Comparison of Waste Volumes on Power Generation and COD Removal in Solid Phase Microbial Fuel Cell (SMFC)

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Abstract. Energy demand rises significantly correlated to human activities in recent years. In contrary, energy supply from unrenewable resource decreases gradually from year to year. OMW as one of the renewable resources has not been expanded well in Indonesia. Therefore, SMFC will answer the alternative technology to generate electricity from OMW. The objectives of this study are conducted to compare of waste volumes on power generation and COD removal in SMFC and determine the optimum waste volume for SMFC application affected by river sediment microorganism source and mixed waste type. SMFC reactor as MFC single chamber was designed by 2.5-liter volume of plastic houseware utilized with single graphene anode and cathode to increase the power generation. The waste volume as the independent variable was adjusted 1/3; 1/2; 2/3 of the 2.5-liter volume of SMFC reactor, whereas river sediment microorganism source and mixed waste were dependent variables. The power density and COD removal percentage in 1/3VR, 1/2VR, and 2/3VR were compared on days 21 which was the typical day of the optimum performance of SMFC. The result shows that power density and COD removal of waste volume 2/3VR was higher than 1/3VR and 1/2VR. Power density of waste volume 2/3VR increased 1.5 - 3 times of power density of waste volume 1/3VR and 1/2VR, respectively. COD removal of waste volume 1/3, 1/2, and 2/3 remained stable. The optimum waste volume, the higher power density and COD removal, in addition to the result that 2/3 of the waste volume was the optimum result.

Keywords: waste volume, power generation, COD removal, SMFC
1. Introduction

The decrease of energy supply from unrenewable resource especially in developing countries like Indonesia needs an effort to meet a demand for energy. As known that Indonesia uses 30% of oil, 22% of coal, 29% of biomass and the other renewable resources, and 19% of natural gas as energy sources [1]. The use of the alternative of biomass from organic municipal waste (OMW) as a renewable resource has not yet developed well in Indonesia because of the regulation closure.

Many scientists around the world are seeking the technologies generating more energy from renewable resources. Indonesia has already used a solar cell, wind turbine, geothermal generator, and a few of biomass reactor, but those have not enough to meet energy demand as population increases. Therefore, SMFC will answer the alternative technology to generate electricity from OMW. SMFC is one of the variants of MFC technology developed first by Reimers [2]. This technology was developed well by using heat-treated soil and applied biological catalyst [3], heat-treated garden compost [4], garden compost [5], household kitchen [6], agricultural waste [7], and leaves litter, canteen and composite waste [8]. SMFC used solid organic matter as substrate and nutrient sources generated to direct electricity through the mechanism of microbial metabolism.

The performances of SMFC were affected by waste and water volume, waste type [7], waste condition (pH and salinity) [9,10], exoelectrogenic microorganism type [11], with/without bio-enzyme [7], the number and type of electrodes [6], and the configurations of SMFC reactor [12]. Waste type, microorganism type, bio-enzyme, and the number and type of electrodes were found much more than other factors, whereas waste and water volume and waste condition were rarely found in many researches. Therefore, the waste volume is focused in this study.

Waste volume is the most important to know because it affects much less of electrical production. The optimum waste volume, the higher electrical production [8]. Other than that, COD removal is also related to electrical output. The optimum waste volume, the higher COD concentration means the higher electrical production. Therefore, the optimum waste volume according to power generation and COD removal can be determined for application purpose.

An appropriate waste volume can be a readily applicable purpose for reality condition. The more waste volume gives the other effect, such as reducing the OMW characterizing the urban area, opening the use of the OMW as biomass in directing the electrical production, etc. The aims of this studies are (1) comparing the waste volumes on power generation and COD removal as the performance parameters of SMFC, and (2) determining the optimum waste volume based on power generation and COD removal in SMFC.

2. Materials and methods

Mixed waste-based leaves litter and food waste were collected using SNI 19-3964-1994 regulation about the standard method of waste collection on urban area [13] from "TPST UNDIP" as the integrated of solid waste management and Faculty of Engineering located in Universitas Diponegoro Semarang. Mixed waste was characterized as follows C-Organic, N-Total, pH, temperature, moisture content, and COD concentration. C-Organic and N-Total represent as macro elements for microbial metabolism, pH, temperature and moisture content were identified as the physical quality of solid waste. COD concentration containing mixed waste was obtained for calculating COD removal. Sediment microorganism was collected from Tanah Mas River located at Semarang Utara district in Semarang City. It was used to enrich the exoelectrogenic microorganism in SMFC process.

