A review of anaerobic landfill bioreactor using leachate recirculation to increase methane gas recovery

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Abstract. Municipal Solid Waste (MSW) treatment with anaerobic landfill bioreactor utilizes landfill as a place of biodegradation and produces methane gas which can be used as renewable alternative energy source. Anaerobic landfill bioreactor technology is a landfill development method that can increase waste degradation and increase biogas production. The increase of biogas and the removal of pollutants from leachate needs to pay attention to the factors that influence the success of anaerobic landfill bioreactor, including pH value, temperature, water content, and COD concentration after recirculation, and methane production. The relationship between these factors was discussed in depth in this paper. The method used is a narrative review where metadata is obtained from Google Scholar and Web of Science. This study explains the development of an anaerobic landfill bioreactor and conducts a synthesis for future research development plans by leachate recirculation.

1. Introduction

Municipal solid waste (MSW) in developing countries generally uses the landfilling method for waste disposal. Cost-effectiveness, easier maintenance, large storage capacity, and the ability to process organic and inorganic waste are the main factors in the use of landfilling [1, 2, 3]. The use of the landfilling method cannot be separated from the negative impacts caused by the operation of landfills in the form of air, water, and soil pollution. These impacts need to be given more attention because they affect human health and the environment, so long-term sustainable management is needed [4, 5]. Air pollution comes from greenhouse gas emissions, while the decrease in soil and water quality is caused by leachate. Both of these pollutants are produced due to the biodegradation process of organic waste material [6, 4].

Because of the high composition of organic waste, greenhouse gases (GHG) and leachate will be emitted to the environment. Moreover, the potential increase in the amount of waste makes management even more complicated. Therefore, mechanical biological treatment (MBT) using anaerobic landfill bioreactors is recognized as technology that can reduce the number of GHG and leachate pollute the environment. Anaerobic landfill bioreactor technology utilizes leachate recirculation to accelerate the
process of stabilizing urban waste, minimizing leachate content, and recovery from methane gas can be achieved [7, 8]. Waste stabilization can be achieved faster, and the methane gas produced can be used economically using this technology [9].

Several researchers have carried out a study of anaerobic landfill bioreactors with leachate recirculation to improve leachate quality. An anaerobic landfill bioreactor produces more gas methane than the aerobic phase because it reaches the optimum conditions for methane gas production [10]. In addition, in the more extended thermophilic phase, the chemical oxygen demand (COD) value tends to decrease lower. Another study also revealed that reactors applying leachate recirculation would increase the decrease in COD concentrations higher than reactors without leachate recirculation [11]. Utilization of leachate with high COD was also carried out by Feng et al., where the study reduced the COD concentration in leachate by 90.7% [12]. This situation can happen because hydrolytic acidification is increased and reduces the pH during acidification. In addition, an anaerobic bioreactor with leachate recirculation and addition of water will reach peak temperatures (60°C – 61°C, respectively) which will increase bacterial metabolic activity so that efficient biodegradation occurs. This condition will increase methane production [13, 14]. Various studies have shown that the anaerobic landfill bioreactor shows satisfactory results when applied on a larger scale. However, no paper has been found that describes these findings in a review article. The relationship between the factors that influence the success of the anaerobic landfill bioreactor process is well understood and can be used as a determinant and decision making how to apply the anaerobic landfill bioreactor. This paper aims to explain the development of an anaerobic landfill bioreactor, describe the factors that influence the success of an anaerobic landfill bioreactor using a narrative method from related references, and carry out a synthesis for further research development plans by combining leachate recirculation with heating elements or using hybrid technology.

2. Literature review

2.1. Current anaerobic landfill bioreactor practices

Many studies on anaerobic landfill bioreactors have been carried out both on laboratory and pilot-scale applications. These studies can be seen in Table 1.

| Reference          | Practices                                                                 |
|--------------------|--------------------------------------------------------------------------|
| Gunarathna et al.  | Rainfall affects the formation of leachate and biological degradation     |
| (2011)             | process.                                                                 |
| Ayuningtias et al. | The concentration of organic matter in lysimeter with recirculation tend  |
| (2013)             | to be higher than without recirculation.                                 |
| Zhang et al.       | The effect of semi-aeration and recirculation can reduce methyl mercaptan |
| (2017)             | concentration in landfills reaching 87.4 – 94.9%, indicating low COD    |
| Kahar et al.       | Comparison for internal pH (in bioreactor) 7.2 and external pH 8 for     |
| (2018)             | mass transfer of leachate and dissolved materials.                      |
| Rasapoor et al.    | The formation of LFG can be increased significantly with a moisture      |
| (2020)             | content of 45%.                                                         |

From the several studies described above, the development of each bioreactor has different specifications because differences influence the characteristics of the landfill in each research area, so the results obtained are also varied. It is necessary to compare the factors that influence bioreactors' success to determine the relationship between them.
3. Result and discussion

3.1. Factor Affecting Anaerobic Landfill Bioreactor Performance

Anaerobic landfill bioreactors with leachate recirculation show that the success of the process is influenced by several factors such as pH, temperature, water content and initial COD concentration.

