The Use of multiple-soil layer bioreactors to boost decomposition of fresh leachate

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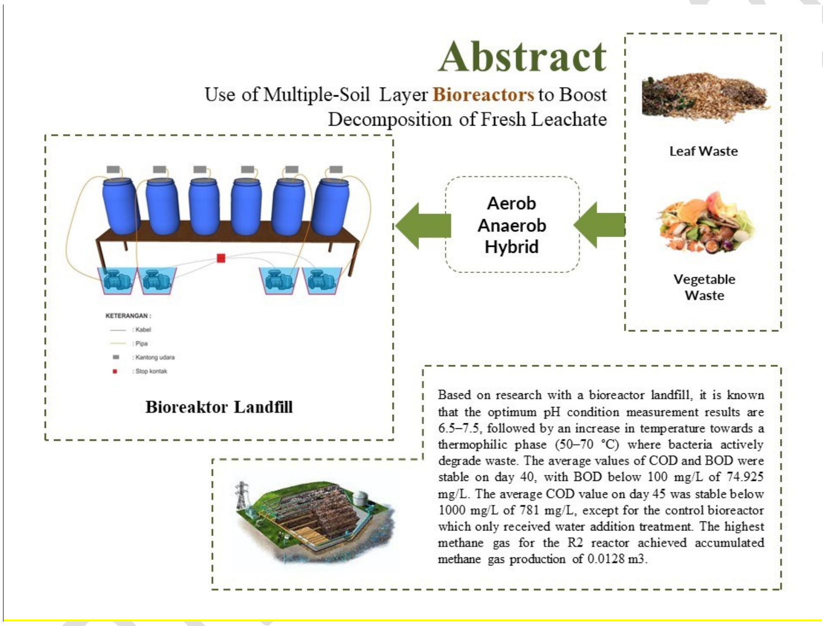
GRAPHICAL ABSTRACT



Based on research with a bioreactor landfill, it is known that the optimum pH condition measurement results are 6.5–7.5, followed by an increase in temperature towards a thermophilic phase (50–70 °C) where bacteria actively degrade waste. The average values of COD and BOD were stable on day 40, with BOD below 100 mg/L of 74.925 mg/L. The average COD value on day 45 was stable below 1000 mg/L of 781 mg/L, except for the control bioreactor which only received water addition treatment. The highest methane gas for the R2 reactor achieved accumulated methane gas production of 0.0128 m3.

ABSTRACT

The amount of waste is increasing daily; however, the available land area is limited. This problem can be overcome by segregating waste and other alternatives by accelerating landfill stabilization using landfill bioreactors. In this study, anaerobic bioreactor A with daily use of water and the leachate, anaerobic bioreactor B with the addition of water and reuse of the leachate daily, and a control bioreactor with the addition of water were used. The parameters measured were the pH, temperature, humidity, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) of the leachate. The reuse of the leachate and addition of water to the bioreactor accelerated waste degradation and caused high humidity. The average COD and BOD in each bioreactor on day 40 were stable. On day 45, the BOD (74.925 mg/L) was below 100 mg/L and the average COD (781 mg/L) was stable below 1000 mg/L.

These results were for all bioreactors except for the control bioreactor, which only received water addition treatment; its COD value was below 1000 mg/L on day 50, at 989 mg/L. Waste decomposition was stabilized, with the BOD below 100 mg/L and the COD below 1000 mg/L.

