Optimization of electricity generation from marine sediment of Kendari Bay using stacked sediment microbial fuel cell

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Abstract. Marine sediments of Kendari Bay has the potential as an alternative source of electrical energy through sediment microbial fuel cell (SMFC) due to the high level of sedimentation. This study aims to optimize the amount of electrical voltage that can be generated through the SMFC system using stacked SMFC in the form of a series connection. The research methods include determining the sampling location, physical-chemical properties measurement of sediments, SMFC assembly (single and stacked SMFC), and electrical voltage measurement. Three station points representing the overall condition of Kendari Bay are determined as sampling locations. The result shows that there was a decrease in the organic matter content of the sediment substrate after the use of SMFC namely organic carbon from 2.78 percent to be 2.68 percent due to microbial activity in sediments. The single SMFC from station 2 (S2) can produce the maximum electrical voltage of 438 mV which then optimized using stacked SMFC in series connection. The maximum electrical voltage of 2.174V can be obtained using stacked SMFC. These results show that marine sediments of Kendari Bay is interesting as an alternative energy source through SMFC and stacked SMFC could optimize the amount of electrical voltage from single SMFC.

1. Introduction

Energy as an important component for human activities is still highly dependent on fossil fuels as the main energy source for most countries in the world. Dependence on fossil fuels has a serious impact on the environment. Carbon emissions resulting from the combustion processes of fossil fuels become the largest contributor to greenhouse gases which are the main cause of global warming [1]. In addition to environmental problems, the nature of fossil fuels as non-renewable energy sources makes their continuous usage causing the problem of their availability for present and future generations [2]. In order to solve these problems, humans need to find and optimize the use of alternative energy sources that are sustainable and environmentally friendly.

Microbial fuel cells (MFCs) are an example of technology that can produce alternative energy sources that are clean and potential for development. MFCs utilize the catalytic activity of microorganisms to convert the chemical energy in organic matter into electrical energy [3]. Basically,

various forms of organic matter can be used as MFCs substrate such as acetate, propionate [4], glucose, fructose, sucrose [5], fatty acids, starch [6], protein [3], wastewater [7], kitchen waste [8], as well as organic and inorganic sediments [9].

The use of sediment as a substrate is a breakthrough in MFCs technology called sediment microbial fuel cell (SMFC). SMFCs consist of anode buried in the anaerobic sediments and connected through an electrical circuit to cathode suspended in the overlying aerobic water as shown in Figure 1 [10].

Marine sediments of Kendari Bay have the potential to be used as SMFCs substrate due to the unique geographic conditions of the Kendari Bay Area that resemble an estuary [11]. The high level of sedimentation in the Kendari Bay Area causes marine sediments of Kendari Bay to have a high content of organic matter so that it has great potential as an alternative energy source through SMFCs technology.

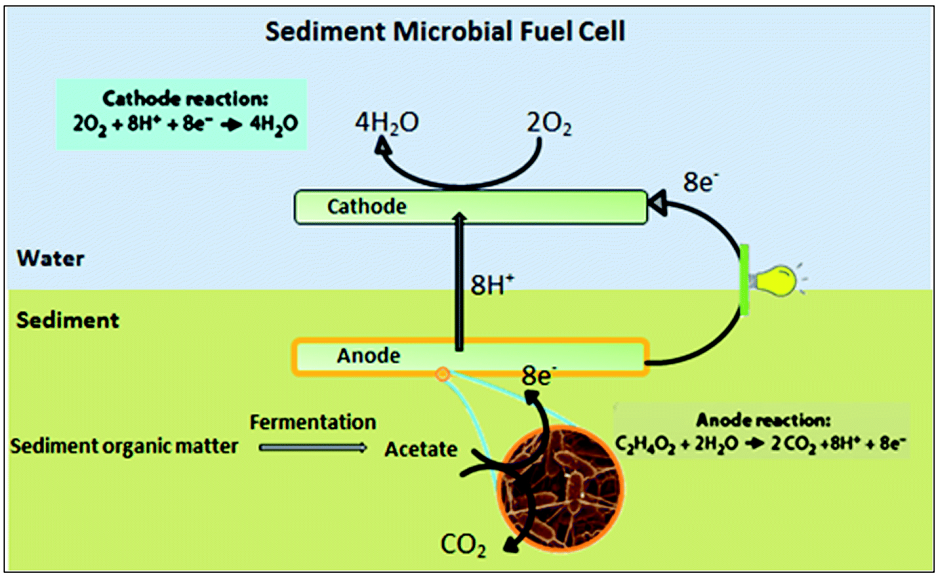


Figure 1. Process illustration scheme of SMFC.

