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APPLICATION OF LEACHATE RECIRCULATION AS AN ALTERNATIVE TREATMENT METHOD IN LANDFILLS

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ABSTRACT

Leachate is the product of biodegradation process in the landfill, which possesses various disadvantages to the environment. It needs proper treatment to avoid those negative impacts of the leachate. On-site treatment of leachate using leachate recirculation is one of the alternative technologies to reduce the hazard. This study evaluated the application of leachate recirculation as an alternative method of leachate treatment in landfills. Experiments were performed in a laboratory using a total of 60 lysimeters, with 1 L in volume for 365 days. The waste was placed on the top of a gravel to avoid any blockage and percolate the leachate to the bottom of lysimeter. The lysimeter was divided into two groups, with 10 reactors each group arranged in series and conducted in triplicate. Leachate recirculation will be given to second reactor until tenth reactor, using high concentration of leachate for the first group and low concentration of leachate for the second. The recirculation of leachate in both treatment groups significantly increased the organic content in the waste. In the reactor group with low-concentration leachate, the increase in organic content was lower than in reactors with high-concentration leachate. It was found that leachate recirculation accelerates reductions in the BOD and COD concentrations of leachate, compared to reactors without leachate recirculation. This condition applied to both treatment groups. In general, reactors with leachate recirculation had higher BOD and COD removal efficiencies than those without.

Keywords: leachate, recirculation, landfill, BOD, COD.

1. INTRODUCTION

The problem of waste management in Indonesia remains unsolved. Based on data from the Ministry of Environment and Forestry (2015), as much as 66.39% of community-generated waste is disposed of in landfill. The rest is stockpiled, composted, thrown into rivers or burned. Landfill is the most acceptable and most-used method of waste management in Indonesia [1]. The most common waste disposal method in Indonesia is open dumping. The open dumping method can cause pollution of groundwater and surface water with leachate [2], produce greenhouse gasses such as methane (CH4) and carbon dioxide (CO2), produce odors, encourage disease vectors (flies, birds, rats, etc.) and cause social problems in communities near landfill locations.

Leachate is the result of water percolation in landfills [3]. The quality of the leachate produced is highly dependent on the amount of water that enters the landfill, including the initial water content of the waste [4]. Leachate contains many organic and inorganic materials, as well as other pollutants found in landfills [5]. Therefore, the leachate produced by a landfill must be processed before being discharged into the environment [1]. Leachate management methods that are often used in Indonesia include off-site management, where leachate is collected from a landfill and then processed in a leachate treatment plant either physically, chemically, biologically, or by a combination of all three [1]. However, many landfills do not have any leachate treatment plant, which is mainly because of the open dumping system and high costs in the treatment process. As a result, the leachate may contaminate the environment [6]. Leachate, being the product of the degradation of organic waste, consists of various chemical compounds, organic compounds, and microorganisms that are pathogens [5, 7]. These materials could lead into the decrease of environmental quality, especially soil and groundwater contamination as well as public health problems [8-10]. The leachate potentially pollutes the environment for a long time, as the leachate will still be produced for decades or even centuries, if there are no adequate treatment [11].

Another alternative method of leachate management is on-site or in-situ management, where leachate is treated by re-flowing the leachate into a pile of garbage [6]. This method allows the garbage pile to function as a bioreactor [12]. Research on landfills utilized as bioreactors has been conducted for more than 20 years in laboratory-scale reactors, pilot-scale lysimeters, and full-scale landfills. It shows that bioreactors are able to control the waste decomposition process in landfills and minimize long-term risks to humans and the environment [13]. In addition, leachate recirculation into landfills can provide various benefits, such as increasing waste moisture, accelerating biodegradation, reducing the time needed for stabilization, reducing the total volume and concentration of leachate that must be processed after the landfill is closed, increasing the rate and amount of gas production, accelerating the growth of microbial populations, increasing the distribution of nutrients and enzymes, controlling pH, diluting the material that inhibits decomposition (inhibitors), recycling and distributing methanogenic bacteria, leachate storage, and increasing leachate evaporation [3, 13-16].

Brandstätter [17, 18] has studied the mass balance of carbon and nitrogen using lysimeters made of stainless steel with the volume of 121 L in the inside. The study used 8 cm of permeable grid with mesh width of 2 mm as a filter to avoid any water accumulation. It was found that the leachate recirculation, which was controlled by a valve in the bottom of the lysimeter, enhanced the degradation of carbon and nitrogen. Moreover, van Turnhout [10], which used the same data as Brandstätter [17, 18], stated that aerobic treatment with leachate recirculation has higher carbon and nitrogen removal than anaerobic even though it is still only a small fraction compared to the solid waste content. However, anaerobic treatment possesses higher rate constant of hydrolysis, but the distribution of electron acceptor in the waste needs to be optimized. Researches on leachate recirculation also have been conducted in American and European countries. It focused on waste with a relatively low air content. Nevertheless, waste in Indonesia has a high water content (60% on average) [19], thus it is important to be studied further. This study investigates the application of leachate recirculation as an alternative to treatment of the leachate produced at landfill sites. This is done by comparing the performance of reactors with and without leachate recirculation.

