Performance of aerobic and anaerobic landfill bioreactor for municipal solid waste treatment in Jatibarang landfill, Semarang

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Abstract. An investigation on the use of landfill bioreactors was conducted to elaborate an alternative solution on the municipal solid waste management in Jatibarang Landfill, Semarang. In addition, this study is also trying to develop a prevention on leachate and greenhouse gases pollution which are potentially emits from a landfilling process. There are six landfill bioreactors that were constructed for this study, which consist of two anaerobic bioreactors (R1 and R2) and two aerobic bioreactors (R3 and R4). Leachate recirculation was applied on R1 and R2 since the leachate production began while R3 and R4 was given air injection with 2 l/min flow rate. R1 and R2 maintained its thermophilic phase longer and generated more methane gases than aerobic bioreactors. Meanwhile, both aerobic bioreactors reached the thermophilic phase on day-7, faster than the anaerobic bioreactors.

1. Introduction
Landfilling has become the most widely final treatment of municipal solid waste management (MSW) in the world [1]. In Semarang, majority of waste that composed by organic and inorganic matter, will be managed in Jatibarang Landfill [2]. As a result of a landfilling process, highly concentrated organic and inorganic materials called leachate were formed [3]–[5]. There are various factor that determine the composition of leachate, such as water content, density, and characteristic of the solid waste [6]. It is categorized as a wastewater which has the potential to pollute surface and ground water [7], [8]. Other than leachate, methane gases are often formed as a product of landfilling process. Methane gases have a potential to trigger global warming 25 times higher than carbon dioxide [9]. Hence, both leachate and methane gases need to be managed proper to avoid the pollution on environment.

To overcome these problems, a mechanical biological treatment (MBT) is needed, such as landfill bioreactor due to its ability in reducing organic contents in leachate, accelerating biodegradation process, and recovering methane gases [8]. By making a biodegradation process become faster, it helps the solid waste to be stabilized quickly [7]. In addition, the recovered methane gases are likely to become an economical landfill gas (LFG) so that it can be used as an alternative source of electricity for housing [9], [10]. The accelerated biodegradation process and improved LFG generation can be achieved through in-situ treatment, for instance leachate recirculation or water addition to control the moisture content in the landfill bioreactor, as well as air injection [10]–[14]. Other parameters can also be controlled by utilizing this method, namely pH, redox, nutrient distribution, and bacteria [15].
This study aims to investigate the use of landfill bioreactor in improving the quality and amount of methane gases from the biodegradation process of organic waste in Jatibarang Landfill. Several parameters like temperature, pH, COD, and CH4 gas volume are monitored. During the research, two types of landfill bioreactor are used, such as aerobic and anaerobic.

2. Methodology

Four (4) landfill bioreactors (2 anaerobic bioreactors and 2 aerobic bioreactors) were built for this study. Figure 1 shows parts of the bioreactor. Two liters of water were given every day to all bioreactors by pumping, while leachate recirculation was given to anaerobic bioreactor by flowing it through the top of the bioreactor. Leachate recirculation was given to anaerobic bioreactor since the beginning of its leachate generation. Meanwhile, aerobic bioreactors are given 2 l/min air injection.

Leaf waste was given in R1 and R3 while R2 and R4 were filled with vegetable waste, all of the bioreactors has a weight of 10 kg each. The study was conducted for 60 days at room temperature. Parameters such as temperature, leachate quality (pH and COD), and methane gas (CH4) were examined. The temperature and pH were monitored every day, while COD tests were carried out every 5 days. To measure the methane gases generation, a test were carried out every 2-3 days. Bioreactor was built from plastic-drum with a diameter of 50 cm and 150 cm in high. The body part of the bioreactor was given 3 layers, namely PE (polyethylene), aluminum foil, and stretch film to prevent any influences from external factors that possibly enter the bioreactor. The lid of the bioreactor was also made of plastic added with iron crates to strengthen the lid and prevent unwanted influx of air. The organic wastes used in this study were 1-week old leaf and vegetable from Jatibarang Landfill, Semarang.

![Figure 1. Arrangement of Landfill bioreactor](image)

3. Result

3.1. Temperature

Temperature fluctuations during the research process is shown in Figure 2. The initial temperature in the bioreactor was around 28-30°C. In R1 and, the temperature was increasing until it reached thermophilic temperatures. R1 and R2 showed that the thermophilic temperature was reached on day-23 (R1) and day-18 (R2). The thermophilic phase is a phase where bacterial metabolic activity occurs optimally so that the biodegradation of organic materials occurs faster [16]. The temperature continued to rise until it reached the peak temperature, which occurred on day-35 for R1 (60°C) and day-37 for R2 (61oC). After reaching its peak temperature, the temperature in all of bioreactors gradually dropped until reached the room temperature.