Keywords: landfill bioreactor, COD and BOD

INTRODUCTION

Landfills constitute the final step in waste management. Semarang has a definitive waste disposal site, i.e., the Jatibarang landfill located in Kedungpane village, Mijen district. Waste generation typically increases with the population growth rate of an area. According to a study [1], the waste generated by the Jatibarang landfill can reach 4000 m^3/day. The waste produced consists of 61.95% organic waste and 38.05% inorganic waste. The diverse content of the waste in the Jatibarang landfill has significant potential to pollute the environment. Therefore, landfill bioreactor technology is required. A bioreactor landfill can accelerate waste degradation by reusing the leachate. Aeration can also accelerate the reduction in the organic matter levels in both waste and leachate [2]. Landfill bioreactors significantly increase the decomposition rate of organic waste, conversion rate of complex organic compounds, and process effectiveness compared to traditional landfill sites [3]. The rate of methane production and municipal solid waste biostabilization in anaerobic bioreactor landfills can be increased by adopting an appropriate combination of operational parameters by considering the benefits and the operational limits [4]. Landfill bioreactors use various technologies, such as water and air injection, leachate recirculation, and in situ treatment, to create a suitable environment for degradation by adjusting pH, redox conditions, and moisture. They employ the same approach as the digestion of solid organic waste and can be optimized with the addition of a leachate or liquid materials [3]. The operation of a landfill bioreactor may also involve the addition of biosolids and other amendments, temperature control, and nutritional supplementation [3]. Moisture content close to the capacity of a waste field (approximately 50% w/w) may be optimal for unsorted domestic waste. It results in faster methanization and 3–4 times higher methane yield during the observation period than 20–30% moisture content [5]. Compared to conventional landfills, the difference lies in the time it takes for waste materials to decompose. In a conventional landfill, waste and other waste materials are deposited and covered with soil or other materials to reduce odours and prevent pollutants from spreading [6]. As time passes, the waste materials break down and release gases like methane and carbon dioxide. However, conventional landfills often have little moisture, which limits microbial activity and slows down the decomposition rate [7]. In contrast, a bioreactor landfill is a waste disposal site designed to actively promote the breakdown of waste materials by introducing moisture and other nutrients [8]. Bioreactor landfills add liquids like leachate or recycled wastewater to increase moisture, promote microorganism growth, and accelerate waste breakdown. These landfills collect and treat resulting liquids, which can be reused or released into the environment [9].

Moisture control is necessary to support metabolic processes and transport nutrients and microorganisms [10], whereas air injection accelerates the degradation process [11, 12]. Landfill bioreactors for metabolic pathways are of three main types : anaerobic, aerobic, and hybrid [13]. Most landfill bioreactors discussed in the literature are operated under anaerobic conditions [14-16], causing accumulation of ammonia, which can partially or completely inhibit methane production. In contrast, systems operated only under aerobic conditions may improve the kinetics of organic matter degradation while completely inhibit methane generation and preventing energy recovery. Hybrid bioreactors operate under various aerobic and anaerobic conditions and offer both these benefits [17, 18].

Potential advantages of using a landfill bioreactor are as follows: (1) increased prepayment before the final closure, which reduces the risk of damage to the final closure; (2) increased waste density and effective landfill capacity; (3) in situ leachate processing; (4) increased gas production rates, which increase energy recovery profitability; and (5) accelerated waste decomposition, which can shorten the regulated post-closure monitoring period and reduce the overall cost of a landfill [19-21]. The use of a landfill bioreactor also ensures sustainability because it has the greatest potential for economic gain owing to the reduced costs associated with long-term monitoring and maintenance, which are avoided and delay placing new landfills [3]. Bioreactors accelerate the decomposition of waste and significantly change the geotechnical characteristics of waste in landfills, thereby increasing the focus on waste stability [22].

Leachate reuse and adding water to bioreactors can affect the quality of the leachate both physically and chemically. Therefore, understanding the characteristics of waste and the leachate produced is essential. The physical parameters to be measured are pH, temperature, and humidity, whereas the chemical parameters to be measured are the chemical oxygen demand (COD) and biochemical oxygen demand (BOD) of the leachate.The majority of research that has been conducted focuses on methane gas production, recirculation rates and also shear strength in MSW covers using bioreactors[5, 22-24]. Therefore, this study aims to determine the effect and relationship between the parameters of leachate pH, temperature and humidity of waste in the production of methane gas. In addition, to determine the effect on the concentration of BOD COD using organic waste with a variety of leaf and vegetable waste and the addition of water and leachate recirculation in landfill bioreactors to increase the decomposition of fresh leachate.

