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The effect of leachate recirculation with enzyme cellulase addition on waste stability in landfill bioreactor

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Abstract. Landfill bioreactor with leachate recirculation is known to enhance waste stabilization. However, the composition of waste in Indonesia is comprised by organic waste which is lignocellulosic materials that considered take a long time to degrade under anaerobic condition. To accelerate the degradation process, enzyme addition is ought to do. Cellulase is an enzyme that can catalyse cellulose and other polysaccharide decomposition processes. Therefore, operation of waste degradation using leachate recirculation with a cellulase addition to enhance waste stabilization was investigated using anaerobic bioreactor landfill. The experiment was performed on 2 conditions; leachate recirculation with cellulase addition and recirculation only as a control. The addition of cellulase is reported to be significant in decreasing organic content, represented by volatile solid parameter. The volatile solid reduction in the cellulase augmented reactor and control reactor was 17.86% and 7.90%, respectively. Cellulase addition also resulted in the highest cellulose reduction. Settlement of the landfill in a bioreactor with enzyme addition (32.67%) was reported to be higher than the control (19.33%). Stabilization of landfill review by the decreasing rate constant of the cellulose and lignin ratio parameter was more rapidly achieved by the enzyme addition (0.014 day⁻¹) compared to control (0.002 day⁻¹).

Keyword: landfill bioreactor, leachate, lignocellulosic

1. Introduction

Limitation of land and the high volumes of waste disposal to landfill are the problems faced in waste management in Indonesia. Coupled with the operation of the landfill in Indonesia almost entirely using open dumping system which gives rise to a variety of environmental problems [1]. Accumulation of waste disposal that degraded for a long time can lead to increased leachate potential percolate into the soil and affect the quality of the ground water around the landfill area [2]. Thus, the alternative solution in an attempt accelerate the degradation process and stabilization of waste is needed.

Composition of waste in Indonesia is comprised by organic waste, paper, and wood which is lignocellulosic materials [2]. Lignocellulosic materials are considered takes a long time to degrade under anaerobic condition [5]. To accelerate the degradation process, enzyme addition is ought to do. The addition of enzyme cellulase will stimulate chemical processes based on biological catalyst reaction [5].

Landfill bioreactor with leachate recirculation is known to enhance waste stabilization [5]. However, the operation of waste degradation using leachate recirculation with a cellulase addition to enhance waste stabilization is a relatively new application technology that still needs to be investigated further. Recent development in the biotechnology industry in expanding the production of cellulase...
with the reduced cost manufacturing has become one of the drivers to the use of cellulase on landfills. Cellulase enzyme is an enzyme that can catalyze cellulose and other polysaccharide decomposition processes [7]. Based on research conducted by [8], addition of cellulose on leachate recirculation enhance the waste stabilization process and doubled the biogas production. The addition of cellulase on leachate recirculation aims to optimize the degradation process of lignocellulosic material in landfill. Acceleration of waste degradation increases the capacity and expand the operational life of the landfill. However, research using cellulase in leachate recirculation has not been performed especially in Indonesia.

The study was conducted using anaerobic bioreactor. The experiment was performed on 2 conditions; leachate recirculation with cellulase addition and recirculation only as a control. The effect of landfill stabilization by the addition of cellulase on leachate recirculation was investigated by a degradation process of cellulose, lignin and volatile solid (VS) content in waste as well as settlement of waste in landfill bioreactor.

2. Research Method

2.1. Feedstock Preparation
Composition of waste used in this study was 100% organic waste, aims to represent lignocellulosic waste derive from plant biomass. Solid waste samples were collected from Pasar Kemiri Depok, West Java. Both reactors used were filled with 53 kg with the same composition of waste in each. Feedstock was manually shredded into 5 – 10 cm considerate the dimension of the bioreactor used. The waste degradation process can be accelerated by the shred process [9].

2.2. Reactor Assembly
The study was conducted using anaerobic bioreactor operated on different conditions; leachate recirculation with cellulase addition and recirculation only as a control. Two bioreactors made from acrylic (PVC) cylinder pipe. The dimensions of the bioreactors were as follows, diameter = 31.5 cm, height = 185 cm, internal diameter = 30 cm. One side of the pipe wall was cut and covered using transparent acrylic for the measurement of reduced waste in the settlement process. Also on both sides of the cylinder pipe connected using ½” diameter pipes as a port for sampling requirement. At the top of the reactor installed pipes served as leachate inlet and gas outlet pipe connected to the 5 L gas bag. One port at the bottom served as a leachate outlet pipe. This reactor was modified from a simulated
reactor study conducted by [8]. Approximately 15 cm gravel layered at the bottom of the reactor, acted to hold the sample into the leachate outlet to prevent clogging. Above the gravel layer, geotextile layer was placed. On top of that, 150 cm feedstock was placed on with weight 53 kg and density 500 kg m$^{-3}$. The reactor was equipped with a temperature sensor to record temperature data connected with the thermologger. The soil was used as a cover above the waste layer.