SMFCs have been developed in recent years for the removal of organic matter in addition to electricity generation [12]. SMFC using marine sediments of Kendari Bay in this study is expected to generate electricity as well as to remove organic matter for bioremediation purposes in Kendari Bay so that it can become the solution to deal with sedimentation problem that causes siltation in Kendari Bay.

According to the studies previously reported, SMFCs can be set to a stacked configuration either in the form of series connections or in parallel connections in order to increase the power output [13]. In this study, SMFCs were stacked together in series connection in order to increase electrical voltage generated by single SMFCs. The stacked SMFCs in this study was operated in batch mode up to 40 days to determine the long-term performance of marine sediments of Kendari Bay as SMFC substrate.

2. Methodology

2.1. Sampling of marine sediments of Kendari Bay

The sampling of marine sediments of Kendari Bay was carried out based on the Purposive Random Sampling method. This method is carried out because it is suited the geographic conditions of Kendari Bay that are morphometrically divided into two major parts, namely the inner Kendari Bay which is relatively closed and the outer Kendari Bay which is more open and directly connected to Banda Sea waters. Desired sample characteristics in this study are based on the distribution of sediment material in the form of organic material carried to the bay. Three sampling stations representing the whole condition

of Kendari Bay were determined: Station 1 (S1) representing the inner Kendari Bay, Station 2 (S2) representing the estuary of Kendari Bay, and station 3 (S3) representing the outer Kendari Bay.

2.2. Physical-chemical properties measurement of marine sediments of Kendari Bay

The physical-chemical properties of marine sediments of Kendari Bay were measured before and after the use of SMFC to observe the pattern change in sediments caused by the microbial activity in SMFC. The measurements include the analysis of organic carbon and nitrogen total content, as well as pH and electrical conductivity measurement.

2.3. SMFC assembly and electricity measurement

The single-chamber SMFC system was designed using a beaker glass of volume 0.5 L (Figure 2). SMFC in this study used electrodes made of cylindrical graphite carbon and resistor of 560 Ω ± 5 % based on research by Riyanto *et al*. [14]. SMFC is operated in dark conditions and room temperature. Electrical voltage measurements are carried out using a multimeter with the measurement time based on the pattern of changes in electrical energy generated from the decomposition of organic matter by microorganisms in SMFC.

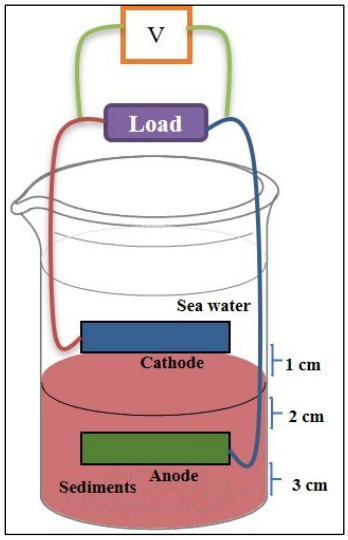


Figure 2. Configuration scheme of single SMFC.

SMFCs in this study was optimized using stacked configuration by combining ten single SMFCs in series connection as shown in Figure 3. This method aims to increase the amount of electrical voltage generated by SMFCs system.