METHODOLOGY

This research was conducted on a laboratory scale using six bioreactors: two anaerobic bioreactors A, two anaerobic bioreactors B, and two control bioreactors. The independent variables were bioreactor, waste, and leachate-reuse variations. The dependent variables were the pH, temperature, humidity, BOD, and COD. The control variable was the addition of water. The material used in the study was organic waste from Jatibarang landfill, Semarang, which was divided into leaf and vegetable waste. After all organic waste was collected, it was enumerated to make it small. Obtaining the geomechanical properties of waste materials under laboratory conditions can be challenging because of the use of modified and large-scale equipment; therefore, using in situ geotechnical investigation methods is very advantageous [25]. The tools used in this study included landfill bioreactors each with a volume of 120 L. Each layer in a bioreactor had a specific height. A hole made in the middle of a plastic barrel was used as a temperature and humidity controller or a sensor hole. The bottom of the barrel collected the leachate output and provided the air for intake into the bioreactor. The addition of water, reuse of the leachate, and output of the resulting methane gas occurred through the lid of the barrel. The bioreactors were tested for air and water tightness by inserting a thermometer and ice cubes for 24 h, to ensure that the temperatures inside and outside the bioreactor can be seen whether there was a difference. To ensure that each bioreactor was under anaerobic conditions, a test was conducted using ice cubes to ensure absence of air in the bioreactor. Ice cubes were placed in a bioreactor, which was subsequently closed tightly. Ice cubes were also placed outside the bioreactor, and the two cases were compared. The ice cubes outside the bioreactor rapidly melted, whereas those inside it remained frozen and did not melt.

Prior to processing the organic waste in each landfill bioreactor, a preliminary analysis was conducted on it. The organic waste was divided into two types: leaf and one-week-old vegetable waste. The preliminary tests were conducted to determine the characteristics of the waste, i.e., to test its water content. The frequency of waste collection was determined by the humidity and moisture content of the waste and influenced by the composition of the waste. The moisture content of a waste sample was determined by its weight loss when heated at standard temperature and time (temperature 105 °C for 2 h). Regarding the principle of testing, the moisture content was tested by heating at 105 °C for 24 h, which caused the water to evaporate without destroying other ingredients.

RESULTS AND DISCUSSION

Before processing in a landfill bioreactor, a preliminary analysis of the organic waste was conducted. The organic waste was divided into two types: leaf and one-week-old vegetable waste. From the results of the preliminary analysis, the water contents obtained from the bioreactors with 66.5% variation in vegetable waste and 43.79% variation in leaf waste were ideal. This is because the required water content for the waste degradation process is 40–60 % [26]. By maintaining the treatment in the form of leachate recirculation and water addition daily, a stable water content was achieved for the waste degradation process.

Effect of Changes in Leachate pH

The pH or acidity of the environment in which aerobic processes occur affects the ability and population of the bacteria working in the existing process stages [27]. pH control is required such that the pH is at most 8.5 [28]. The pH required by organisms at the beginning of decomposition is 7.3–7.6, and an acceptable range is 5–12. Concurrently, organisms break down organic matter in the pH range of 6.5–8.3 [29]. Bacteria work efficiently only at low pH levels (6.5–8.0) [30]. At the beginning of the measurement, the pH of each bioreactor was acidic conditions because bacteria work in the hydrolysis phase, producing acid. Acidity is a main factor influencing methanogenic bacteria, which work efficiently only at low pH levels (6.5–8.0) [30]. The plot of the changes in the leachate pH of each bioreactor shows the type of bioreactorwith a variety of leaf or vegetable waste that can maintain the optimum pH for the methanogenesis phase, which ranges from 6.5 to 8.