Meanwhile, the aerobic bioreactor experienced a significant temperature increase in the first 2 weeks, which was caused by aeration. R3 and R4 reached thermophilic phase starting from day-7,
which was maintained until day-21. The peak temperature of R3 and R4 was reached on the day-12 and day-16 respectively, with a temperature of 55°C, which then decreases the temperature to near room temperature. In the other hand, vegetable waste can maintain thermophilic temperatures longer than leaf waste.

![Figure 2. Variation of temperature in landfill bioreactor.](image)

3.2. Leachate pH

The pH value is an important parameter to note because it describes the quality of the leachate produced. The fluctuations of the pH value every day are illustrated in Figure 3. Optimum pH value has the range from 6.5-8.0 to provide a good environment for bacteria to metabolize [17]. Initially, R1, and R2 had pH value above 5.0 and decreased until day-7, which had a pH value ranging from 4.7-4.9. The fall of pH value could be caused by acid accumulation due to the hydrolysis process under anaerobic conditions because microbial organisms need environments with different acidity to do their activities [18], [19]. The pH value of the bioreactor R1 and R2 began to rise until it reached a value of 7, which is a normal pH, on day-34 and day-37 respectively and continued with a gradual increase to reach the value of 7.0 in end of the study. In the bioreactor R3 and R4, a decrease in pH did not occur. This is likely due to the time for a short accumulation of acids so that the pH value increases and aeration is reducing fermentation process so that acidic compounds are not formed much [20], [21]. The pH value increases significantly until it reached the optimum value (6.5) on the day-3 for R3 and day-4 for R4. Fluctuations in pH values continued with a slow increase until the end of the study. The pH values of all bioreactors were still in the range of effective values, but the temperature parameter indicated that bacterial activity has decreased.
Figure 3. Variation of pH value in landfill bioreactor

3.3. Leachate COD

Beside the pH value, COD also determines leachate quality, which indicates the organic content contained in leachate. The COD value tends to decrease from the start of the study, as illustrated in Figure 4. Initially, the COD values of the waste were about 1,300 mg/l. R1 and R2 were decreasing until it dropped to about 1,100 mg/l in day-30. After day-30, more significant decrease happened because of the temperature entered thermophilic phase. R2 showed a lower COD value in the end of study, which had longer thermophilic period. COD removal for R1 reached 31.3% and 34.1% for R2. Meanwhile, R3 and R4 decreased rapidly in the early of the study because it reached thermophilic phase in the first 7 day. It continued to decrease until the end of the study with 38.7% COD removed in R3 and 37.7% COD removed in R4, which R3 showed slightly lower COD value from day-15.

Figure 4. Variation of COD in landfill bioreactor

3.4. Methane production

Figure 5 illustrates the changes of methane gas generated from each landfill bioreactor. Initially, R1 and R2, which reached the thermophilic phase on day-23 and day-18, produced methane gas of 2.1 µg/m³ and 4.8 µg/m³ on day-5. The production of methane gas continues to rise until the temperature
of the bioreactor reached its peak, with the amount of 32. µg/m³ for R1 and 35.2 µg/m³ for R2 on the day-40 respectively.

On the other hand, R3 and R4 began producing methane gas on the day-5, which were about 13.1 µg/m³ and 14.7 µg/m³. This value continues to increase until day-10 with methane gas produced at 21.1 µg/m³ and 22.1 µg/m³. After the temperature in the bioreactor gradually decreases, the production of methane gas also decreases following bioreactor temperature. The total production of methane for each bioreactors were 199.7 µg/m³, 228.7 µg/m³, 100.4 µg/m³, and 110.6 µg/m³ for R1, R2, R3, and R4 respectively. Methane gas in the anaerobic landfill bioreactor was generated more than aerobic landfill because of in the anaerobic landfill the stable condition for methane production was reached [22].