2. MATERIALS AND METHODS

Artificial leachate was made in high concentrations (Biochemical Oxygen Demand/BOD 3758.19 mg/l and Chemical Oxygen Demand/COD 7406.67 mg/l) and low concentrations (BOD 641.30 mg/l and COD 1279.33 mg/l) and recirculated in reactors containing waste fruit and vegetables from a market transfer station in the Banyumanik Region of Semarang (Central Java, Indonesia). The study was conducted in an experimental laboratory using a lysimeter reactor run for one year, by which time the waste had reached stability (leachate concentration < 1000 mg/l).

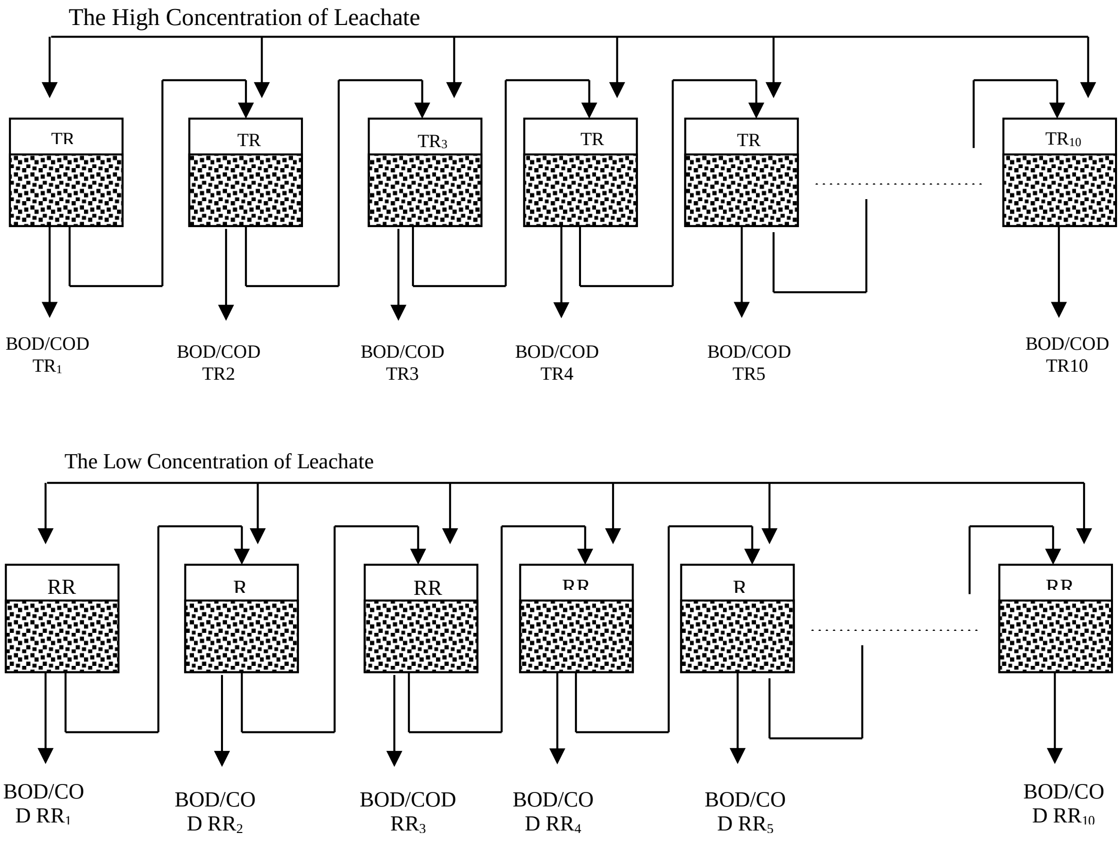

Figure-1. Reactor operational conditions.

Leachate recirculation was carried out under two treatment conditions-high and low leachate concentration-with each using 10 reactors arranged in series. The tests were conducted in triplicate; therefore, the total reactor use amounted to 60 units. The reactors were cylindrical plastic tubes with a volume of 1 liter as shown in figure 1. The bottom layer of the reactor comprised 1 cm-thick gravel as a filter, equipped with a valve in the center to recirculate the leachate that will be opened daily. Gauze layer was added on top of the gravel to prevent garbage particles from entering the gravel and causing blockages. The center of the reactor was filled with up to 10 cm of waste with a weight of 0.8 kg. Meanwhile, the top of the reactor was filled with a 1 cm-thick layer of sand serving as a cover layer to prevent the entry of oxygen and attenuate the flow of leachate into the reactor. The topmost area was an empty space where the leachate recirculation mechanism could be placed. This set up is a common configuration of landfill in Indonesia, which is also similar with Kasam [20]. The temperature outside the lysimeter was maintained within room temperature (25-29 ºC). Brandstätter [17, 18] also used fine mesh grid (2 mm in size) to prevent any accumulation of water in the waste and ensure the leachate percolation.

