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Comparison of leachate and mixed waste generated electricity in Compost Solid Phase Microbial Fuel Cells (CSMFCs)

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Abstract. This study was conducted to compare between leachate and mixed waste produced electricity as one of the performance parameters of Compost Solid Phase Microbial Fuel Cells (CSMFCs) besides complying with compost requirements. Mixed waste as solid-phase produced from composting has higher potency to obtain electricity than leachate as the liquid phase. Composting of mixed waste was applied in CSMFCs reactor utilizing two anodes placed on leachate chamber at the bottom of the reactor and mixed waste at half of the reactor height and 1 cathode at above of two-third reactor height for electron transfer that its condition was adjusted on more or less 60% of moisture content, seven times of turning frequency, and 50:1 of initial C/N ratio during 23 days process running. The result shows that electrical production in mixed waste is a little more than leachate means that leachate and mixed waste produce the same result on power density as a total value of electricity, but the different of those in electrical production is that mixed waste produces more faster than leachate due to the first exposed electron, the faster-producing electricity.

1. Introduction

Energy scarcity is a big problem worldwide, especially in developing countries like Indonesia, due to supporting almost human activities. The unrenewable energy source has still intensively exploited and used since a long year ago until today. It is used much more than renewable energy, which is not popular to promote energy availability due to energy generation capacity. The main impact of using unrenewable energy is the increasing contribution to global warming, which is CO₂ emission, environmentally harmful, and accelerating climate change globally [1,2]. Many scientists who have consciousness in a better environment compete to find a renewable energy source, which produces high energy. One of them is from waste material known containing high substrate, nutrition, and also calories.

One of the technologies which convert waste to energy is solid-phase microbial fuel cell (SMFC) or is known as terrestrial microbial fuel cells (TMFCs) [3]. It uses compostable organic waste material (COWM) which has high biodegradability converting to bioenergy through microbial metabolism. A lowland peat bog, hummus, sawdust, and cattle manure as natural biodegradable are greatly and appropriately used as biobatteries in MFCs [4]. Bioelectricity has been successfully generated from sediment, soil, and compost [3]. The main advantage of SMFCs is using higher external resistance from the complex matrix (i.e., solid waste) to increase power output [5]. The variant of SMFC adopting composting is Compost Solid Phase Microbial Fuel Cell (CSMFC), which uses COWM generating



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electricity in aerobic conditions. CSMFC is the modification of composter used as the alternative technology to produce electricity and compost simultaneously [6]. Composting can be applied in many ways and methods to rejuvenate waste to the beneficial material [7,8]. The use of CSMFC is producing electricity and compost complying the mature compost as required in Indonesia National Standard (SNI) 19-7030-2004: Compost specification from domestic organic waste. CSMFC used garbage that has organic substrate and nutrition to produce compost and direct electricity [6]. Microbial fuel cell (MFC) is divided by two base matter that are liquid phase MFC, which is typically wastewater (household, livestock, food, etc.) [9,10], and solid-phase MFC, which is commonly sludge from the wastewater treatment plant, contaminated soil, and lignocellulosic waste [10].

The use of graphene as an electrode is evaluated in this study. The high performance of CSMFC produced electricity 3-10 times of previous CSMFC research [6]. The difficulty in electron transfer in solid substrates is due to having high internal resistance and producing little electrical power [10]. High COD concentration containing organic base matter did not always produce high electricity due to various factors [11,12,13,14]. This study's problem in converting solid-phase waste material to energy is lower electrical generation than liquid phase waste. The liquid MFCs (LMFCs) based on the volume of liquid waste has developed faster than terrestrial microbial fuel cells (TMFCs) in voltage output [3]. Therefore, one solution is knowing the differences between solid and liquid phase waste converted to energy through the dual graphene anode utilized in CSMFCs.

This study aims to compare leachate represents a liquid phase, and mixed waste represents solid waste delivered electricity in CSMFCs. The different result of electrical production from leachate and mixed waste describes the recommendation of used material in CMFCs application.

2. Methodology

Garbage as mixed waste was collected from the integrated waste management organized by *TPST* UNDIP as the waste management agency under the command of the UNDIP rector. Mixed waste had a pro-portion 50:50 by weight over 0.61 kg and been entered into CSMFCs reactor to comply with two-thirds of reactor height.

2.1. Tools and materials

Analytical balance: METTLER TOLEDO, spectrophotometer: Genesys 10s VIS Thermo Scientific-USA, Erlenmeyer: Merck, pipette: Merck, hot plate, centrifuge, vortex mixer, Atomic Absorption Spectrophotometer (AAS), digital pH meter, digital thermometer, digestion apparatus, destilator, titrator/burette, oven: Memmert, desiccators vacuum: DURAN, digital multimeter: Heles HE-930L-China were used as tools. Whereas, the used materials to support the analysis were H_2SO_4 pa.97%, $\text{K}_2\text{Cr}_2\text{O}_7$ 1 N, standard solution 5,000 ppm C, borate acid 1%, conway indicator, selenium reagent mixture, NaOH 40%, NaOH 6%, butanedioic acid, dipotassium tetraiodomercurate(II) in dilute sodium hydroxide, HNO_3 65%, vanadat molybdate, aquadest. Mixed waste over 0.61 kg, Tanah Mas River sediment, pencil carbon 2B: KENKO, wood glue: FOX, 2.5L-volume of plasticware, polyurethane, sulfate acid 96%: PA-ISO Pancreac-ESPANA, NaOH 0.1 N, HCl 0.1 N, and phosphate acid 85%: EMSURE Merck-Germany were used as materials.

