Effect of Biocover Thickness on Methane Oxidation Rate of Landfill Gas Emission from Municipal Solid Waste Landfill in Tropical Climate Region

Yusnan1, F. Razi2 and E. Munawar2,*
1Postgraduate Student at Chemical Engineering Department, Faculty of Engineering, Syiah Kuala University
2Chemical Engineering Department, Faculty of Engineering, Syiah Kuala University, Banda Aceh 23111
*e-mail: edi.munawar@unsyiah.ac.id

Abstract. The landfilling of municipal solid waste (MSW) in developing countries mostly is carried out by means of open dumping or control landfills. The degradation of organic compounds of MSW inside the landfill will produce the landfill gas, where the main component is methane (CH4) and carbon dioxide (CO2) are categorized as the greenhouse gas (GHG). These gases if not managed properly will escape and increase the GHG accumulation in the atmosphere. There is many methods has been established and apply to reduce landfill gas emission, but mostly required high investment so not affordable for developing countries. Method that might be applied to reduce GHG emissions from landfill in developing countries is utilization the microorganism to oxidizing CH4 commonly called biocover. The purpose of the study was to analyze the effect of biocover thickness on the oxidation efficiency of CH4 from landfill gas in tropical countries. The concentration CH4 in landfill gas throughout landfill simulator reactor (LSR) covered by 20-60 cm of thick the biocover was measured daily by using the gas analyzer (Sewerin, Multitec 540). The LSR was made of acrylic pipe with a diameter of 25 cm and height of 100 cm. The landfill gas was used has an initial concentration of CH4 approximately 30% and the moisture content of biocover used was maintained at 40%. The experimental results obtained shows the CH4 oxidation efficiency of biocover for 20 cm, 40 cm and 60 cm thick were 8.12%, 9.72% and 4.56%, respectively.

Keywords: municipal solid waste; landfills gas emission; greenhouse gas emission; tropical climate region, landfill gas oxidation, biocover landfill.

Introduction
Municipal solid waste generation has become a complex environmental problem and poses health problems for people all over the world, especially in developing countries. This problem arises because of the rapid pace of urbanization and population (UNEP. 2004).

Leachate pollution and gas emissions from landfills to the environment are the main concern of environmental experts because gas emissions from the decomposition of organic matter in the form of CO2 and CH4 are the main components of landfill gas. These gases are very strong in absorbing infrared light, causing the earth's temperature to increase or commonly called the greenhouse effect (Popov 1999).

Regarding emissions from landfill, research has been carried out generally in non-tropical countries. Even though tropical countries have different environmental characteristics so the emissions produced will certainly be different. For example, the leachate characteristics produced are influenced by precipitation, evapotranspiration, moisture content in waste, density, storage capacity, composition of waste and age of waste in the dump (Kasam, Sarto et al. 2016).

Control of CH4 gas emissions in landfill can be taken, among others, by controlling since at the source which means reducing organic waste brought to TPA, taking gas either actively to be used as energy, or landfill biocover system to naturally oxidize CH4 by methanotrophic bacteria (Morales 2006), and finally aeration in landfills so that anaerobic conditions do not occur. One alternative to the
management of greenhouse gases at the closure of open dumping landfills is the closure system as a medium for the CH₄ gas oxidation process. The oxidation process of CH₄ gas in landfills requires a medium that is capable of being a place to grow methanotrophs. CH₄ gas is a gas with a stable molecule, but it is ready to be oxidized by the bacteria methanotrophs on the ground (Escoriaza 2005).

Research Methodology

Experimental Setup

The equipment used in this study is a landfill reactor simulator (LSR) made of cylindrical acrylic with a diameter of 25 cm, height of 100 cm.