Leachate samples were analyzed for 15 weeks with testing conducted each week and each month. The tests including measurements of COD, BOD, and pH. The leachate volume used in the tests was 10 ml in each reactor, in triplicate. A COD analysis is performed by the closed reflux titrimetric method based on SNI 06-6989.2.2004, while BOD analysis was carried out weekly according to SNI 6989.02.2009. Measurement of leachate pH was conducted daily by the electrode-potentiometry method using a pH meter.

3. RESULTS AND DISCUSSIONS

3.1 Reduction of BOD

The decrease in BOD is illustrated in Figures 2 and 3, which shows the average BOD concentration in reactors RR1 to RR10 and TR1 to TR10 from the first week to the end of the study (day 365). According to Figure-2, reactor RR1 (without recirculating low concentration of leachate) had a higher BOD concentration compared to reactors RR2 to RR10, which was given recirculation of low concentration of leachate. In the first week, the BOD concentration in reactor RR1 experienced a fall that was similar to other reactors. Over time, the decrease in BOD concentration in reactor RR1 became slower with higher average BOD concentration than in the RR2 to RR10 reactors. The lowest concentration in reactor RR1 was 943.52 mg/l on day 316. The highest decrease in BOD concentration occurred in reactor RR10, which mostly had the lowest BOD concentration of all reactors over the study period. The lowest BOD concentration in reactor RR10 was 473.72 mg/l on day 365. Beside reactor RR1 and RR10, the average reduction of BOD concentration in reactors that used recirculation of low concentration of leachate were similar with the highest average values from the highest to the lowest sequentially are RR2, RR3, RR4, RR5, RR6, RR7, RR8, and RR9.

A comparison of the reductions in average BOD concentration in the high-concentration leachate reactor group was conducted to determine the pattern of decreasing BOD concentration in each reactor. Figure-3 shows the average BOD concentrations in reactors TR1 to TR10 over the 1-year study period. The average reduction in BOD concentration in reactor TR1, which did not receive leachate recirculation treatment, had similar characteristics that of low-concentration leachate reactors. Based on the graph, reactor TR1 had a lower decrease in average BOD concentration than reactors TR2 to TR10 (with leachate recirculation) except on the 15th day, where the average concentration in reactor TR2 was higher than that in reactor TR1.

The lowest concentration in reactor TR1 was 3654.76 mg/l on day 316. The greatest decrease in average BOD concentration occurred in reactor TR10, which had the lowest average BOD concentration over the study period. The lowest average BOD concentration in reactor TR10 was 1010.13 mg/l on day 346. In addition, the average reduction in BOD concentration in reactors TR2 to TR9 had a similar pattern from the highest to the lowest average concentration sequentially is TR2, TR3, TR4, TR5, TR6, TR7, TR8, and TR9.

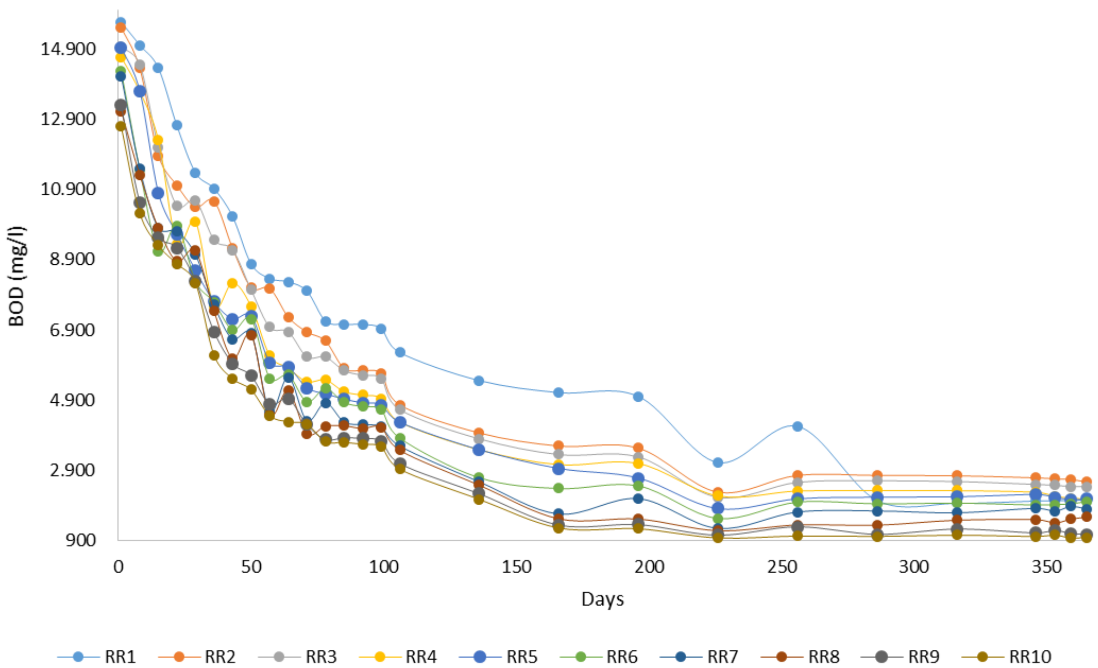

Figure-2. Average BOD concentration in reactors with addition of low concentration leachate.