2.3. Leachate Recirculation and Cellulase Enzyme
Leachate recirculation reduces the organic content by utilizing the activity of microorganisms in leachate. The design volume of leachate recirculation in landfills is determined by geographic location, seasonal rainfall and input volume waste disposal in landfill [10]. Volume leachate recirculation at the anaerobic bioreactor used the low recirculation rate equilibrium flow rate of 5 L.ton$^{-1}$ [11], so leachate recirculation performed on both reactors was 270 ml. Addition of water performed to simulate rainfall in landfill (600 ml day$^{-1}$). Treatment of lignocellulosic waste was achieved by enzymatic hydrolysis using cellulase enzyme. Cellulase enzyme used in this study was Cellulase CEL 150 produced by Trichoderma reesei, purchased from Sinobios (China) [12]. The CEL 150 enzyme activity consists of several cellulase enzyme including Endo-ß-1.4-glucanase (CMC) /1,500,000 U/g, FPA, Xylanase, ß-glucanase. According to study [11], the amount of enzyme added was equivalent to 15 million u ton$^{-1}$. As for this study, the 0.53 gram cellulase was added on leachate recirculation.

2.4. Analytical Method
The moisture content was measure using the gravitational method of Standard Method 2540-B. Samples are dried to constant mass in an oven at (105 ± 5)ºC at an interval of minimum 1 hour, then cooled at desiccator and weighed using an analytical balance. A modified Standard Method APHA Method 2440-E was used to measure volatile solid. The constant weight of samples (105 ± 5) ºC drying result was combust in the furnace 550ºC for 1 hour. The lost weight of combustion results from weight of total solid is content of volatile solid. Waste temperature was measured using temperature sensor connected to the thermologger unit. Settlement of waste in bioreactor determined using a measuring tape mounted near the transparent acrylic side of the reactor. Measurements are made daily to illustrate the ongoing waste stabilization process. Lignin and cellulose content were measured using Chesson–Datta Method and reported as percentage w/w.

3. Results and Discussion

3.1. Characteristics of Feedstock.
Physical and chemical characteristics of feedstock were required to determine the initial condition of waste and as a reference of degradation process due to treatment in this study. Parameters measured in this study were waste settlement, temperature, C:N ratio, moisture content, volatile solid, and lignin:cellulose ratio. The initial of waste layer was 150 cm on both reactor. The settlement of waste at both reactors at the end of the study were compared. The initial feedstock temperature was 32.6 ºC. In general, temperature in landfill equipped with water addition is in the range of 30 – 45ºC and will increase due to microorganism activity and the characteristics of the waste itself (Kim, 2004). The C:N feedstock ratio was 17:1, indicated that the feedstock has adequate nutrient availability for the degradation process by microorganisms. Volatile solid can describe the cellulose content of waste and estimate the readily degradable organic content. Volatile solid of the feedstock was 73.73%TS. The C:L ratio in feedstock was 4.16 with 50.30 %w/w cellulose content and 12.09 %w/w lignin content.

3.2. Settlement of Waste
Settlement of waste described the degradation process in the reactor. Based on Figure 2, settlement in the reactor with augmented cellulase was considerably different than settlement in the reactor with leachate recirculation only. Settlement of waste in a reactor with augmented cellulase was 13.3% larger than the control. Settlement that occurred until day 91st in the cellulase augmented reactor and the control reactor was 32.67% and 19.33%, respectively. The first order settlement rate for the reactor with cellulase addition was 0.0028 day$^{-1}$ and reactor with leachate recirculation only was 0.0016 day$^{-1}$. 
The settlement behavior of landfill is due to the consolidation and degradation that occur in landfill [13].

The degradation of organic matter in landfill caused a major amount of settlement as the organic material is converted into different phase as decomposition product consist of liquid form and the landfill gas. Settlement in this study has a strong correlation with the reduction in organic content indicated by volatile solid parameter. Statistical analysis with significance level set at 0.05, indicated that there was a significant difference in the cumulative percentage of the settlement between the reactor operated with cellulase addition on the leachate recirculation and the reactor operated with recirculation only (t(182)=14.812, p=0.000).

