Impact of Leachate Recirculation on Stabilization of Solid Wastes Leachate in Simulated Anaerobic Bioreactors

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Abstract. The purpose of this study was to analyze the effect of leachate recirculation on decreasing organic pollutant content in leachate which was investigated in a laboratory-scale experiment using simulated landfill anaerobic bioreactors (lysimeters). Leachate used in this study was artificial leachate which was made in high concentrations (BOD 3,758.19 mg/l and COD 7,406.67 mg/l) and low concentrations (BOD 641.30 mg / l and COD 1,279.33 mg / l). Leachate recirculation was carried out on biodegradable waste in reactors with two operating conditions. The first group of reactors was operated with high concentration leachate and the second group was operated with low concentrations leachate. Each operation condition is carried out on 10 reactors which were arranged in series, while the reactor R1 as a control (single pass reactor) was operated without leachate recirculation. Recirculation is carried out every day for 90 days. BOD and COD in leachate samples were regularly monitored every week with two repetitions (duplo). The results indicate that leachate recirculation further increases the reduction of BOD and COD concentrations when compared with reactors without leachate recirculation. Removal of BOD in R1 reactors with addition of low and high concentrations leachate are 68% and 68.13% respectively. While removal of BOD in reactors with addition of low and high leachate concentrations are 83.98% and 92.15%. In general, reactors with leachate recirculation have higher BOD and COD removal compared to reactors without leachate recirculation.

1. Introduction

Waste management is an issue that has not been fully resolved until now. This issue is not only on a local and regional scale but has become a problem at the national level. Based on the Adipura Secretariat of Ministry of Environment and Forestry data in 2015, amounted to 66.39% of the waste generated by the community was disposed at the landfill (TPA), while the rest was piled up, made into compost, thrown into rivers, or burned. Landfilling is the most acceptable and most widely used method in the waste management system in Indonesia of all the available method options. The commonly used final disposal method in Indonesia is the open dumping, where garbage is only disposed of at a landfill site without further management. The use of the open dumping method results in the negative impact of waste in the form of
liquid/leachate which has the potential to contaminate groundwater and surface water, the production of methane gas (CH₄), and carbon dioxide (CO₂).

Gas is the main material produced by a landfill, so as leachate, which is a result of water percolation [1]. The quality of leachate produced highly depends on the amount of water entering the landfill including the initial water content of the waste [2]. Leachate contains a lot of organic and inorganic materials as well as other pollutants so that the leachate produced by a landfill must be pretreated before entering the environment. The commonly used method of leachate management in a landfill in Indonesia is the off-site method where leachate is collected and distributed to the treatment plant to be processed either physically, chemically, biologically or a combination of all three. This method has a consequence of high costs that must be incurred in the treatment process.

Another option of leachate management is the on-site method, which applies leachate treatment by reflowing the leachate produced into a pile of garbage. This method allows the garbage pile to function as a bioreactor. The bioreactor landfill is defined as a waste collection system that is built on the same scale as a typical landfill, equipped with a biological decomposition acceleration system through controlling the level of wastewater in the landfill [3]. Research on landfill that functions as a bioreactor has been conducted for more than 20 years. The study results show that the operation of bioreactors can control the waste decomposition process in landfills, also minimize long-term risks to humans and the environment [4]. The operation of leachate recirculation into landfills will provide various benefits such as increasing the humidity in the garbage, accelerating biodegradation, reducing the time needed for the stabilization process, reducing the total volume and concentration of leachate that must be processed after the landfill is closed, increasing the rate and total gas production, reducing the total volume and concentration of leachate that must be processed after the landfill is closed, increasing the rate and total gas production, accelerating growth microbial population, increasing the distribution of nutrients and enzymes, controlling pH, diluting materials which inhibit decomposition rates, inhibiting and distributing methanogens bacteria, storing leachate and increasing the chances of leachate evaporation [1].

The same thing was also shown in a study conducted by Demir et al. in Chen & Cheng [5] who examined the effect of leachate recirculation on the rate of methane production in backfilled land. The conclusion obtained in the study showed that the rate of waste decomposition in reactors with leachate recirculation treatment increased by 79% compared to reactors without leachate recirculation.