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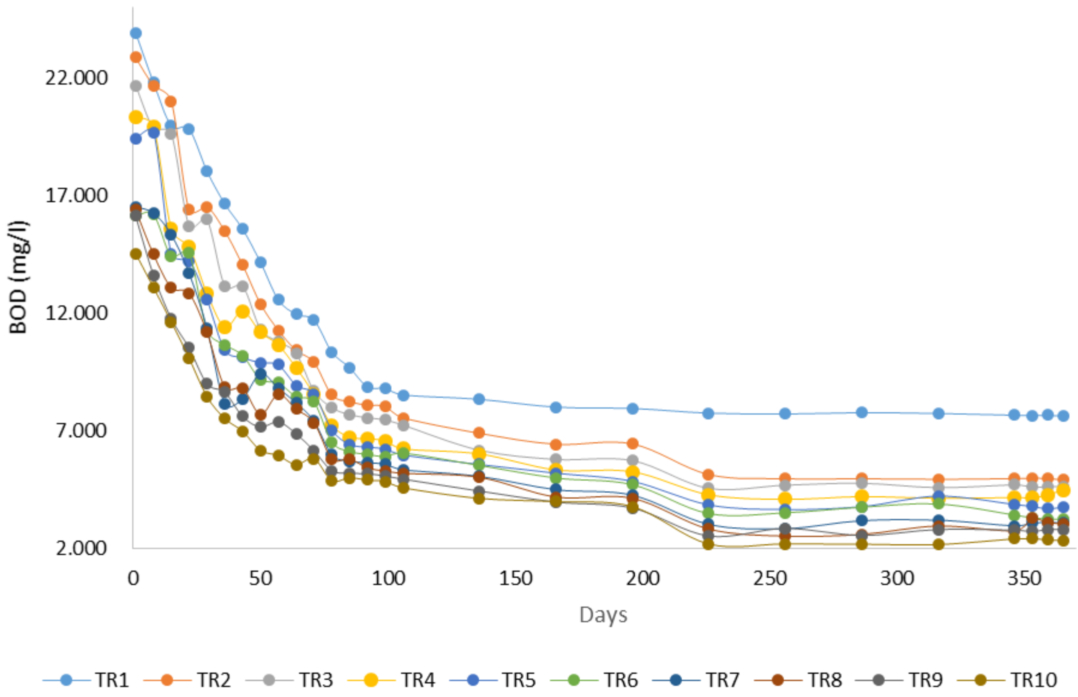

Figure-3. Average BOD concentration in reactors with addition of high concentration leachate.

3.2 Reducing BOD Efficiency

The efficiency of BOD reduction is shown in Figures 4 and 5 for each group of reactors with low- and high-concentration leachate. In the group with low-concentration leachate, reactor RR1 (control reactor) had the lowest concentration reduction efficiency; it was only able to reduce the BOD concentration by 68% over the study period. Likewise, in reactor TR1 (high-concentration leachate), the BOD concentration reduction efficiency was 68.13%, which was the lowest in the group.

The highest BOD removal occurred in the TR10 reactors in both treatment groups with leachate addition: an efficiency of 83.98% with low leachate concentration and 92.15% with high leachate concentration. In general, the performance of both reactors in reducing the BOD concentration was similar, although at the end of the study, the low-concentration leachate reactor group had a slightly higher average. This study had lower removal rate compared to [21] but showed similar pattern to [20]. There are several factors that affect the degradation process of the waste, such as the size, composition, complexity of waste and the operating temperature. Smaller particle size, higher degradable material, and higher waste complexity lead to faster degradation process [20]. Meanwhile, the optimum temperature in the lysimeter is about 29-35 ºC [21].

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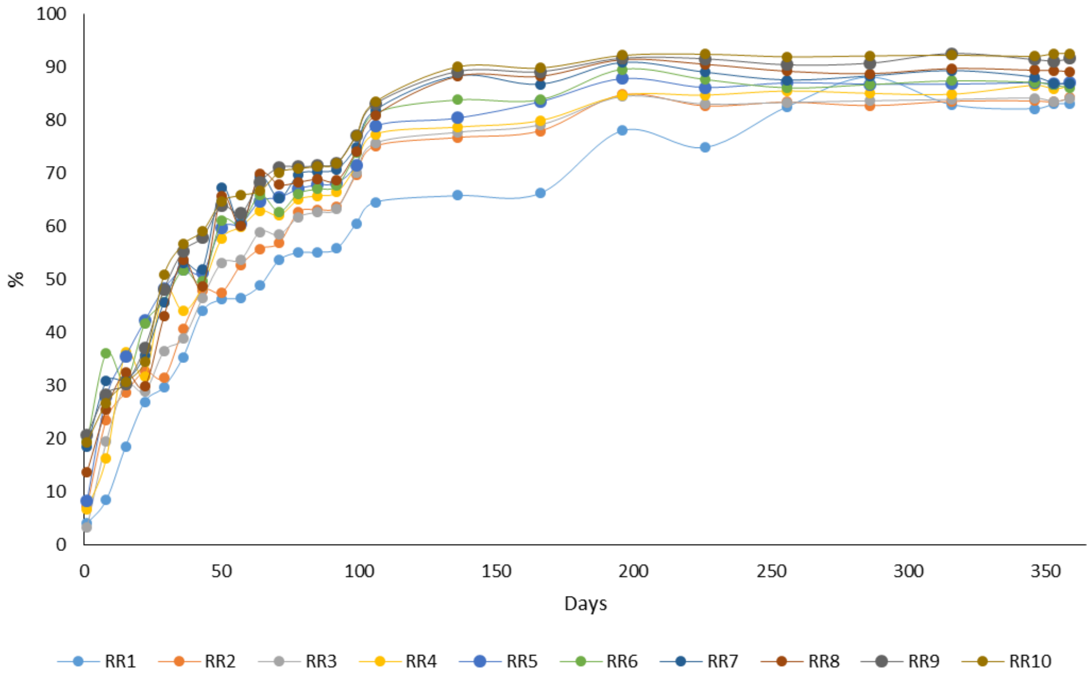