![Figure 1. Schematic experimental set-up](image)

The LSR was equipped with 5 sampling ports which are located at 2 ports at the bottom as gas inlets and leachate vapor outlets (water drainage channels), and 3 ports at the top as gas sensor outlets, air inlets (channels for air supply) and water sprinkle uses a water pump flow. In addition, the LSR was also equipped with 3 ports on the side of the LSR to thermocouple as a temperature sensor. The lower part of the LSR was equipped with a gravel layer for uniform gas distribution and as a buffer. To get oxygen that is flowed using air compressor. Operating temperature according to laboratory temperature and humidity of 40% according to the conditions of the oxidation media.

Biocover material was inserted into the LSR according to the thickness of the layer 20 cm, 40 cm and 60 cm, and then mixture CH₄ and CO₂ gases flowed continuously from the bottom to up of the LSR (up flow) through the media by setting the flow rate of 2.0 ml/minute. Flow meter was used to regulate the flow rate of mixture CH₄ and CO₂ gases which is flowed into the LSR. Analysis of gas concentrations at the top of the LSR was carried out during the research process was carried out every day using gas analyzer (Multitec 540 Sewerin). The gas analysis parameter of gases out of LSR includes the concentration CH₄, CO₂, O₂, and H₂S.

Material Preparation

In this study the sample used was compost taken from the composting center at the Ilie Compost House, Ulee Kareng District, Banda Aceh City, while the cover land was taken from the cover land used in the Gampong Jawa landfill in Banda Aceh City.
To determine the characteristics of oxidation media from municipal solid waste and overburden compost, a sieve analysis using a 4 mesh, 10 mesh, 20 mesh, and 40 mesh sieve was carried out to separate the size of the municipal waste compost and cover so that it is easier to separate the biocover material from other ingredients. Analysis method for water content, in this measurement media measurements were carried out at the beginning and end after heating the media in the oven at 105º C for 3 hours. pH analysis is done using a pH meter. Furthermore, compost and cover land are adjusted to the content of moisture content by 40% by adding water using a water pump.

The source of biogas landfill is used by two sources, namely a mixture of CH₄ gas and CO₂ gas with a concentration composition of 29.9% and 34%, respectively. Methane gas and carbon dioxide will be injected from the bottom of the LSR, thus simulating the production of gas landfills. At the top of the CH₄ and CO₂ concentration was analyzed in off gas using a gas analyzer (Multitec 540 Sewerin).

Results and Discussion

Compost Analysis

The use of compost as a biocover media is widely developed in various European countries, the high composition of organic waste and composting, enabling compost technology to be used as a landfill biocover media in tropical climates such as in Indonesia. Based on the physical characteristics of the compost material, the experiments did not meet the standards as the mature compost was seen from dry conditions with a water content that did not meet 20% and brownish compost color. In mature compost, the water level is increased to allow bacterial metabolic activity to increase the rate of biodegradation. Compost which is used as biocover media in LSR, meets the compost quality standards with mature conditions. The physical characteristics of compost under mature conditions were first tested for temperature, odor, color and moisture content. Good water content in compost as a biocover media is 50% (Huber-Humer et al. 2009).

The amount of compost and soil in the LSR in this experiment was 38.24 kg of compost and 41.65 kg of soil, the largest percentage of compost particle size at 20 mesh size was 29% and compared to the 4 mesh size of the largest 44 mesh. This percentage can be seen in (Figure 2.a). The texture of compost and soil particle size affects the consumption of CH₄ by microbes. The compost and soil biocover media was carried out by a sieving analysis process by passing 4 mesh, 10 mesh, 20 mesh and 40 mesh sieve so that the size of the compost and soil granules became smaller and more uniform and made it easier to separate material from other materials. Compost has a high capacity to store moisture, so it can maintain the highest moisture content of the soil, resulting in low gas permeability.