3.3. Volatile Solid, Cellulose and Lignin Content
Chemical characteristic parameters of the waste decomposition process used in this study are volatile solid (VS), lignin and cellulose. Volatile solid is commonly used to estimate the organic content of waste [14]. The major organic content of waste is composed of cellulose. Volatile solid should not decrease to zero as a point of stabilization [16], but low cellulose and low volatile solid may be possible parameters of stabilization [17].

Both reactors showed the decreasing of volatile solid content, indicated that decomposition of organic matter occurs. At the end of this study, volatile solid reduction in the cellulase augmented reactor and the control reactor was 17.86% and 7.90%, respectively. Reduction of volatile solid indicated organic content had been degraded during the operation. The addition of cellulase is reported to be significant in decreasing organic content represented by volatile solid parameters (t(11)=-7.712, p=0.000). The average difference of volatile solid content on both reactors was 7.19%TS.

Based on study [18], when the cellulose is degraded, the lignin content will remain and the percentage of its contents on the waste will increase. Cellulose content on both reactors decreased. Cellulose content reduction in the cellulase augmented reactor and the control reactor was 24.50% w/w and 18.40% w/w, respectively. While lignin until the end of the study was increased. This occurrence caused by lignin considerably difficult to degrade under anaerobic condition [8]. Lignin is not decomposed until cellulose reaches level below 25% [17]. In the study [16], the lignin level at the beginning of the study increased and began to decrease slowly after cellulose has been degraded.

Cellulase enzyme is an enzyme that can catalyze cellulose and other polysaccharide decomposition processes [7]. Statistical analysis determined there was a significant difference in cellulose content in the bioreactor with the cellulose addition, compared to control (t(5)=-3.8000, p=0.013). Cellulose to lignin ratio can be used as an indicator of waste stability in landfills. The cellulose to lignin ratio of less than 0.2 may indicate that the waste has reached a stabilization point (Kim, 2004). The initial of the ratio C:L in the feedstock was 4.16 and continued to decrease until the end the study in a reactor with cellulase addition and control; 0.96 and 1.41, respectively. Until the end of this study, based on C:L parameters the waste in both reactors has not reached stable condition. The higher constant of the first degradation rate of ratio C:L showed in a reactor with cellulase addition than control. The first
order degradation rate of ratio C:L for the reactor with cellulase addition was 0.014 day\(^{-1}\) and reactor with leachate recirculation only was 0.012 day\(^{-1}\). Cellulase significantly enhanced the stabilization of waste in this study based on a ratio C:L parameter \((t(5)=-3.280, p=0.022)\).

**Figure 3.** Volatile solid and cellulose in bioreactors.  **Figure 4.** Ratio C:L in bioreactor.

### 3.4. Output of the treatment with cellulase addition to leachate recirculation

The cellulase enzyme added to leachate recirculation significantly affects organic degradation as indicated by parameters such as settlement, cellulose, ratio cellulose to lignin and volatile solid. The highest reduction of organic matter was showed in a reactor with cellulase addition and this also indicated shorten the waste stabilization process. Application of cellulase enzyme in landfill based on this result can accelerate the stabilization process, thus increase the capacity and age of the landfill. However, further research is needed to improve efficiency, especially in terms of operational costs. It is important to acknowledge in advance the optimum enzyme addition required at the time of application in landfill operation.

#### Table 1. Output of the treatment results.

| Parameters          | Initial  | Post Treatment | \(\Delta\) (%) |
|---------------------|----------|----------------|-----------------|
| Settlement (cm)     | 150      | 101            | 32.67           |
|                     |          | 121            |                 |
| Cellulose (%w/w)    | 50.30    | 25.80          | 48.71           |
|                     |          | 31.90          |                 |
| Ratio C:L           | 4.16     | 0.97           | 76.78           |
|                     |          | 1.41           |                 |
| Volatile Solid (%TS)| 73.73    | 55.86          | 24.23           |
|                     |          | 65.82          |                 |

### 4. Conclusion

Degradation of organic content in waste significantly increased due to the effect of the addition of enzyme cellulase on leachate recirculation investigated by a degradation process of cellulose, lignin and volatile solid content in waste as well as settlement of waste in landfill bioreactor. Stabilization of landfill review by the decreasing rate constant of the cellulose and lignin ratio parameter was more rapidly achieved by enzyme addition compared to control. It is important to identify the optimal quantity of the enzyme cellulase to enhance stabilization and improve the efficiency of the operation in landfill.

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