Figure-4. Efficiency of reducing BOD in reactors with low c leachate addition.

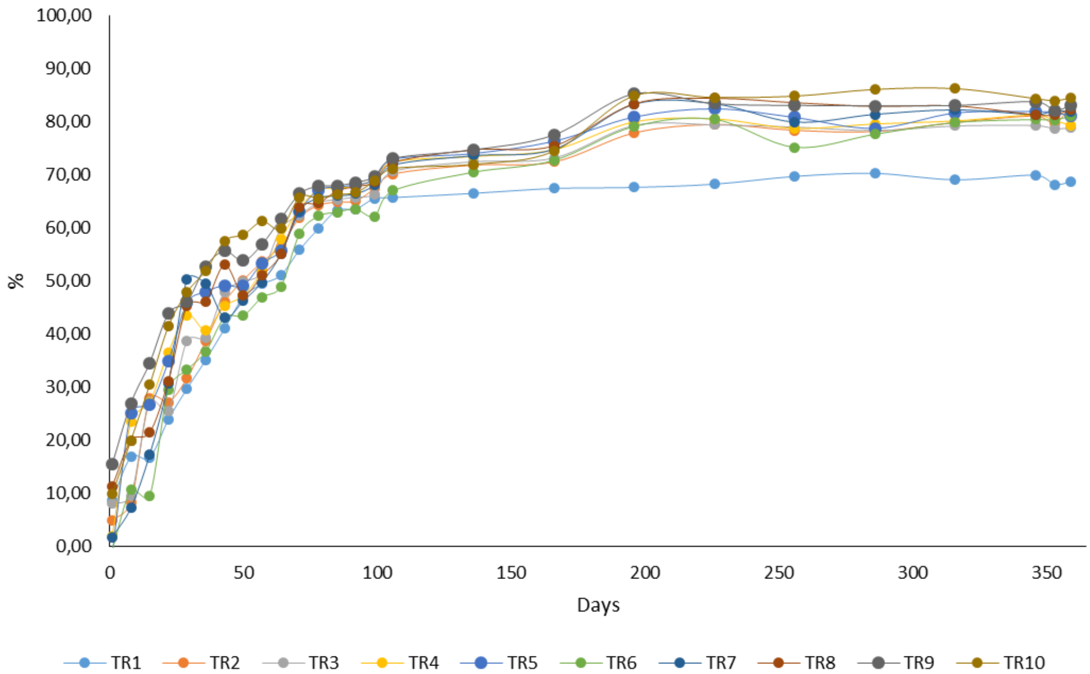

Figure-5. Efficiency of reducing BOD in reactors with high c leachate addition.

3.3 Decreased COD Concentration

Figures 6 and 7 show the average COD concentrations in reactors RR1 to RR10 and TR1 to TR10 from the first week of testing to the 365th day. Referring to Figure 6, the RR1 reactor that did not receive leachate recirculation treatment had a higher average COD concentration compared to reactors RR2 to RR10, which did receive leachate recirculation treatment. In the first week, the COD concentration in reactor RR1 was similar to that in reactor RR2, with a concentration of 15,000 mg/l. The decrease in COD concentration in reactor RR1 was slower than that in reactors RR2 to RR10. The lowest average COD concentration in the reactor was 3,125.69 mg/l on the 226th day, while the average reduction in the highest COD concentration occurred in reactor RR10, which also had the lowest average COD concentration over the study period. The lowest average COD concentration in reactor RR10 was 996.47 mg/l on day

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365. The average reduction in COD concentrations in reactors RR2 to RR9 had similar patterns, with the average value COD concentrations ranked from highest to lowest as RR2, RR3, RR4, RR5, RR6, RR7, RR8, and RR9.

Similar to the reactor that received low-concentration leachate, the reactor group that received high-concentration leachate was compared with the average reduction in COD concentration to determine the pattern of COD concentration reduction in each reactor. The Figure-7 shows the average COD concentration in reactors TR1 to TR10 over the study period. The decrease in average COD concentration in reactor TR1 (which did not receive leachate recirculation treatment) had a similar pattern to the reactor that received low-concentration leachate. Based on the graph, reactor TR1 (which did not receive leachate recirculation treatment) had a lesser decrease in average COD concentration than reactors TR2 to TR10 (which did receive leachate recirculation treatment), except in the 15th week where the average concentration in reactor TR2 was higher than that of reactor TR1. The lowest concentration in reactor TR1 was 7,625.14 mg/l at 27.