A decrease in the concentration of CH₄ using soil as a biocover medium has been carried out by several researchers (Abichou, 2009). The result of the decrease in the concentration of CH₄ methane obtained based on the texture is quite significant because of the large percentage of particle size. The sample has a large porosity and is easy to absorb water. Based on the texture that is owned it is expected that the soil has a distribution of dissolved nutrients, oxygen and methane gas that is easily
utilized by bacteria and accelerates the process of degradation of methane gas in it. Generally, substrates rich in organic matter increase the rate of methane oxidation high. But not only is the nutrient supply determined by the organic content, besides that, physical properties such as porosity of the substrate and structure also affect. Soil texture, pore volume, and particle size influence methane consumption, with higher rates occurring on coarse substrates.

Soil composition is an important parameter because soil texture and grain size affect the diffusion of oxygen to the soil biocover. To find out the soil texture of the compost sample, a filter analysis is performed, the results of which can be seen in (Figure 2.b). Soil organic content generally increases the rate of oxidation (Christophersen et al., 2004) and increases soil moisture content more optimally. Nutrients are needed by microorganisms to grow as a constituent of cell matter and are also needed for enzyme activity. Biocover media with high organic content usually have high porosity and humidity, thus supporting the speed of oxidation biologically. Has a strong correlation that the more organic soil and oxygen content, the higher the number and type of microorganisms. Compost and soil naturally will have different nutrient content, because nutrients are used for the synthesis of methanotrophic bacterial cells in inorganic forms such as ammonia and nitrates or organic nitrogen as contained in compost content (Kurniasari et al. 2013).

Effect of Biocover Thickness on CH₄ Oxidation

Changes in the concentration of CH₄ and CO₂ through the biocover process are influenced by the thickness factor of the biocover used. The effect of each biocover thickness on the LSR on operating time can be seen in (Figure 3) which is a graph of the concentration of methane gas detected at the top of the LSR outlet. Decrease in CH₄ concentration in each layer thickness until the 40th day seemed to fluctuate, and subsequently the CH₄ concentration gradually began to decrease with a tendency to be unstable. Based on this, it is estimated that methane degrading bacteria need time to move. In the initial experiment, the concentration of methane gas decreased and a few days later increased with the graph line up and down unstable, because of the adsorption process that may occur during the initial period of the experiment until it reaches saturation. The factor of the adsorption process can be ignored because methane gas is continuously flowed into the LSR.

The results of the observation of the LSR 1 which is a control that uses soil biocover with a thickness of 80 cm, during the first 3rd days the CH₄ concentration was not read by gas analysis politicians. The results of changes in the concentration of CH₄ landfill gas to the operating time at the LSR was found to start the activity of methanotrophic bacteria on the 4th days of CH₄ by 0.2% and CO₂ on the 2nd days by 4%. Then the highest increase in the value of CH₄ concentration on the 45th day was 6.6% and CO₂ on the 32nd day was 25% as shown in Figure 3. The LSR 2 using compost biocover media with a thickness of 20 cm for the first 4 days, the CH₄ concentration was not read by gas analysis politicians. This occurs because the biocover stabilization period in the LSR has not been achieved due to undeveloped methanotrophs and activities in reducing CH₄ concentrations completely (Borjesson et al., 1998; Wilhusen et al., 2004). CH₄ concentration began to be seen on the 5th day at 2.2% and CO₂ on the 4th day at 5%. The highest CH₄ concentration was obtained on the 45th day at 6.8%. The CO₂ concentration of 28% on the 32nd day was the highest concentration as shown in Figure 3. The picture shows that methanotrophic bacteria need time to adapt to biocover (Hanson and Hanson 1996).
Figure 3. Effect of biocover thickness on CH\textsubscript{4} oxidation, LSR 1: soil without biocover, LSR 2: 20 cm biocover, LSR 3: 40 cm, LSR 4: 60 cm biocover.