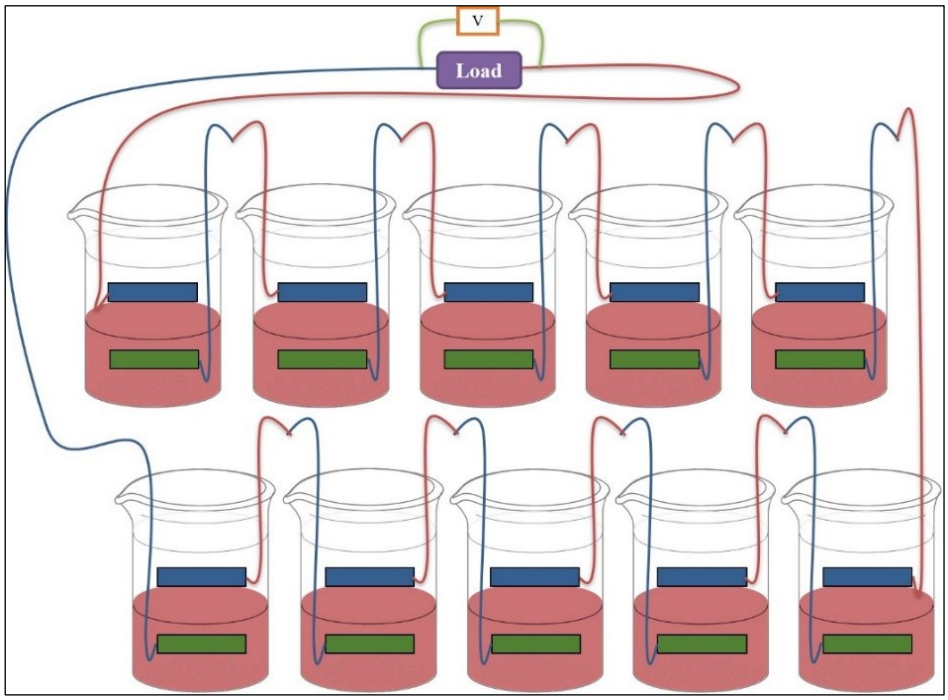
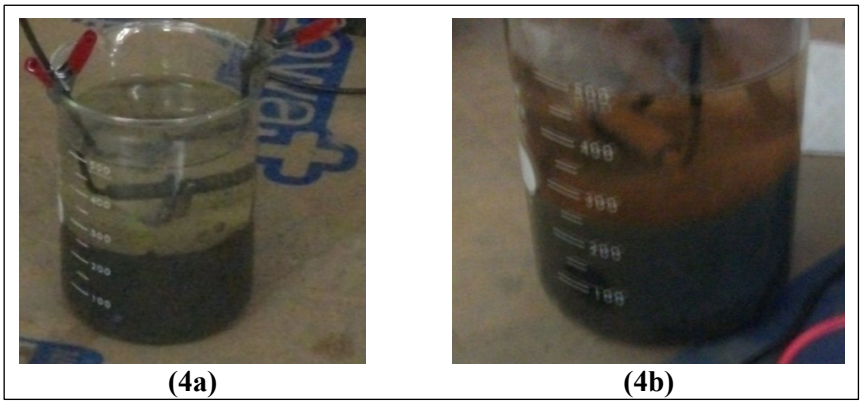


Figure 3. Configuration scheme of stacked SMFC.

3. Results and Discussion

3.1. The Change of Physical-chemical properties of marine sediments of Kendari Bay

Marine sediments of Kendari Bay are blackish gray mud soils and after the use in SMFC visually changed color to brown as shown in Figure 4. Black color indicates the amount of organic matter in sediments is higher than sediments that are brown.



(4a) **(4b)**

Figure 4. The color of marine sediment of Kendari Bay before the use of SMFCs (4a) and after the use of SMFCs (4b).

Sediments characteristics such as water content, amount of organic carbon and total nitrogen, pH values (H2O and KCl), and electrical conductivity values are shown in Table 1. Organic carbon in sedimentary soils is a representation of sedimentary organic matter which is the result of overhaul and re-arrangement carried out by microorganisms of sedimentary soils.

Table 1. Characteristics of marine sediments of Kendari Bay.

Test Parameter	Before the use of SMFCs				After the use of SMFCs			
	S1[a]	S2[b]	S3[c]	Average	S1[a]	S2[b]	S3[c]	Average
Water Content (%)	43.9	38.9	28.4	37.1	42.1	30.5	22.3	31.6
C (%)	3.41	3.04	1.89	2.78	3.34	2.87	1.83	2.68
N (%)	1.45	1.09	1.10	1.21	1.35	0.91	0.94	1.07
C/N	2.35	2.79	1.72	2.29	2.47	3.15	1.95	2.52
Conductivity (dSm^{-1})	0.99	0.93	0.84	0.92	1.76	1.20	3.22	2.06
pH (H_2O)	7.24	6.72	7.30	7.09	7.38	7.12	7.64	7.38
pH (KCl)	7.16	6.90	7.70	7.25	7.58	7.34	8.07	7.66

[a] Marine sediments from station 1 – inner Kendari Bay
[b] Marine sediments from station 2 – estuary of Kendari Bay
[c] Marine sediments from station 3 – outer Kendari Bay

Based on Table 1, it is known that the organic carbon content in marine sediments of Kendari Bay is relatively high at 2.78%. The high organic carbon content in marine sediments of Kendari Bay is similar to the organic carbon content in closed ecosystems such as lakes. This is probably caused by the physical condition of the Kendari Bay area which is also relatively closed resembling an estuary which is supported by the existence of freshwater flow that occurs continuously from the upstream and the process of water movement due to tides phenomena that transport minerals, organic matter, and sediments.