2.2. Reactor design

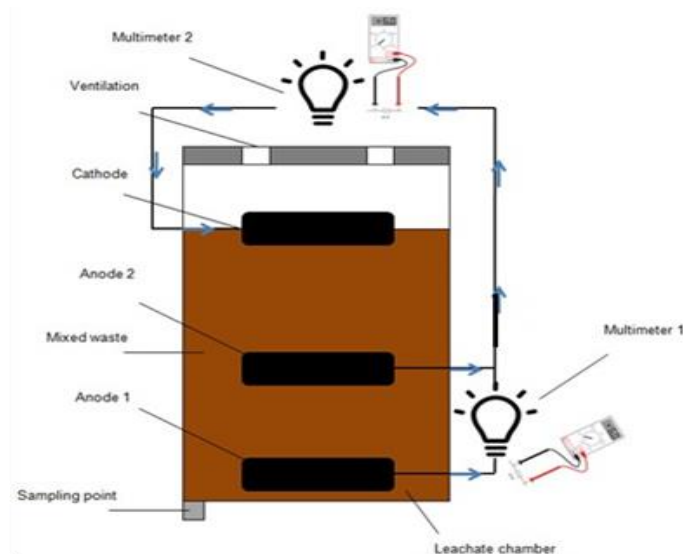


Figure 1. CSMFCs reactor design.

The CSMFCs reactor design is adopted from the study of the determination of the specific energy of mixed waste decomposition in CSMFCs by Samudro, et al. (2018) [6]. This study's difference is that the first publication used two results of power density from leachate and mixed waste or called the summation of power density from two anode configurations.

The first anode was placed at the base of the reactor, and the second anode was placed in half of the reactor height, then the electrical output was measured for both of the anodes using a measuring instrument called digital multimeter which read voltage (Volt), resistance (Ohm), and current (Ampere).

2.3. Research procedure

The research procedure consists of three main steps which were initial research, reactor design, and primary research. The initial research was conducted to know the condition of mixed waste, electrode, and microbial seeding for the first time, while CSMFCs reactor was designed based on the initial research to reach the optimum condition of the operational reactor. Whereas, the primary research was operated on day 0th to day 23rd, which followed the previous research about Solid Phase Microbial Fuel Cell (SMFC) Samudro, et al. (2018) [6]. Due to in the same principle of reactor operation with the different condition where CSMFCs in the solid phase and SMFC in semi-solid phase, then CSMFCs was operated by a destructive method which had 14 unit reactors plus 1 unit reactor as process control during 23 days running. Graphene electrode was characterized in voltage, resistance, current, surface area, and power density. Microbial seeding was characterized, in the beginning, using Methylene Blue Active Substances Surfactants (MBAS) method.

The independent variable of this study is the materials that are leachate as liquid phase and mixed waste as solid-phase generated electricity in power density unit, while the dependent variables are moisture content as the control parameter, CNPK, C/N ratio, pH, and temperature.

3. Results and discussion

Mixed waste obtained the initial characteristics as follows: 54.61% of moisture content, 27.64% of C-organic, 0.45% of N-total, 0.92% of P-total, 0.95% of K-total, 61.87% of C/N ratio, 6.9 of pH, and 29.5°C of temperature. The closed result was also obtained from the study of the optimum turning in CSMFCs [15]. Then, after the mixed waste was treated by adding water to increase the moisture content, the results changed as follows in table 1 on day 0. Graphene electrode characterization was 159 mV, 912 ohm, 0.17 mA, 0.005 m², and 4.7 mW/m², which meant that characterization was not affecting the production of electricity due to a little voltage, resistance, current, and power density, whereas microbial

identification was identified as *Escherichia coli* sp. which was categorized as phylum Proteobacteria known as electrical producer be-side other exoelectrogenic bacteria like phylum Acidobacteria and Firmicutes [16].

Table 1. The results of composting performance in CSMFCs.