Observations on the LSR 3 experiment using compost biocover media thickness of 40 cm, commencement of an increase in CH\textsubscript{4} concentration on the 5\textsuperscript{th} day by 6.6\% and CO\textsubscript{2} on the 4\textsuperscript{th} day by 6\% the highest increase in the CH\textsubscript{4} concentration on the 30\textsuperscript{th} day by 10.5\% and CO\textsubscript{2} on the 28\textsuperscript{th} day the highest concentration was 32\%. The average change in oxidation of CH\textsubscript{4} landfill gas concentrations of 2.91\% and CO\textsubscript{2} of 12.55\% can be seen in Figure 3. Compost is known to have a higher CH\textsubscript{4} capacity due to organic matter, water holding capacity and porosity (Hanson et al., 1996). Nutrient limitations during methane oxidation are unlikely to be a factor in organic rich compost. Changes in the reduction of landfill gas concentrations in the LSR 4 with 60 cm compost biocover thickness began to increase the CH\textsubscript{4} concentration on the 5\textsuperscript{th} day by 3.4\% and CO\textsubscript{2} on the 4\textsuperscript{th} day by 9\%. The highest CH\textsubscript{4} concentration was obtained on the 32\textsuperscript{nd} day which was 4\%. The CO\textsubscript{2} concentration of 22\% on the 17\textsuperscript{th} day was the highest concentration as shown in Figure 3. The overall results of the experiment showed that the decrease in the average CH\textsubscript{4} concentration in the LSR increased at each thickness of the biocover layer 20, 40, and 60 cm with respectively 2.43\%, 2.91\% and 1.36\%. Changes in the average CO\textsubscript{2} concentration with 11.01\%, 12.55\% and 5.77\%, respectively, can be seen in Figure 3. The process of reducing the concentration of CH\textsubscript{4} gas requires a media that is able to be a place to grow methane gas-eating bacteria (methanotrophs). Many media that have been studied can be used as biocover to reduce methane gas emissions such as compost with various types and characteristics (Humer and Lecner, 2001, Kurniasari et al. 2013). According to (Huber-Humer et al. 2009) during a decrease in CH\textsubscript{4} concentration, the carbon in methane is partially converted to CO\textsubscript{2} and becomes microbial biomass. Most of the methane consumed is converted to bacterial biomass and not converted to CO\textsubscript{2}, especially when bacteria have a high growth rate (Borjesson et al., 2001). The type of biocover media used also determines the emission of landfill gas concentrations. This is evidenced in laboratory-scale experiments using LSR. Changes in CH\textsubscript{4} concentrations at each compost layer thickness on the first day have begun to decline, because microorganisms already exist do not take long for bacteria to adapt and restart the activity and work of methanotrophic bacteria that have the ability to reduce methane concentration through metabolism of methanotrophic bacteria (Wilshusen et al. 2004).
Efficiency of CH₄ Oxidation in Compost Biocover

The efficiency of CH₄ oxidation was calculated based on CH₄ and CO₂ concentrations that enter and exit from the LSR. The experimental results show that the efficiency of changing the CH₄ concentration in the LSR at each thickness of the biocover layer 20 cm, 40 cm and 60 cm seems to fluctuate, then the CH₄ concentration gradually begins to decrease with a tendency to be unstable. Based on this, methane degrading microorganisms need time to move. The efficiency of CH₄ concentration with respect to operating time at 20 cm compost biocover thickness has the highest efficiency of CH₄ concentration around on day 46 of 24.08% and 40 cm compost biocover layer thickness of the highest efficiency of CH₄ concentration around day 30 of 35.11%, and at 60 cm compost biocover thickness the highest value of efficiency on day 14 of 19.06% can be seen in (Figure 4.a). However, this does not conclude that the thicker the media, the greater the efficiency of oxidation in microorganism metabolism. Experiments for 92 days in the LSR where 40 cm compost biocover layer thickness resulted in a better CH₄ concentration decrease than 20 cm layer thickness and 60 cm thickness.

Figure 4. Efficiency of CH₄ oxidation and percentage of CO₂ increase.