2.1 Tools and Materials

Spectrophotometer: Genesys 10s VIS Thermo Scientific-USA, COD reactor, digital multimeter: Heles HE-930L-China, pH meter, and thermometer: Walklab Microprocessor TI9000-Singapore were used as tools to analyze of C-Organic, N-Total pH, temperature, moisture content, and COD concentration, respectively. 2.5-L volume handmade plasticware, Tanah Mas River sediment, mixed waste, aquaest, pencil carbon 2B: KENKO, polyurethane, phosphate acid 85%; EMSURE Merck-Germany, HCl 0.1 N, NaOH 0.1 N, wood glue: FOX, COD high digestion, COD low digestion, and sulphate acid 96%:
PA-ISO Pancreac-ESPAÑA were used as materials to conduct primary research, reactor and graphene electrode production.

### 2.2 Reactor Design
SMFC was designed using 2.5 L plasticware utilizing two handmade graphene electrodes consist of an anode in half of waste volume and cathode in two-thirds of reactor height. Anode and cathode were connected by wire and clip/nippers. Waste volumes were as independent variables that it was affecting the number of reactors which consist of 45 reactor units. The number of reactors was three units which were 1/3; 1/2; 2/3 multiplied to fifteen of sampling time. For example, 1/3 of the solid waste volume was added by water to 2/3 of reactor volume where working volume was 1,330 ml. The configuration of SMFC reactor was illustrated in Figure 1 as follows:

**Figure 1. Configuration of SMFC reactors**
(i) 1/3VR (ii) 1/2VR (iii) 2/3VR
(a) Anode (b) Cathode (c) Waste (d) Water (e) Ventilation Pipe (f) Wire (g) Digital Multimeter

### 2.3 Research Procedure
The research was conducted on greenhouse which was 3 x 3 m of space area at Laboratory of Environmental Engineering, Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro Semarang. There were three steps of research procedures which were preparation, implementation, and analysis phase. At the beginning of research called preparation phase, there were reactor manufacture, graphene preparation and production, initial test, and tools and materials preparation. Reactor manufacture was created by 2.5 L-volume plasticware. Graphene preparation was begun by activating the aluminium plate with HCl 0.1 M solution and NaOH 0.1 M solution [14], blending the carbon powder with polyurethane solution in ratio 1:2, spreading back with the carbon powder at the surface of aluminium plate, let it stand for a while until dry, then smearing all side of the plate with phosphate acid 85%. The initial test was conducted to know the characteristics and performances of graphene handmade. Tools and materials were explained at sub-chapter 2.1. In addition, mixed waste was prepared by combining leaves litter and food waste in a container and evenly stirred until reaching homogeneous; then it was entered on an appropriate container adjusted 1/3 of reactor volume (1/3VR); 1/2 of reactor volume (1/2VR); and 2/3 of reactor volume (2/3VR). At the process of research called implementation phase, there were seeding-acclimatization and running in batch mode. Seeding-acclimatization was conducted at day 0 and directly followed by running during 44 days which had fifteen times of sampling time. SMFC reactor was configured by single chamber type of MFC; however, there was adaptability according to the previous research to reach the optimum of SMFC performance [6]. At the end of research called analysis phase, the axis of the abscissa represents as "x" was time in day unit and axis of the ordinate represent as "y" was %COD removal and PD (mW/m²), was correlated to waste volumes which were 1/3VR, 1/2VR, and 2/3VR. The equation formula of power density: \( P = I \times R \); where \( I \) is the current (amps), and \( R \) is the applied
external resistance (ohm). The equation formula of current: \( I = \frac{V}{R} \); where \( V \) is voltage (volt) \[15\]. The other formulation of power density is calculated using the following equation: \( P = \frac{V \times I}{A} \); where \( A \) (\( m^2 \)) is the surface area of graphene anode \[16\]. The parameters analysis were COD, pH, temperature, voltage, current, and resistance.

3. Result and Discussion

C-Organic, N-Total, pH, temperature, moisture content, and COD concentration containing mixed waste characteristics was analysed as follows: C-Organic 89.61%; N-Total 1.02%; pH 7.37; Temperature 25.9 °C; Moisture content 45.9%; and COD 19,567 mg/l. Those characteristics were identified as highly biodegradable waste material because it was sourced from one of the composite wastes which was the OMW containing food waste \[6\]. The available C and N affect the degradation performance. Initial moisture content of mixed waste affects the microbial metabolism at the initial time and the whole processes. The value of pH at 7 – 8 affects the microorganism growth \[17\]. The result of those characteristics analysis met the requirements of input waste in SMFC reactor.