Research on leachate recirculation, which is mostly done in American and European countries, is research on waste which has relatively low water content. The causes of variations in water content in landfills are seasonality, air humidity, and waste characteristics. Higher levels of water in waste will occur in the rainy season than those that occur in the dry season. High humidity, which occurs in many tropical countries, will also affect the water content contained in waste. Garbage in Indonesia has high water content. Based on the preliminary test of the waste generated in the city of Semarang, the water content contained in temporary landfills (TPS) and the landfill was 75% and 55%, respectively.

2. Experiment

This study aims to analyze the effect of leachate recirculation on the biodegradability of domestic waste conducted on a laboratory scale (experimental laboratory) using a lysimeter (waste reactor). Leachate used in this research is artificial leachate and recirculated in a reactor containing vegetable and fruit waste. The research was conducted in three stages, namely the preparation phase, the implementation phase, and the data analysis. The research is planned to be carried out for 3 months which is estimated to have significantly decreased the concentration of BOD and COD. Leachate is made in two types of concentrations, namely high concentrations (BOD 3,758.19 mg / l and COD 7,406.67mg / l) and low concentrations (BOD 641.30mg / l and COD 1,279.33 mg / l). Domestic waste in the form of vegetables and fruits (biodegradable) used originating from the TPS of a market in the Banyumanik Region of Semarang, where is the closest TPS to the study site.
The study using 40 reactors in which 20 reactors used for high concentrations leachate and the other 20 used for the low one. The reactor is made of plastic tubes with a volume of one liter. The reactor section consists of: the bottom layer in the form of gravel as thick as 1 cm that serves as a filter, on the top of gravel layer installed of gauze that serves to prevent garbage particles from entering the gravel which can cause clogging; the center layer of the reactor filled in the form of a garbage mass as high as more or less 10 cm; the top of the reactor is filled with 1 cm thick of sand which serves as a cover, preventing oxygen from entering and leveling the leachate flow into the reactor; and the very top is a blank space that functions as a placement space for leachate recirculation mechanism.

![Diagram of leachate recirculation mechanism](image)

**Figure 1.** Leachate recirculation mechanism

3. **Results and Discussion**

3.1. **Decreasing of BOD concentration**

Based on the study results, the average BOD concentration in the R1 to R10 reactors from the first day to the end of the study on the day 92 is as shown in Figure 2 and Figure 3. Reactor R1 (no leachate recirculation treatment) had a higher BOD concentration compared to reactors of R2 to R10 which received leachate recirculation treatment. In the first week, the BOD concentration in reactor R1 is relatively the same as the other reactors. In line with the addition of the time to decrease the BOD concentration, reactor R1 has slower
with an average BOD concentration above the average BOD concentration of the reactors R2 to R10. The lowest BOD concentration of R1 and R10 was 4,514.29 mg/l and 1,836.91 mg/l, respectively, which was achieved on the day 92. The highest average decrease in BOD concentration occurred in reactor R10 which has the lowest average BOD concentration from the first day to the day 92 when compared to other reactors. In addition to reactor R1 and reactor R10, the average decrease in BOD concentration in reactor R2 up to reactor R9 has characteristics that are relatively like the highest to lowest average values, R2, R3, R4, R5, R6, R7, R8, and R9, respectively.

![Figure 2. Average BOD concentration in reactors with addition of low concentration leachate](image1.png)

![Figure 3. Average BOD concentration in reactors with addition of high concentration leachate](image2.png)

A comparison of the average decrease in BOD concentration in the reactor group with the addition of high concentration leachate was also carried out to determine the pattern of decreasing BOD concentration in each reactor. The graphs above show the average BOD concentration in reactors R1 to R10 from the first day to the day 92. The average decrease in BOD concentration that occurs in reactor R1, which does not receive leachate recirculation treatment, has the same characteristics as the reactor that gets the addition of low concentration leachate. Based on the graphs above, reactor R1 has a lower average BOD concentration decrease compared to reactor R2 to reactor R10 which received leachate recirculation treatment, except on the day 15 where the average concentration of reactor R2 is higher than the reactor R1. The lowest concentration in reactor R1 of 3,576.76 mg/l was achieved in day 92.