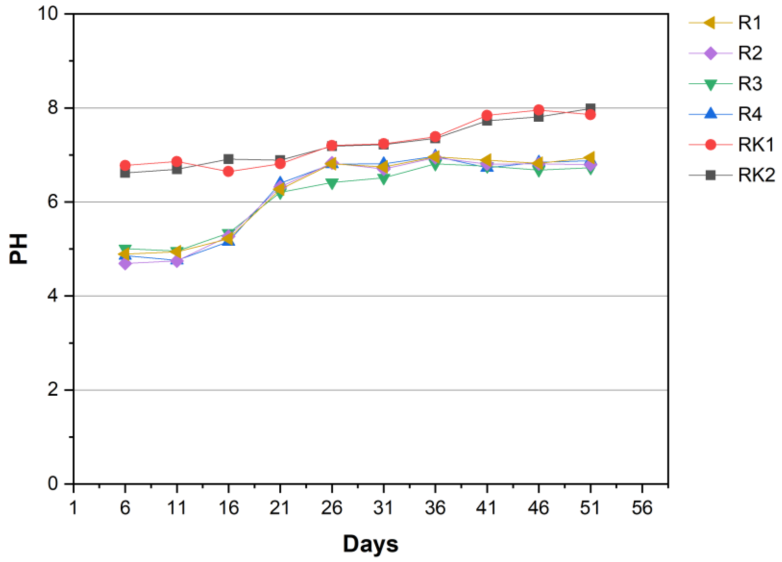


Figure.1 Change of pH Value for 60 Days

Reactors R1, R2, R3, and R4 received the treatment of both water addition and leachate recirculation, whereas reactors RK1 and RK2 received the treatment of only addition of water and leachate recirculation, respectively. However, RK1 and RK2 showed sufficient absorption capabilities for organic leachate and metal contamination under aerobic conditions. Laboratory and field studies have proven that leachate recirculation in waste piles can reduce the organic load of the leachate by up to 90% [31]. Based on the data obtained from the changes in the leachate pH and its relationship with the production of methane gas, reactor R2 underwent the longest methanogenesis phase under the optimum pH condition. Specifically, a hybrid landfill bioreactor with variation in vegetable waste achieved an accumulated methane gas production of 0.0128 m^3.

The Effect of Leachate Temperature Changes

Waste degradation is influenced by microbial activity. There are three temperature conditions in the anaerobic degradation process: psychrophilic (10–18 °C), mesophilic (20–45 °C), and thermophilic (50–70 °C). Under the thermophilic conditions (50–70 °C), more methane gas is produced than under the other conditions. The ideal temperature required at the start of decomposition is 55–60 °C, and the temperature allowed for the decomposition process is 40–70 °C [32]. An increase in temperature during active decomposition is caused by exothermic reactions related to the respiratory metabolism [33].In each anaerobic bioreactor (R1 and R2), on days 23 and 18, the temperature reached thermophilic conditions, i.e., 50 °C. Therefore, they must be treated with leachate reuse to accelerate the degradation of organic matter. After the thermophilic temperature was reached, it returned to a mesophilic temperature, i.e., below 50 °C. Each anaerobic bioreactor B (R3 and R4) reached thermophilic temperature on days 32 and 30, and on day 53, the temperature returned to the mesophilic phase because the thermophilic bacteria were no longer working. In the control bioreactors (RK1 and RK2), on days 9 and 8, the temperature reached thermophilic conditions, and on day 21, it returned to the mesophilic phase.

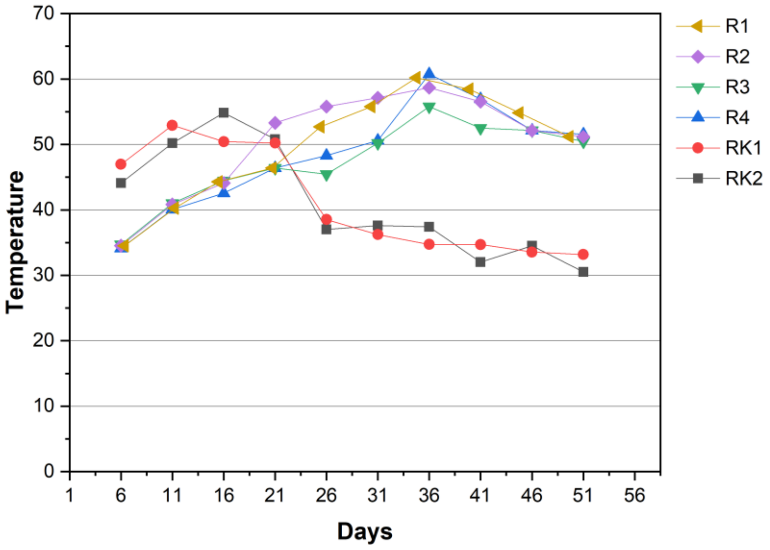


Figure 2. Temperature Value Change for 60 Days

An increase in temperature is an influencing factors for methanogenic bacteria; they work most efficiently under thermophilic conditions, i.e., in the temperature range of 50–70°C [32]. Therefore, three bioreactors could reach the optimal waste temperature and maintain it for the longest time under the optimum conditions for the methanogenesis phase. Specifically, these were R1, R2, and R4 under the thermophilic conditions, as discussed in the previous subsection. The data obtained from the change in the waste temperature and its relation to the production of methane gas, revealed that bioreactor R2 experienced the longest thermophilic condition for 11 days. Specifically, a landfill hybrid bioreactor type with variation in vegetable waste achieved an accumulated methane gas production of 0.0128 m^3.

