *et al.* (2009)
[4] Characteristics of sediments from Ilgam Lake, Seoul based on a study by Hong et al. (2008)

representation of soil organic matter from the destruction and reorder carried out by microorganisms. According to (Killops and Killops, 2005) the accumulation of organic matter is strongly influenced by the amount of organic matter inside, the rate of deposition in sediments, and the rate of degradation of the organic matter. The difference in the characteristics of the substrate and the amount of organic matter is expected to have an impact on the performance of the existing SMFC (Chaudhuri and Lovley, 2003).

Current and Voltage Production from Sediment Microbial Fuel Cell (SMFC)

Measurements were made in 40 days with a fixed resistor of 820 Ù ± 5%. The results of the measurement of electric current and voltage produced can be seen in Figure 1.

Figure 1 showed the highest electrical current obtained at 432.69 mA/m² on the 20th day. The electrical current generated on the first day is thought to originate from the accumulation of electrons that had existed before, then a decrease in current was observed, this is because microbes on the substrate need time to adapt and reproduce until a stable microbial consortium is formed.

The electricity generated using Muara Padang sediments was relatively high compared to river sediments which produce a maximum electric current of 20.2 mA/m² (Hong *et al*., 2010). The amount of current obtained was directly proportional to the amount of organic matter. According to Chae *et al.* (2008) substrate characteristic and the amount of organic matter contained in sediments as well as the type of dominant microorganisms in MFC affect the amount of electric current produced. This was proved by Holmes *et al.* (2004) that live sea sediments produce an electric current of 30 mA/m², which was higher than the sediments being sterilized using autoclaves for 1 hour and sediment given formalin concentration of 0.5%.

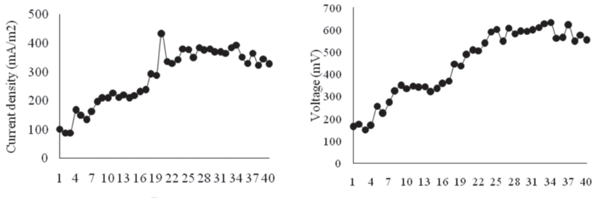

Fig. 1. Current (current density) and voltage (voltage) result

The structure and activity of microbes on the substrate were also influenced by various parameters, such as pH, oxidation reduction potential, ionic strength, and temperature, which will affect the process of proton transfer efficiency and anode performance (Torres *et al*., 2008). From the graph, it can be seen that the current decrease is not yet significant, due to the remaining organic compounds. According to (Logan *et al*., 2006) electricity production will decrease if the organic compounds on the SMFC substrate have been completely degraded, thus will stop the oxidation process.

Characteristics of Sediments as SMFC Substrate

Sediment substrate characterization was carried out after measuring electric current for 40 days. The results of the characterization are shown at Figure 2.

Figure 2 showed the color of the estuary water used was changed from clear to yellowish. At the top of the substrate, the sediment changed color to brown, but on the inside it was still black. This is presumably due to the high levels of organic matter left during the operation of the SMFC system which

Table 2. Characteristics of Sediments as an SMFC Substrate

Parameters	Result (SMFC Substrate)[1]	Hong *et al.* (2009)[2]	Hong *et al.* (2008)[3]
C (%)	1.5	2.44	1.37±0.13
N (%)	0.25	-	-
C/N	6.50	-	-
P_2O_5 (ppm)	53.881	-	-
pH : H_2O	8.12	-	9.0
KCl	8.11	-	-

[1]SMFC substrate characteristics
[2]Sediment characteristics in Sihwa Lake, South Korea from the study by Hong *et al.* (2009)
[3]Sediment characteristics in Ilgam Lake, South Korea from the study by Hong *et al.*(2008)

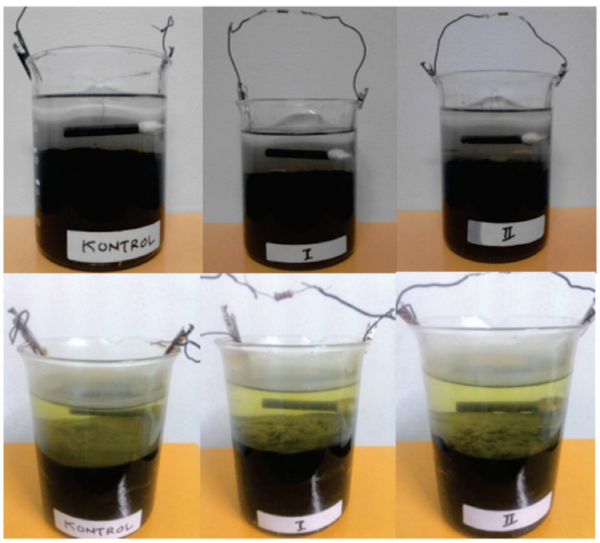

Fig. 2. (A) SMFC pre condition (B) SMFC post condition

can be seen in Table 2.

Table 2 showed C-organic sediment after being used for biolistric production of 1.65%. This showed a decrease in the initial C-organic content of 3.9% with magnitude of decline reaching 2.25%. Tender *et al.* (2002) stated that this was caused by the activity of microorganisms that break down the organic matter in the sediment. Unlike the case with the result of N-total of 0.25%, which showed an increase even though small increase from the initial N-total content of 0.17% with a magnitude of increase of 0.08%. This increased tendency is thought to be due to the large number of bacterial cells in the SMFC substrate.