The decrease in the highest average BOD concentration occurred in reactor R10 which has an average value of the lowest BOD concentration from the first week to the day 92 when compared with other reactors. The lowest average BOD concentration in reactor R10 was 2,481.04 mg/l which was achieved on the day 92. In addition to reactor R1 and reactor R10, the average decrease in BOD concentration in reactor R2 up to reactor R9 has a pattern that is relatively the same as the average concentration of the highest to lowest sequentially is R2, R3, R4, R5, R6, R7, R8, and R9.
The efficiency of the BOD decrease can be seen in figure 4 and figure 5, respectively for the reactor group with the addition of low and high concentration leachate. In reactors with the addition of low concentration leachate, reactor R1 which is a control reactor, has the lowest concentration decrease efficiency, it can be seen from the reactor performance which is only able to decrease the BOD concentration by 68% at the end of the study (day 92), thus also R1 in the reactor group that received the addition of leachate with high concentration, the efficiency of BOD concentration decrease at the end of the study was only 68.13%, which is the lowest percentage compared to the other reactors in the group.

The highest percentage of BOD removal occurred in reactor R10 in both treatment groups with leachate addition, with a value of 71.91% in reactors with low concentration leachate and 68.62% in reactors with high concentration leachate. In general, the performance of each reactor in decreasing BOD concentrations was relatively the same, although at the end of the study the reactor group with the addition of low concentration leachate had a slightly higher average percentage.

3.2. Decreasing of COD concentration
The graphs above show the average COD concentration in reactors R1 to R10 from the first week to day 92. The average COD is higher than the reactors R2 to R10 which received leachate recirculation treatment. In the first week, the COD concentration in reactor R1 was relatively the same as reactor R2 with a concentration in the range of 15,000 mg/l. The decrease in COD concentration in reactor R1 is slower than reactor R2 to R10. The lowest average COD concentration in reactor R1 was 7,053.83 mg/l achieved on the day 92, while the average reduction in the highest COD concentration occurred at reactor R10 which also had the lowest average COD concentration from the first week until day 92 compared to other reactors. The lowest average COD concentration value in reactor R10 is 3,647.67 mg/l achieved on day 92. In addition to reactor R1 and reactor R10, the average decrease in COD concentration in reactor R2 to reactor R9 has a relatively similar pattern, with the highest to the lowest COD concentrations are R2, R3, R4, R5, R6, R7, R8, and R9, respectively.

Similar to the reactor with the addition of low concentration leachate, in the group of reactors that received the addition of high concentration leachate also carried out a comparison of the average decrease in COD concentration to determine the pattern of COD concentration decrease in each reactor. The graphs above show the average COD concentration in reactor R1 to R10 from the first week to the day 92. The decrease in the average COD concentration that occurred in reactor R1, which has no leachate recirculation treatment, had a similar pattern to the reactor that received the addition of low concentration leachate. Based on the above graph, reactor R1 that did not receive leachate recirculation treatment has a lower average COD concentration reduction compared to reactor R2 up to reactor R10 which received leachate recirculation treatment, except at the week 15 where the average concentration of the reactor R2 is higher compared to reactor R1. The lowest concentration in reactor R1 was 6,204.56 mg/l which was achieved at day 92.

The highest average decrease in COD concentration occurred in reactor R10 which has the lowest average COD concentration from the first day to the day 92 when compared with other reactors. The lowest average COD concentration in reactor R10 was 4914.39 mg/l achieved at day 92. In addition to reactor R1 and reactor R10, the average decrease in COD concentration in reactor R2 up to reactor R9 has a relatively similar pattern with the highest to lowest average values, R2, R3, R4, R5, R6, R7, R8, and R9, respectively.