The efficiency of the change in CO₂ concentration with respect to operating time at 20 cm compost biocover thickness had the highest efficiency of CO₂ concentrations ranging on the 28th day by 70.58%. At the 40 cm compost biocover layer thickness the highest efficiency of CO₂ concentration ranged from 28th day to 94.11%, while at 60 cm compost biocover thickness the highest value of the efficiency value on the 15th day was 64.70% can be seen in (figure 4. b), the thickness of the 60 cm compost biocover layer shows a decrease in CO₂ production, very drastic on the 40th day to the 92th day of a stable tendency, this is due to the dilution of oxygen coming from the top of the LSR cover. But this does not conclude that the thicker the media, the lower the efficiency of concentration will decrease. The optimum thickness value is the thickness value where the CH₄ and CO₂ landfill gas can still penetrate to be utilized by methanotrophic bacteria to metabolize cells and reduce levels of CH₄ concentration. The thickness of 40 cm compost biocover has a methanotroph population more than 20 cm and 60 cm compost, so that the hope for more biological oxidation processes against CH₄ becomes greater. Theoretically, oxygen penetration (O₂) in compost 20 cm is better than compost 40 cm and this allows better conditions for decreasing CH₄ concentrations to occur, but ultimately the presence of methanotrophs is more decisive in the CH₄ oxidation rate when viewed from the results of this experiment at (Figure 4.a). That the decrease in CH₄ concentration is followed by an increase in CO₂ production in the LSR shows a decrease in methane concentration by methanotrophic bacteria (Humer and Lechner 2001, Albanna 2009).
Table 1: The average efficiency results in changes in CH\textsubscript{4} and CO\textsubscript{2} concentrations in biocover thickness in the LSR

| Biocover | Thickness (cm) | CH\textsubscript{4} Oxidation Efficiency (%) | Increased of CO\textsubscript{2} Concentration (%) |
|----------|----------------|--------------------------------------------|-----------------------------------------------|
| LSR 1    | Soil           | 80                                         | 10.12                                         | 26.76                                         |
| LSR 2    | Compost        | 20                                         | 8.12                                          | 32.38                                         |
| LSR 3    | Compost        | 40                                         | 9.72                                          | 36.62                                         |
| LSR 4    | Compost        | 60                                         | 4.56                                          | 16.98                                         |

The results showed that the efficiency of the average reduction in CH\textsubscript{4} concentration in the LSR increased at each thickness of the biocover layer 20, 40, and 60 cm with respectively 8.12%, 9.72% and 4.56% and the efficiency of the average change the average CO\textsubscript{2} concentration with 32.38%, 36.92% and 16.98%, respectively, can be seen in (Table 1). That the decrease in CH\textsubscript{4} concentration is followed by an increase in CO\textsubscript{2} production in the LSR shows the oxidation of methane by methanotrophic bacteria (Humer and Lechner 2001, Albanna 2009). Biocover layer thickness of 40 cm provides better CH\textsubscript{4} oxidation results than layer thickness of 20 cm and thickness of 60 cm.

Conclusion

Based on observational data obtained the decrease in CH\textsubscript{4} concentration in the LSR can be proven through a process involving methanotrophic bacterial microorganisms present in compost biocover in oxidizing CH\textsubscript{4} gas. The experimental results obtained an average value of CH\textsubscript{4} oxidation efficiency of 8.12%, 9.72% and 4.56%. This shows that the decrease in the average CH\textsubscript{4} concentration in the LSR increases at each thickness of the biocover layer 20 cm, 40 cm, and 60 cm with respectively 2.43%, 2.91% and 1.36%. Biocover layer thickness of 40 cm provides better CH\textsubscript{4} oxidation results than biocover thickness of 20 cm and biocover thickness of 60 cm.

Methods that can be used to reduce GHG emissions from landfill, among others, by oxidizing CH\textsubscript{4} using compost as a medium for oxidizing concentrations of methane, commonly called biocover.

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