The Effect of Changes Moisture in Bioreactor Landfill

The optimal humidity range allowed in solid waste piles is 50–60%, and the most optimal humidity value is 55% [34]. The highest production of methane gas is achieved under the optimal humidity conditions. The humidity of each anaerobic bioreactor A, anaerobic bioreactor B, and control bioreactor the humidity was high. The humidity increased daily because of the treatment of addition of water and reuse of the leachate. This treatment also accelerates the waste decomposition process. Decomposing organisms can utilize the organic matter that can dissolve in water [35].

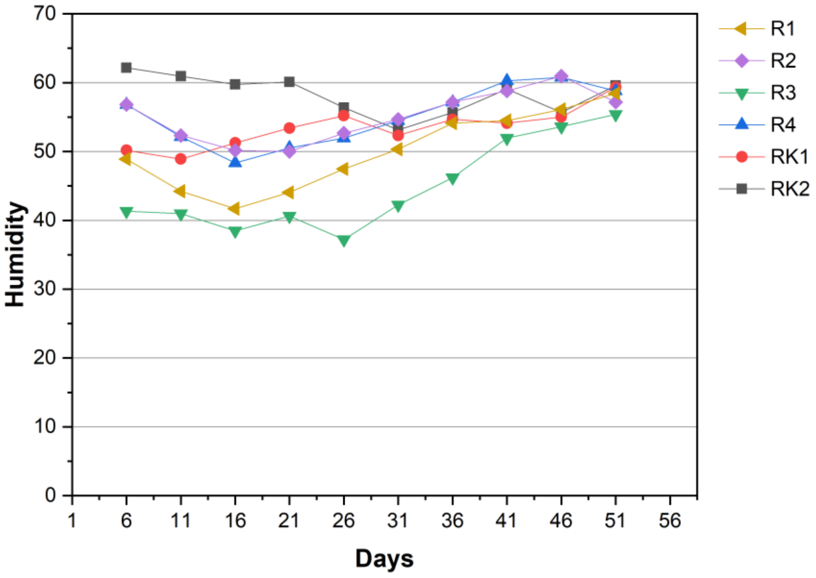


Figure 3. Changes in Moisture Value for 60 Days

The plot of the changes in waste moisture shows the type of bioreactor with a variety of leaf or vegetable waste that can achieve the optimal waste moisture for a sufficiently long time. This will play an important role in accelerating degradation and affect production. Methane gas is produced. Three bioreactors can reach the optimal waste temperature and maintain it for the longest time under the optimum conditions for the methanogenesis phase; these are R2, R4, and RK1. Bioreactor R2 achieves the optimal humidity conditions for the longest time, i.e., 27 days. It is a landfill hybrid bioreactor with a variety of vegetable waste.

Biochemical Oxygen Demand (BOD)

A BOD test generally produces a lower oxygen value than a COD test because materials that are stable to biological reactions and microorganisms can be oxidized in a COD test. The standard five-day BOD is commonly used to describe the level of organic pollutants in wastewater [36]. The BOD is measured to determine the biodegradability of organic materials by bacteria in waste [37]. The BOD value gradually decreases daily because of leachate reuse treatment and addition of water. The decrease in BOD value is due to the addition of water and the reuse of leachate [38].

In this study, in the first measurement, the BOD was still high, the pH was still acidic, and the temperature was mesophilic. When the pH is low under an acidic condition, the BOD is high, and daily it decreases as the pH increases. Bacteria work efficiently only at low pH levels (6.5–8.0) [37]. Concurrently, as explained in Han et al. (2019) the waste degradation process is influenced by microbial activity. The three temperature conditions in the anaerobic degradation process are psychrophilic (10–18 °C), mesophilic (20–45 °C), and thermophilic (50–70 °C) [30].