The C/N ratio of the SMFC substrate was 6,50, which showed a drastic reduction from the initial C/N ratio of 22.9 with magnitude of decrease of 16.4. This indicates the occurrence of organic matter degradation in the SMFC substrate. Similarly, the level of phosphate obtained was 53.81 ppm, which showed a decrease from the initial phosphate level of 82.075 ppm, with magnitude of reduction of 28.194 ppm. Then the measurement results for the pH of the SMFC substrate were 8.12 (H_2O) and 8.11 (KCL) which showed there was an increase of pH from initial value of 6.86 (H_2O) and 6.42 (KCL). According to Jadhav and Ghangrekar (2009) this could be because the rate of proton transfer (H^+) from sediments to water is faster than the formation of proton in the sediment.

CONCLUSION

The production of electrical energy from estuarine sediments through the Sediment Microbial Fuel Cell (SMFC) has the potential to supply energy in the future. This can be seen from the high amount of current generated reaching 432.69 mA/m^2. In terms of remediation, it will be beneficialbecause a decrease of initial C/N ratio of 22.9 to 16.4 after observation.

REFERENCES

Chae, K. J., Choi, M., Ajayi, F. F., Park, W., Chang, I. S. and Kim, I. S. 2008. Mass Transport through a Proton Exchange Membrane (Nafion) in Microbial Fuel Cells. *Energy & Fuels.* 22 (1) : 169–176.

Chaudhuri, S. K. and Lovley, D.R. 2003. Electricity generation by direct oxidation of glucose in mediatorless microbial fuel cells. *Nature Biotechnology.* 21 (10) : 1229–1232.

Franks, A.E. and Nevin, K.P. 2010. Microbial fuel cells, a current review. *Energies*. 3 (5) : 899–919.

Holmes, D.E., Bond, D.R., Neil, R.A.O., Reimers, C.E., Tender, L.R. and Lovley, D.R. 2004. Microbial Communities Associated with Electrodes Harvesting Electricity from a Variety of Aquatic Sediments. 48(1): 178–190.

Hong, S. W., Choi, Y. S., Chung, T. H., Song, J. H., Kim, H. S. and Collection, A.S. 2009. Assessment of Sediment Remediation Potential using Microbial Fuel Cell Technology. 3 : 678–684.

Hong, S.W., Kim, H. J., Choi, Y. S. and Chung, T.H. 2008. Field Experiments on Bioelectricity Production from Lake Sediment Using Microbial Fuel Cell Technology. *Production.* 29 (11) : 2189–2194.

Hong, S. W., Kim, H. S. and Chung, T. H. 2010. Alteration of sediment organic matter in sediment microbial fuel cells. *Environmental Pollution.* 158 (1) : 185–191.

Jadhav, G. S. and Ghangrekar, M. M. 2009. Performance of microbial fuel cell subjected to variation in pH, temperature, external load and substrate concentration. *Bioresource Technology.* 100 (2) : 717–723.

Killops, S. and Killops, V. 2005. *Introduction to Organic Geochemistry*.

Logan, B. E., Hamelers, B., Rozendal, R., Schröder, U., Keller, J., Freguia, S. and Rabaey, K. (2006). Microbial fuel cells: Methodology and technology. *Environmental Science and Technology.* 40 (17) : 5181–5192.

Lovley, D.R. 2006. Microbial fuel cells: novel microbial physiologies and engineering approaches. *Current Opinion in Biotechnology.* 17 (3) : 327–332.

Lovley, D.R. 2012. Electromicrobiology. *Annual Review of Microbiology.* 66 (1) : 391–409.

Potter, M.C. 1911. Electrical Effects Accompanying the Decomposition of Organic Compounds. *Proceedings of the Royal Society B: Biological Sciences.* 84 (571) : 260–276.

Rabaey, K. and Verstraete, W. 2005. Microbial fuel cells: Novel biotechnology for energy generation. *Trends in Biotechnology*. 23 (6) : 291–298.

Rayment, G.E. and F.R. Higginson. 1992. *Australian Laboratory Handbook of Soil and Water Chemicals Methods*. Inkata Press. Sydney.

Tender, L.M., Reimers, C.E., Stecher, H.A., Holmes, D.E., Bond, D.R., Lowy, D. A. and Lovley, D.R. 2002. Harnessing microbially generated power on the seafloor. *Nature Biotechnology.* 20 (8) : 821–825.

Torres, C.I., Marcus, A.K. and Rittmann, B.E. 2008. Proton transport inside the biofilm limits electrical current generation by anode-respiring bacteria. *Biotechnology and Bioengineering.* 100 (5) : 872–881.

Voroney, R. P. 2007. The Soil Habitat. Di dalam: Paul EA (editor). *Soil Microbiologi, Ecology, and Biochemestry*. Chennai: Elvesir Inc.

Watanabe F.S. and Olsen, S.R. 1965. Test of an ascorbic acid methods for determinationof phosphorus in water and $NaHCO_3$ extracts from soil. *Soil Sci Am Proc.* 29 : 677-678.

Zhang, L., Yin, K., Wang, L., Chen, F., Zhang, D. and Yang, Y. 2009. Estuarine, Coastal and Shelf Science The sources and accumulation rate of sedimentary organic matter in the Pearl River Estuary and adjacent coastal area, Southern China. *Estuarine, Coastal and Shelf Science.* 85 (2) : 190–196.