![Figure 2](image)

**Figure 2.** The pattern of power density and COD removal percentage in time

Figure 2. describes the pattern of power density and COD removal percentage in time when the SMFC reactor was operated on days 0 to 44. Overall trend figured a significant rise on power density and COD removal started from days 13 to 20, but it figured fluctuated decrease until days 44. The availability of C-Organic and N-Total affected the performance of SMFC that the sufficient availability of substrate and nutrition engaged for microbial metabolism producing significant electricity and decreasing COD as organic matter.

The power density reached a peak on range from 18.72 mW/m\(^2\) – 25.20 mW/m\(^2\) meaning of the maximum electron transfer and production on days 15 to 19. Whereas the COD removal percentage reached at above average range from 73.17% - 92.85% meaning of the maximum use of carbon source...
by microorganism on days 14 to 23. After up to 23 days, the pattern of power density and COD removal percentage decreased slowly. Therefore, the power density and COD removal percentage reach the optimum on range days from 14 to 23.

At the beginning from days 0 to 5, the performance of SMFC in COD removal of waste volume 1/3VR, 1/2VR, and 2/3VR was a significant rise, but in power density was slightly increase. COD removal of waste volume 1/3VR was higher than waste volume 1/2VR and 2/3VR, respectively, but power density of waste volume 2/3VR was higher than waste volume 1/2VR and 2/3VR, respectively. From days 5 to 15, the performance of SMFC in COD removal and power density was still stood in the same trend. COD removal of waste volume 1/3VR was higher than waste volume 1/2VR and 2/3VR, respectively, on days 5 to 10, but power density of waste volume 2/3VR was higher than waste volume 1/2VR and 2/3VR, respectively. COD removal of waste volume 2/3VR exceed that of waste volume 1/2VR and 1/3VR and still begun after days 10.

From days 15 to 25, the performance of SMFC in COD removal and power density of waste volume 1/3VR, 1/2VR, and 2/3VR reached a peak. Power density of waste volume 2/3VR reached a peak on days 20, so was power density of waste volume 1/2VR reached a peak on days 17. Power density of waste volume reached a peak on days 25. Overall trend, COD removal and power density of waste volume 1/3VR, 1/2VR, and 2/3VR were that in the highest performance.

From days 25 to 44, the performance of SMFC in COD removal and power density of waste volume 1/3VR, 1/2VR, and 2/3VR fluctuated decrease. COD removal of waste volume 2/3VR and 1/2VR was a significant decrease on days 25 before increasing on the next days 25. COD removal of waste volume 1/3VR was remained stable on the highest performance until it was a significant decrease from days 25 to 44. Power density of waste volume 1/3VR, 1/2VR, and 2/3VR was gradual decrease to 0 mW/m², except waste volume 1/2VR and 2/3VR were still remain approximately 8 mW/m² and 4.5 mW/m², respectively.

For the application purpose, mixed waste could be added on day 21 to maintain the maximum performance of SMFC. Respectively, on day 21, 1/3VR has 85.24% of COD removal and 8.3 mW/m² of power density; 1/2VR has 86.08% of COD removal and 3.5 mW/m² of power density, and 2/3VR has 92.72% of COD removal and 11.52 mW/m² of power density.

The power density and COD removal percentage in 1/3VR, 1/2VR, and 2/3VR were compared on day 21; then those were selected one as the optimum of waste volume. Figure 3 describes the correlation among waste volume to the power density and COD removal percentage.

![Figure 3. The correlation among waste volume to the power density and COD removal percentage](image_url)
The pattern of COD removal percentage shows smoother than power density. The optimum waste volume, the higher COD removal percentage [8], whereas power density shows that 1/2VR was lower power density and COD removal percentage than 1/3VR and 2/3VR. According to the selection of the optimum waste volume, then 2/3VR is selected, because of having higher power density and COD removal percentage than 1/3VR and 1/2VR. Power density of waste volume 2/3VR increased 1.5 - 3 times of power density of waste volume 1/3VR and 1/2VR, respectively. COD removal of waste volume 1/3, 1/2, and 2/3 remained stable.

4. Conclusion
Power density and COD removal of waste volume 2/3VR was higher than 1/3VR and 1/2VR when it was compared on days 21 as the optimum day. Power density of waste volume 2/3VR increased 1.5 - 3 times of power density of waste volume 1/3VR and 1/2VR, respectively. COD removal of waste volume 1/3, 1/2, and 2/3 remained stable. The optimum waste volume at 2/3VR, the higher power density and COD removal.

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