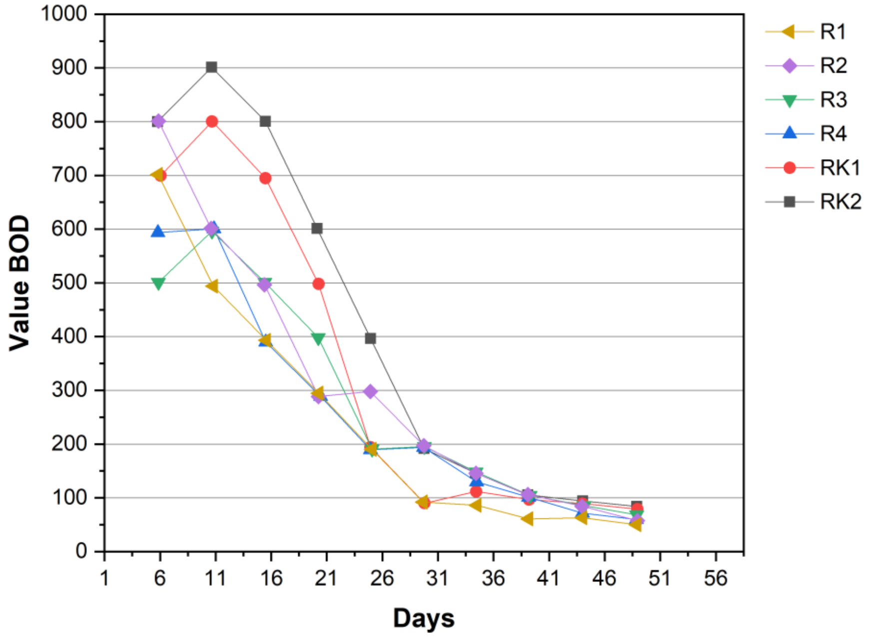


Figure 4. Changes in BOD Value for 60 Days

Chemical Oxigen Demand (COD)

COD is the amount of oxygen required to chemically oxidize organic matter in water. The COD is typically higher than the BOD because more waste material can be oxidized by chemical processes than by biological processes [39]. The leachate COD was measured once every five days to ensure that a significant difference in the results could be observed. The COD at the beginning of the measurement was very high but gradually decreased. This high COD was due to the presence of organic material in the waste, which broke down the organic compounds into smaller components dissolvable in the leachate [40]. Thus, the subsequent decrease in the COD suggests a short process of decomposition of the organic material [41].

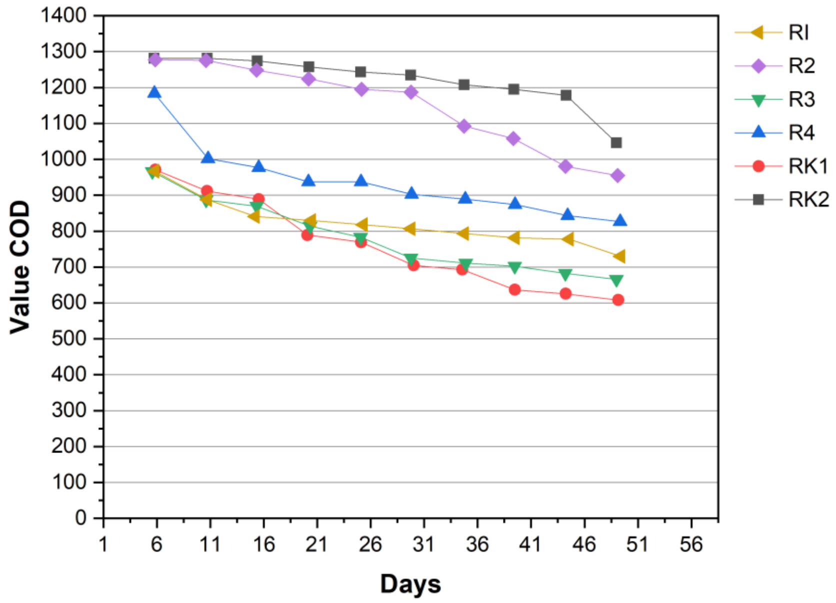


Figure 5. Changes in BOD Value for 60 Days

Bacteria work efficiently only at low pH levels (6.5–8.0) [29]. Concurrently, as explained in [30] the waste degradation process is influenced by microbial activity. The three temperature conditions in the anaerobic degradation process are psychrophilic (10–18 °C), mesophilic (20–45 °C), and thermophilic (50–70 °C). In this study, the COD gradually decreased until it reached below 1000 mg/L. The BOD and COD measurements showed that the COD was higher than the BOD. BOD and COD values can be used as indicators of the stability of waste decomposition. In this study, waste decomposition was stabilized, as shown by BOD values below 100 mg/L and COD values below 1000 mg/L [42].