The greatest average decrease in COD concentration occurred in reactor TR10, which had the lowest average COD concentration from weeks 1 to 27. The lowest average COD concentration in reactor TR10 was 2,174.72 mg/l. In addition to reactors TR1 and TR10, the average reduction in COD concentration in reactors TR2 to TR9 had similar patterns, being ranked from highest to lowest as TR2, TR3, TR4, TR5, TR6, TR7, TR8, and TR9.

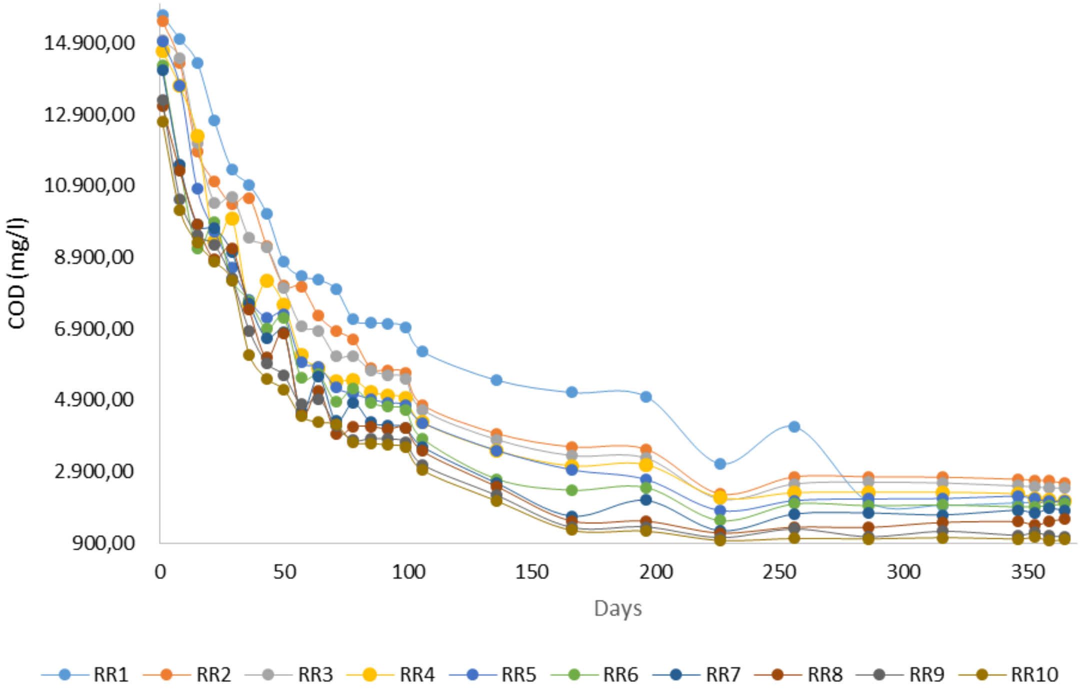

Figure-6. Average concentration of COD in reactors with the addition of low concentration leachate.

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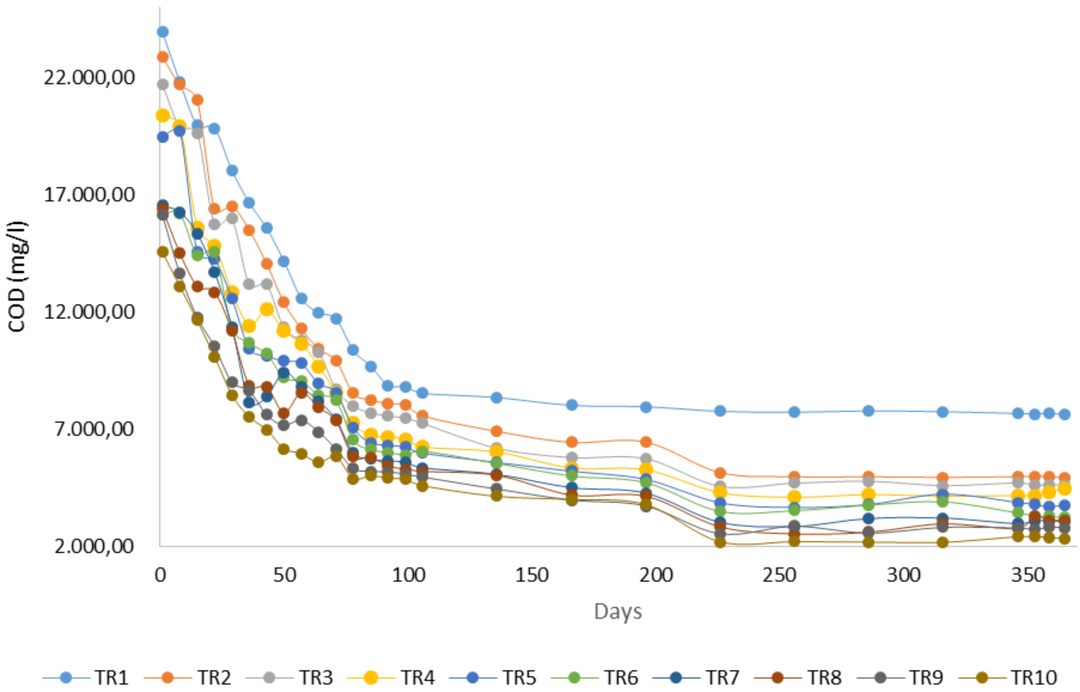

Figure-7. Average concentration of COD in reactors with the addition of high concentration leachate.