**Figure 8.** The efficiency of COD decrease in reactors with addition of low concentration leachate

**Figure 9.** The efficiency of COD decrease in reactors with addition of high concentration leachate
The efficiency of COD decrease can be seen in figure 8 and figure 9 above. In the reactor with the addition of a low concentration leachate, the reactor R1 which is a control reactor has the lowest concentration decrease efficiency, it can be seen from the reactor performance which is only able to decrease the COD concentration by 54.97% at the end of the study (day 92), as well reactor R1 in the reactor group that received the addition of high concentration leachate, the efficiency of COD concentration decrease at the end of the study was only 59.49%, which is the lowest percentage compared to other reactors. The greatest COD removal efficiency occurred in reactor R10 in both additions of leachate treatment groups. In the reaction group with the addition of low concentration leachate achieved 71.25% efficiency while the reactor with high concentration leachate had an efficiency of 66.62%. Generally, the performance of each reactor in decreasing BOD concentration was relatively the same, although at the end of the study the reactor group with the addition of low concentration leachate had a slightly higher average percentage.

The graph above shows the average concentrations of BOD and COD in the reactor R1 to the reactor R10 during the study time with the addition of low and high concentration leachate. From the figure above, the average decrease in BOD and COD concentrations for both leachate concentration groups has the same pattern of concentration decrease. The reactor R1 which is a control reactor (without leachate recirculation) in both treatments showed a slower decrease in BOD and COD with higher concentrations compared to other reactors. The reactor R10 is the reactor with the fastest decrease in BOD and COD concentration, with the lowest concentration value when compared to other reactors. This condition applies to both groups of leachate addition with high or low concentrations. The overall reactor average reached a stable BOD and COD concentration values on day 50. The lowest BOD concentration value is 2,338.72 mg/l in reactors with high leachate concentrations and 3,141.46 mg/l in reactors with low leachate concentrations. While the lowest COD concentrations with values 4,634.09 mg/l and 6,204.59 mg/l in reactors with the addition of high concentration leachate and low concentration leachate, respectively.

Reactor R1 is a control reactor, where receives leachate addition like the other reactors but does not get leachate recirculation treatment, while reactor R2 up to reactor R10 receives leachate recirculation treatment. Reactor R2 is a reactor which has a higher organic content than the other reactors because the reactor R2 is the first reactor to get an artificial leachate recharge. The leachate is then stored in a pile of organic material (garbage) in the reactor until reaching the field capacity. Field capacity is the ability of a landfill to collect water. Qasim and Chiang [6] define field capacity as maximum humidity that can be maintained without continuous percolation down by gravity. After reaching the field capacity in the reactor R2, it will cause a leach then flows to the next reactor (reactor R3). Leachate which is accommodated in reactor R2 until reach the field capacity before it flows to reactor R3 has undergone a decomposition process which causes the organic content in leachate to decrease in concentration. Furthermore, in reactor R3, leachate originating from reactor R2 will be stored until reaching the field capacity of reactor R3. The leachate also undergoes a decomposition process before the leaching occurs and flows towards the reactor R4. This process will also occur repeatedly with the same pattern in the reactor R4 up to the reactor R10. Leachate flowing in the reactor R10 also undergoes a decomposition process until it reaches the field capacity before it is streamed back to the reactor R2. Thus, the leachate concentration at the time of recirculation has decreased compared to when the leachate flowed from reactor R2 to reactor R3. This condition occurred repeatedly during the research. Reactors receiving leachate recirculation treatment have higher BOD and COD removal performance and faster time compared to Reactor R1, which is a control reactor or has no leachate recirculation. This result corresponds to research conducted by Pohland [7], Tittlebaum [8], Sanphoti et al [9], Warmadewanthi and Tangahu [10], and Mayur, et al [11].
4. Conclusion
The conclusions of this study results are as follows:
1. The addition of artificial leachate in both reactor treatment groups significantly increased the organic content in the leachate. But, in the group with the addition of a low concentration leachate, it caused an increase in the lower organic content.
2. Leachate recirculation, both in the reactor group with the addition of low and high concentration leachate, further accelerates the reduction and results in lower BOD and COD concentrations when compared to reactors without leachate recirculation. Generally, reactors with leachate recirculation have higher BOD and COD removal efficiency compared to reactors without leachate recirculation. The group with the addition of low concentration leachate had higher BOD and COD removal rates compared to the reactor group with the addition of high concentration leachate.
3. Leachate recirculation does not affect changes in the level of waste biodegradability. The difference between reactors without leachate recirculation and reactors with leachate recirculation does not show significant differences in biodegradability values and has the same pattern of pH changes.

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