All bioreactors showed different reductions in BOD and COD values. For bioreactor R1 with variation in leaf waste, on day 30, the BOD was below 100 mg/L, and for bioreactor R2 with variation in vegetable waste, only on day 45, it reached below 100 mg/L. For bioreactor R3, on day 40, the BOD value was below 100 mg/L, and for bioreactor R4 with variation in vegetable waste, on day 40, it was below 100 mg/L. For control bioreactor RK1, on day 40, the BOD reached below 100 mg/L, whereas this occurred for RK2 only on day 45.

The COD of waste is considered to be stable if it is below 1000 mg/L. For the anaerobic and control bioreactors with vegetable waste, the COD from the first measurement was below 1000 mg/L, unlike for the bioreactors with various vegetable waste. For bioreactor R2 with variation in vegetable waste, on day 45, the COD value was below 1000 mg/L; for R4, on day 15, the COD was below 1000 mg/L; for RK2, only on day 50, it reached below 1000 mg/L.

Relationship Between Water Addition and Leachate Recirculation on Methane Production in Landfill Bioreactors

Leachate recirculation in landfills creates a suitable environment for accelerating waste biodegradation [42]. In R1, R2, R3, and R4, which were treated with leachate recirculation, the rate of waste degradation increased, which also played an important role in enhancing the production of methane gas. Concurrently, RK1 and RK2, which did not receive leachate recirculation treatment, maintained the optimal conditions required for the methanogenesis process owing to the air intake and the addition of a liquid. These steps maintained the temperature and humidity of the waste, even though additional moisture in the form of leachate recirculation was absent.

A bioreactor process requires the addition of a liquid to achieve and maintain the optimal conditions [43]. The optimal humidity range allowed in solid waste piles is 50–60% and the most optimal humidity is 55% [44]. If the humidity in a solid waste pile is extremely low, the microbial activity decelerates, whereas if it is extremely high, the spaces between solid waste particles become filled with water, thereby inhibiting air movement in the solid waste pile. In each bioreactor, 2 L water was added daily to accelerate the waste degradation process. In this study, the volume of additional water to obtain the optimum conditions to increase the rate of waste degradation process in a landfill bioreactor was 2 L [27].

CONCLUSION

In this study, the effects of and relationships between the parameters of leachate pH, temperature, and humidity of waste on the production of methane gas and the BOD and COD were investigated. Organic waste with a variety of leaf and vegetable waste was used, and the treatment of addition of water and leachate recirculation to a landfill bioreactor was examined. From the measurement results it was concluded that the optimum pH conditions were 6.5–7.5, followed by an increase in the temperature toward the thermophilic phase (50–70 °C) in which bacteria are active to degrade waste. The temperature gradually decreased to a mesophilic temperature (30–40 °C). During the initial phase, hydrolysis occurred under the acidic conditions, the BOD and COD values were high, and as the day progressed, the pH increased and the temperature decreased. Methanogenic bacteria worked and almost always led to an increase in temperature toward the thermophilic phase (50–70 °C), which was the most effective phase for the methanogenic process. Thus, a high pH of the leachate under the optimal pH condition implies a significant increase of the temperature toward the thermophilic phase.

The reuse of leachate and the addition of water to a bioreactor accelerates waste degradation and causes high humidity. In this study, the average COD and BOD values of each bioreactor were stable on day 40, with the BOD below 100 mg/L at 74.925 mg/L. The average COD value on day 45 was stable below 1000 mg/L at 781 mg/L, except for the control bioreactors, which only received water addition treatment. For them, on day 50, the COD was below 1000 mg/L at 989 mg/L. An increase in temperature toward the thermophilic condition directly affects the humidity, whereas it decreases the waste moisture. The optimal humidity range allowed for solid waste piles is 50–60%. In addition, leachate recirculation in landfill bioreactors can accelerate the waste biodegradation process. In reactors R1, R2, R3, and R4, which were treated with leachate recirculation, the rate of waste degradation increased, which also played an important role in enhancing the production of methane gas. This was evidenced by the highest methane gas acquisition for reactor R2, which was a hybrid landfill bioreactor type with a variety of vegetable waste achieving an accumulated methane gas production of 0.0128 m^3.

Acknowledgments

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