3.4 Reduction in COD Efficiency

The efficiency of COD reduction is shown in Figures 8 and 9. In the low-concentration leachate reactor group, reactor RR1 (control reactor) had the lowest concentration reduction efficiency. This is evident in the performance of the reactor, which was only able to reduce the COD concentration by 68% at the end of the study. Likewise, in reactor TR1 in the high-concentration leachate group, the efficiency of COD concentration reduction at the end of the study was only 68.13%, which was the lowest of all reactors.

The greatest COD removal efficiency occurred in reactor RR10 and TR10 in the two leachate addition treatment groups. In the low-concentration reactor group, leachate achieved 83.98% efficiency, while the reactor with a high leachate concentration had an efficiency of 92.15%. In general, the performance of each reactor in reducing BOD concentration was similar; although at the end of the study, the group with low-concentration leachate had a slightly higher average percentage. The removal rate of COD in this study was higher than [20] and [22], although the previous studies also had lower initial COD concentration. It could be due to the amount of waste and its composition in the reactor as these factors determine the rate of degradation process and rapidly decrease COD concentration [23].

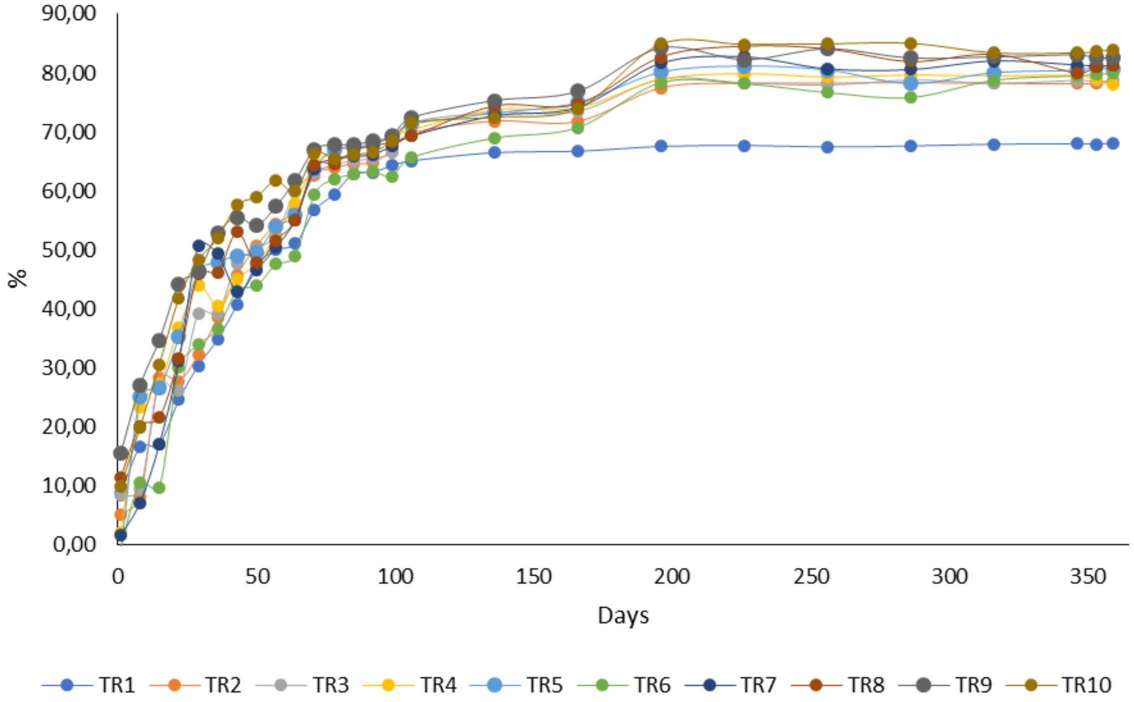

Figure-8. Efficiency of reducing COD in reactors with low c leachate addition.