The characteristics of the sediment substrate changed after being used in the SMFC system as shown in Table 1. The average organic matter content of marine sediments of Kendari Bay after use in the SMFC system decreased by 0.10% to become 2.68%. The total nitrogen content of the marine sediments of Kendari Bay was also reduced by 0.14% after being used in the SMFC system to be 1.07%. The organic matter content of marine sediments of Kendari Bay in the form of organic carbon and total nitrogen decreased after being used in the SMFC system due to microbial activity that breaks down the organic material in the sediments. These results show that SMFC can be used for bioremediation purpose so it can become the solution to deal with sedimentation problem in Kendari Bay.

3.2. Electrical energy production of SMFC

The electrical energy of the SMFC system of each station measured in this study is in the form of electrical voltage measured every day for 40 days. This is done to observe the tendency of the SMFC system to produce electricity every day and to determine the long-term performance of marine sediments of Kendari Bay as SMFC substrate. In this research, the electrical voltage generated by the SMFC system fluctuates at each observation time as shown in Figure 5. The value of the voltage that fluctuates at each observation time can be caused by interactions between the microbes that make up the consortium. Fermented products from one type of bacteria can be a substrate for other types of bacteria. This causes the fermentation product is not oxidized to produce free electrons so that the measured electrical voltage at a certain time decreases.

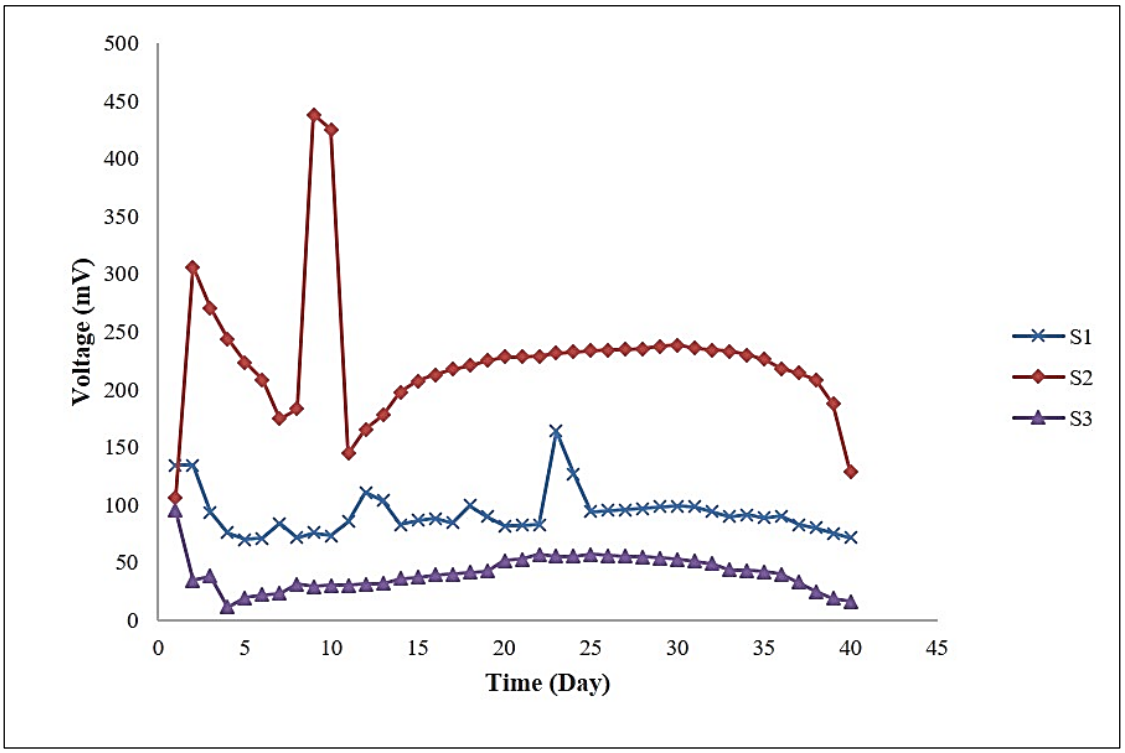


Figure 5. Electrical voltage production of SMFCs from 3 stations of Kendari Bay.

Sediments originating from Kendari Bay have a long life to be used as SMFC substrates. This is indicated by the SMFC system which can still produce electric voltage up to 40 days of measurement even though towards the end of the measurement continues to decrease. The high content of organic matter causes the longevity of sediments to use as an SMFC substrate.

The SMFC system from Station 2 can produce the highest electrical voltage of 438 mV achieved on the 8th day. This shows that marine sediments of Kendari Bay have the prospect of being used as a renewable alternative energy source. Sediments at station 2 originating from the Kendari Bay estuary has the best potential in producing electrical energy through the SMFC system as shown in Figure 5.