3.1.1. pH value. Optimal pH value for bacteria to metabolize is 6.5-8.0 [15]. The decrease in pH value in the early stages is caused by the accumulation of acid due to the hydrolysis process because microbes require an environment with different acidity levels to carry out their activities [10]. Biogas production will achieve optimum results at the end of the hydrolysis stage if the pH value is in the range of 6.8-7.2 [16].

3.1.2. Temperature. The hydrolysis process causes the temperature to rise and fall again due to bacterial activity [14]. The initial temperature in the bioreactor is carried out between 28°C-30°C [10]. The temperature will increase and reach the thermophilic phase (45°C-60°C), which is the phase where bacterial metabolic activity occurs optimally and biodegradation occurs more quickly [13]. After reaching the thermophilic phase, the temperature will gradually decrease until it reaches a temperature of 28°C-30°C, which indicates that bacterial activity is decreasing [14].

3.1.3. Water content. The water content will encourage microbial activity to increase biogas formation in the range of 85-90% [17]. The water content is influenced by the pressure of the overburden and the level of degradation of municipal solid waste or MSW [18]. Deeper landfills have higher moisture content, high-density values, and lower porosity [19]. The optimal water content in gas formation is in the range of 40%-60% [20]. The conventional landfill has a high-density value but low water content. For that, it is necessary to adjust the humidity to increase biogas production [21].

3.1.4. Initial COD (chemical oxygen demand) concentration. COD growth was relatively slower before day 10 because the lag phase represented a delayed response of microbes to environmental changes [22, 12]. COD concentration increased rapidly in the next 10 days, as leachate recirculation increased the moisture in the waste [12]. Recirculating leachate increases the concentration of organic substrates in the waste pile, which is decomposed by microbes so that the concentration increases and the COD degradation rate decreases at the final stage [23]. The reactor with leachate recirculation had a higher COD removal performance than the reactor without recirculation [14]. The concentration given is 7,406 mg/L with an efficiency of removing pollutants of 68%. The COD value decreased since the beginning, and after entering the thermophilic phase, the decrease would be more significant and would continue to decline until the end [10]. Methane gas production will continue to increase until the bioreactor temperature reaches its peak, after which the temperature in the bioreactor decreases, causing methane production to decrease [10]. More methane gas is produced in an anaerobic landfill than in anaerobic landfill because stable conditions for methane production are achieved [8, 12]. The COD reactor of 6,000 mg/L showed the highest volume of methane at 89%, while the control reactor was 78% and the COD reactor was 9,000 mg/L 71%. This difference is caused by the proportion of methanobacterium that utilizes H2/CO2 to form methane. Therefore, the correct concentration of COD during recirculation will increase methane production.

3.2. Future development of anaerobic landfill bioreactor

In addition to leachate recirculation, the development of a bioreactor can be done by the addition of temperature controller to obtain an ideal bioprocess condition and endorse a rapid organic matter decomposition by the microorganism [24]. Another technology that can be developed from bioreactors is hybrid technology. Aerobic bioreactors produce less gas than hybrid bioreactors, with 80.5 µg/m³ for leaf litter and 44.3 µg/m³ for vegetable waste. Due to more prolonged aeration, there is more oxidized organic material compared to hybrid bioreactors. Bacterial metabolic activity that occurs does not
produce methane [25, 26]. On the other hand, anaerobic bioreactors only produce methane gas of 30.2 µg/m³ and 54.4 µg/m³ for leaf waste and vegetable waste, respectively. This low yield can be caused by not achieving stable conditions for the methane gas production process during the processing.

4. Conclusion
This paper shows that an anaerobic landfill bioreactor with leachate recirculation effectively reduces pollutants and increases methane gas production from landfills. Factors that affect the anaerobic landfill bioreactor process are pH, temperature, water content, COD concentration, and methane gas production. Some of these factors are very helpful in deciding the design of bioreactor development to optimize the desired results. Future research development should employ temperature controller to obtain an ideal condition.

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