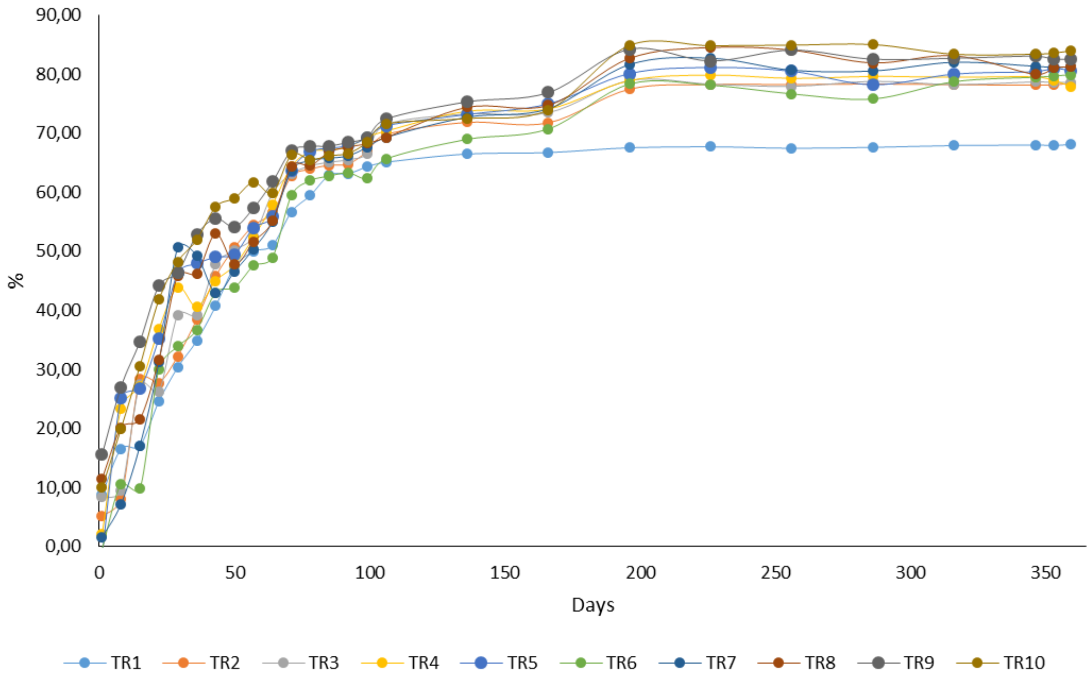

Figure-9. Efficiency of reducing COD in reactors with high c leachate addition.

The average reductions in BOD and COD concentrations had similar patterns in both treatments (low and high C leachate addition). Reactor 1 (control reactor without leachate recirculation) in both treatments showed slower decreases in BOD and COD and higher concentrations. Reactor 10 had the most rapid decreases in BOD and COD concentrations and the lowest concentrations. These conditions applied with both high and low concentrations of leachate. On average, the reactors reached stable BOD and COD concentrations on day 226, with the lowest BOD concentrations being 1,135.87 mg/l in reactors with high leachate concentrations (TR) and 473.72 mg/l in reactor RR10 with a low leachate concentration. Meanwhile, the lowest COD concentrations were 2,807.42 mg/l and 996.47 mg/l in reactors with high and low leachate concentrations respectively.

Reactor 1 was a control reactor, which had leachate addition (like the other reactors) but did not have leachate recirculation treatment. Reactors 2 to 10 did receive leachate recirculation treatment. Reactor 2 had a higher organic content because it was the first to receive artificial leachate addition. During the experiment, leachate was stored in a pile of organic material (garbage) in the reactor until field capacity conditions were reached. Field capacity is the ability of a landfill to collect water. Qasim and Chiang [24] defined field capacity as the maximum humidity that can be maintained without continuous percolation by gravity. After the field capacity in reactor 2 was reached, there was a flow of reflux to the next reactor (reactor 3). Leachate accommodated in reactor 2 until field capacity was reached and before it flowed to reactor 3 underwent a decomposition process, which caused the organic content in the leachate to decrease in concentration. Furthermore, in reactor 3, leachate originating from reactor 2 was stored until the field capacity of reactor 3 was reached.

The leachate also underwent a decomposition process before leaching occurred and it flowed towards reactor 4. This process occurred repeatedly with the same pattern in reactors 4 to 10. Leachate flowing into reactor 10 also underwent a decomposition process until it reached field capacity before it was streamed back to reactor 2. Thus, the leachate concentration at the time of recirculation had decreased compared to when the leachate flowed from reactor 2 to reactor 3. This condition occurred repeatedly during the research process. The reactor group that received leachate recirculation treatment had higher BOD and COD removal performance and a faster time compared to reactor 1. This result is consistent with the research conducted by Pohland [25], Tittlebaum [26], Sanphoti *et al.* [27], and Jirapure *et al.* [28].

CONCLUSIONS

The addition of artificial leachate to reactors in both treatment groups increased the organic content in the leachate significantly. In the reactor group with low-concentration leachate recirculation, it caused an increase in the minimum organic content compared to the reactor with the addition of high-concentration leachate. Leachate recirculation accelerated the reductions in leachate BOD and COD concentrations compared to those in reactors without leachate recirculation, which resulted in lower concentrations. These conditions prevailed in both treatment groups. In general, reactors with leachate recirculation had higher BOD and COD removal efficiencies than those without. The group with low-concentration leachate had higher BOD and COD removal rates than the reactor group with high-concentration leachate. As this technology could enhance the biodegradation process of the waste, the potential of greenhouse gas recovery from this treatment can be explored further. Hence, the landfill can be more environmental friendly because the leachate can be managed properly and the greenhouse gas that is emitted can be recovered.

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