Day	Moisture content (%)	C-organic (%)	N-total (%)	P-total (%)	K-total (%)	C/N Ratio	pH	Temperature (°C)
0	65.00	36.83	0.88	0.25	1.04	47.54	6.25	30.50
1	62.00	35.33	0.94	0.26	1.07	42.89	6.15	33.25
3	65.00	31.58	1.00	0.25	1.10	33.68	5.50	38.25
5	62.00	24.07	0.94	0.24	1.31	27.64	6.40	36.25
10	62.00	22.37	1.00	0.27	1.78	23.39	6.70	32.50
15	62.00	19.88	1.10	0.28	2.09	18.78	6.60	27.25
20	61.00	19.23	1.22	0.37	2.08	16.27	6.80	27.25
23	62.00	18.07	1.31	0.39	2.29	14.20	7.00	27.25

Table 1 describes that moisture content as the control parameter was not meeting the SNI 19-7030-2004, which maximum value at 50% due to the recommended parameter value resulting in high power density value [17]. Whereas CNPK, C/N ratio, pH, and temperature were complying with the standard of mature compost. As mentioned in SNI 19-7030-2004 about the specification of com-post from domestic organic waste that 9.8 – 32% of C-total, 0.4% of N-total minimum, 0.1% of P-total minimum, 0.2% of K-total minimum, 10-20 of C/N ratio, 6.8-7.49 of pH, and soil temperature between 25-30°C [17]. The other visual parameter complying with the compost standard were blackish, texture close to the ground, and smelling soil. The mature compost resulted in a minimum on day 20. Otherwise, 60% of moisture content could accelerate composting, especially in process time, overall, in addition to enhancing the electrical generation.

In addition, CSMFCs at the most accelerate the composting and enhance to produce electricity in the appropriate conditions [10] as follows: 60% of moisture content, minimum four times of turning frequency, 50:50 of mixed waste ratio depends on the volume or weight mass, and C/N ratio up to 45 at the first process. 60% of moisture content represented the ideal condition in composting, especially using the Takakura method which is known in Indonesia to compost the COWM on a household scale [6,18]. The other conditions affect each other to reach the optimum process.

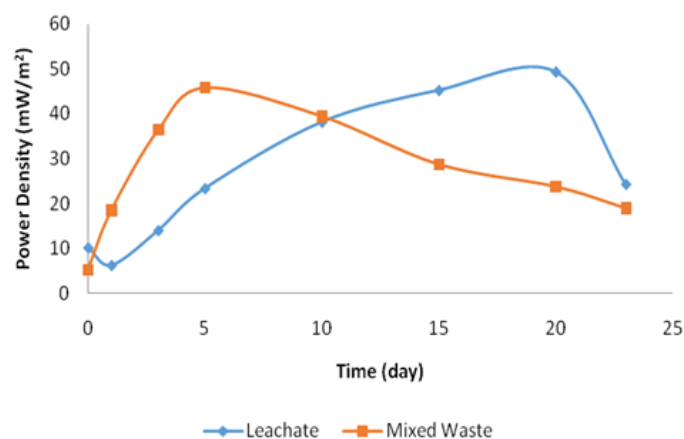


Figure 2. Comparison of leachate and mixed waste generated electricity.

Figure 2 shows the difference in electrical production, which represents the performance of CSMFCs from applying leachate in the liquid phase and mixed waste in the solid phase. Mixed waste is faster to produce electricity in power density units and also contributing to more power density value total than leachate. At the end of time, power density value from mixed waste and leachate are closer in the same power density value, but the power density value from leachate is still higher than the power density value from mixed waste.

Leaves litter and food waste from canteen containing mixed waste generate high power density value at 45.89 mW/m² on day 5th, while leachate produced electricity is still increasing, and low power density value at 23.34 mW/m² under the mixed waste generated electricity. Leachate produces a high power density value at 49.37 mW/m² on day 20th, while mixed waste generated electricity continues to decline with a power density value at 23.79 mW/m² under leachate produced electricity. Composite waste, as same as mixed waste in SMFC, generates the value of power density up to 4 mW/m² [14], which means the complex matrix of mixed waste in CSMFCs generates power density higher than power density in SMFC.

The CSMFC using carbon felt with the mix of rice husk, coffee, and nuts waste as substrates shows that at 60% of moisture content was obtained power density 4.6 mW/m² [19]. Then [20] also state that CSMFC using the mixed fruits, soil, and vegetables with C/N ratio of 24:1 was obtained a power density of 5.29 mW/m². It means that this research configuration increases 9-10 times of the system using the graphene electrode utilized in this CSMFCs. Both mixed waste and leachate generated electricity has the same power density value on day 10th. It describes that mixed waste and leachate produced electricity provides the same trend of power density value. It can be proven that the power density value total is not much different at the end of the time process. Therefore, both mixed waste and leachate generated electricity could be chosen, one of them to be used simultaneously in the CSMFCs reactor or using both of those configurations. In addition, due to the anode placement divided into 2 point at the base and a half of reactor height, it probably affects the trend of power density output that at the first stage, the first anode at half of the reactor exposed earlier than the second anode at the bottom of the reactor. It can be explained that the first exposure of electron containing solid or liquid waste, the faster-producing electricity in power density value. This result agrees Mohan, et al. (2013) that the closer distance between anode and cathode, the higher power and current density result [21].

4. Conclusion

Mixed waste generated electricity is faster than leachate due to the first exposure of the electron, the faster-producing electricity, but both of them result in almost the same power density total value within 23 days process running. The placement of graphene electrode for application purposes can be conducted in one of mixed waste or leachate or both of mixed waste and leachate.

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