3.3. Optimization of electricity generation using stacked SMFC

Single SMFC from sediments at station 2 (S2) was optimized using stacked SMFC due to the highest electrical voltage obtained by SMFC from S2. The electricity production of stacked SMFC system was observed for 40 days as shown in Figure 6.

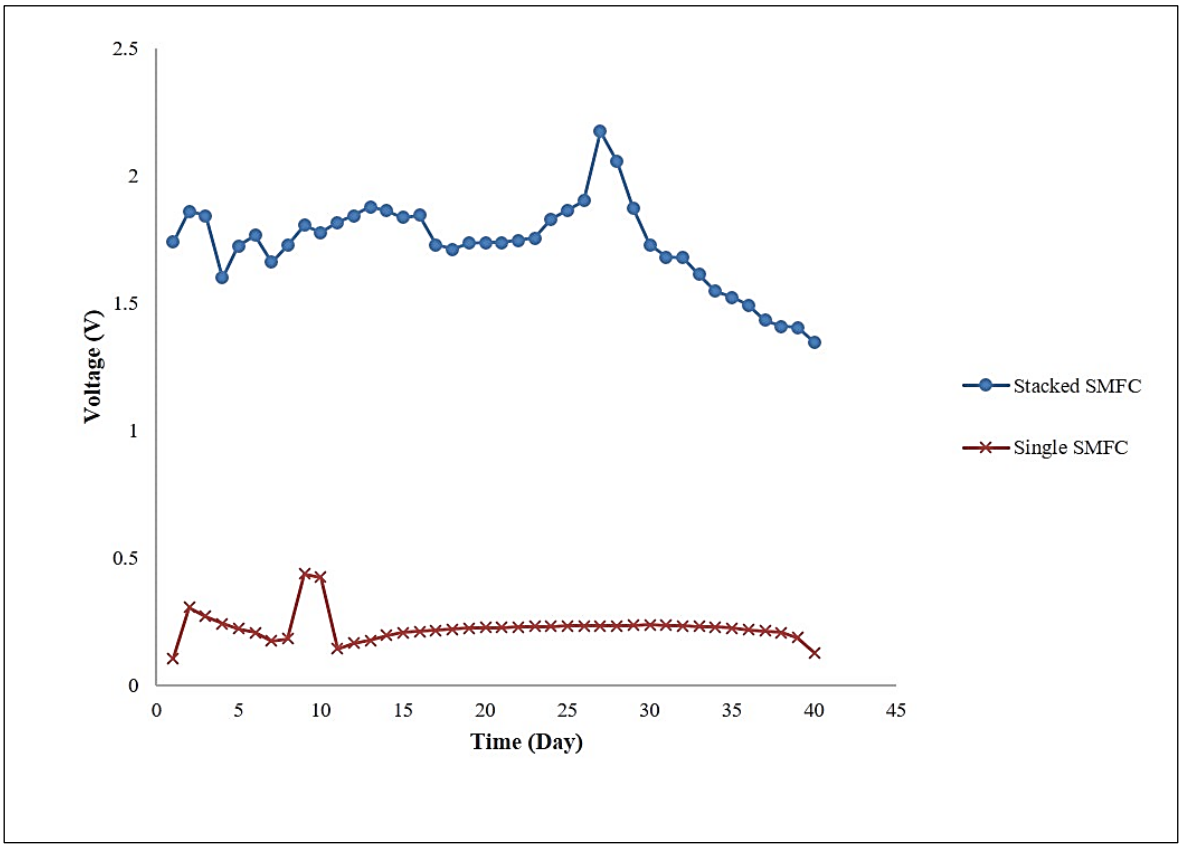


Figure 6. Electrical voltage production of stacked SMFC and single SMFC from station 2.

Based on the observations seen in Figure 3, it can be seen that the stacked SMFC system can increase the amount of electrical voltage up to five times where the amount of voltage produced is equivalent to a battery (± 1.5V). The maximum electrical voltage of 2.174V obtained by this SMFC system on the 26th day of operation.

The more the number of single cells combined, the greater the voltage generated. This is similar to the results obtained by Oh and Logan who combined a single MFC and succeeded in increasing the voltage of the two combined cells [11]. According to Arsov and Georgievski, to use a fuel cell as an energy source in practice, a number of single fuel cells must be stacked either in series or parallel to obtain a larger voltage output [3].

4. Conclusions

Marine sediments of Kendari Bay have good prospects to be used as a source of renewable energy through sediment microbial fuel cell (SMFC) technology due to the relatively high organic matter content of this sediment. Optimization of single-SMFC using stacked SMFC in series connection could increase the electrical voltage up to five times and stable for a long time.

5. References

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