![Figure 5. Profiles of methane generation](image)

4. Conclusion
This study showed different results of aerobic and anaerobic landfill bioreactors performance. R1 and R2 were given leachate recirculation from it started generating leachate, whereas R3 and R4 given air injection. These conditions were given to accelerate the biodegradation process, which can shorten the stabilization of the waste. Aerobic bioreactor has faster biodegradation process because it reached thermophilic phase and optimum pH faster than anaerobic, because the suitable environment of bacteria are affected by these parameters. Meanwhile, anaerobic bioreactor produced more methane gas than aerobic because it reached the optimum condition for methane gas production. In the other hand, vegetable waste can maintain thermophilic phase better than leaf waste but it contains more organic materials than leaf. Nevertheless, further investigation is needed in a larger scale to ensure the method is suitable to improve Jatibarang Landfill.

References
[1] Giusti L 2009 A review of waste management practices and their impact on human health Waste Manag vol 29 no. 8, pp. 2227–2239
[2] Budihardjo M A and Wahyuningrum I F S 2018 Recovery Practice of Unsorted Solid Waste: from Landfill towards Economic Benefits in Semarang, Indonesia MATEC Web Conf vol 159, p. 02019
[3] Maria F D, et al 2013 Leachate purification of mechanically sorted organic waste in a simulated bioreactor landfill Waste Manag Res vol 31 No. 10, pp. 1070–1074
[4] Maria F D, et al 2013 Experimental and life cycle assessment analysis of gas emission from
mechanically-biologically pretreated waste in a landfill with energy recovery Waste Manag vol 33 No 11, pp. 2557–2567

[5] Maria F D and Micale C 2014 What is the acceptable margin of error for the oxygen uptake method in evaluating the reactivity of organic waste Waste Manag vol 34 No. 8, pp. 1356–1361

[6] Mochamad A. B, et al 2018 Characterization of Leachate from the Integrated Solid Waste Treatment Plant at Diponegoro University Indonesia E3S Web Conf vol 73, p. 07017

[7] Yang Q, et al. 2015 A novel pretreatment process of mature landfill leachate with ultrasonic activated persulfate: Optimization using integrated Taguchi method and response surface methodology Process Saf. Environ. Prot vol 98, pp. 268–275

[8] Wei H 2019 Strategy of rapid start-up and the mechanism of de-nitrogen in landfill bioreactor J. Environ. Manage vol 240 no. 1, pp. 126–135

[9] Broun R and Sattler M 2014 A comparison of greenhouse gas emissions and potential electricity recovery from conventional and bioreactor landfills J. Clean. Prod vol. 112 no. July 2014, pp. 2664–2673, 2016.

[10] Reinhart D R and Townsend T G Landfill Bioreactor Design and Operation. 1998 Boca Raton, FL (USA): CRC Press LLC.

[11] Byun B, et al 2019 Stability of bioreactor landfills with leachate injection configuration and landfill material condition Comput Geotech vol. 108 no. April 2018, pp. 234–243

[12] Maria F D, et al 2016 Treatment of mechanically sorted organic waste by bioreactor landfill: Experimental results and preliminary comparative impact assessment with biostabilization and conventional landfill Waste Manag vol. 55, pp. 49–60

[13] Townsend T 2015 Sustainable Practices for Landfill Design and Operation 2015

[14] Ritzkowski M, et al 2016 Aeration of the teuftal landfill: Field scale concept and lab scale simulation Waste Manag vol. 55, pp. 99–107

[15] Norbu T 2005 Pretreatment of municipal solid waste prior to landfilingWaste Manag vol. 25 no. 10, pp. 997–1003

[16] Kumar S 2011 Bioreactor landfill technology in municipal solid waste treatment: An overview Crit. Rev. Biotechnol vol. 31 no. 1, pp. 77–97

[17] Sekman E, et al 2011 Pilot-scale investigation of aeration rate effect on leachate characteristics in landfills Fresenius Environ. Bull vol. 20 no. 7 A, pp. 1841–1852

[18] Budihardjo M A, et al 2018 Leaves Composting Process and the Influence of Rumen Content and Bran Addition MATEC Web Conf vol. 159, p. 02033

[19] Long Y, et al 2009 Nitrogen transformation in the hybrid bioreactor landfill Bioreour. Technol vol. 100 no. 9, pp. 2527–2533

[20] Qiu Z, et al 2010 Effect of Aerating Frequency on Stabilizing Process of Aerobic Bioreactor Landfillin 2010 4th International Conference on Bioinformatics and Biomedical Engineering, pp. 1–4.

[21] Borglin S E, et al 2004 Comparison of aerobic and anaerobic biotreatment of municipal solid waste J. Air Waste Manag. Assoc vol. 54 no. 7, pp. 815–822

[22] Xu Q, et al 2014 Methane production in simulated hybrid bioreactor landfill Bioreour. Technol vol. 168, pp. 92–96