The Effect of Leachate Resirculation on The Greenhouse Gases Emission from Municipal Solid Waste (MSW) Landfill in Tropical Climate Region

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Abstract. Indonesia is facing serious problem with huge amount of Municipal solid waste (MSW), whilst landfilling still the main option to dealing with it. The landfilling of the MSW is associate to the environmental issue, especially due to the leachate and landfill gas emissions. The leachate produces which is containing hazardous materials, while the landfill gas which mainly containing CO₂ and CH₄ that categorized as greenhouse gases. The leachate and landfill gas emissions were influenced by many factors, including climatic condition. This research was aimed to determine the effect of leachate recirculation on leachate production and landfill gas emissions of MSW landfill in tropical climate region. The experiment was carried out by using 2 landfill simulator reactors (LSRs) made of high density polyethylene (HDPE) pipe with 50 cm OD and 150 cm length. The sample used was collected from the Blang Bintang landfill, a regional landfill constructed to accept MSW from Banda Aceh municipality and Aceh Besar District. The LSRs were operated under difference operation mode, the first LSR were operate without leachate recirculation, however a certain amount of water was added to simulated the MSW landfill operated under conventional method. While the second LSR were operate with leachate recirculation to represent the MSW landfill operated under bioreactor landfill mode. Results of this study show the leachate recirculation has significant affects on the rate of waste degradation and the landfill gas production. The highest CH₄ concentration in landfill gas emission first and second LSRs were about 58% and 59%, respectively. This relatively small difference is probably due to the high rainfall in the tropics region. This results indicated that the potential of MSW landfill in tropical climate region as renewable energy, either operated under conventional or bioreactor landfills.

Keywords: municipal solid waste, greenhouse gas emissions, landfills gas emissions, tropical climate region, landfill simulator reactor, leachate recirculation.

Introduction

Like other developing countries, Indonesia is facing serious problem dealing with huge amount the municipal solid waste (MSW). The MSW problems related to the lifestyle and the culture in the area, therefore waste management is not only government responsibility but also public participation needed in this issues (Syamsuri et al. 2016). Improper MSW management can cause the environmental problems due to the landfill gas and leachated emissions which produce from the degradation of organic fraction of MSW, such as the air and underground water pollutions. The piles of MSW can also become a hotbed vectors of various diseases. While, in other side the population of big cities in Indonesia has increase rapidly. This conditionpose to threat the environment, such as poor quality of the environment and sanitation. These is getting worst by inappropriate MSW management. In the national level, it is estimated that only 60%-70% of total MSW generate was collected and transported to landfills by the government agencies (Damanhuri 2005). The rest was handled by community itself by means burned or throw away into an open space or river. A small portion of waste was collected by scavengers to be sold to waste collector and subsequently send to recycling process.
In Asian countries, the MSW term usually refers to all the waste generated by society, but does not include industrial or agricultural wastes. So far the concept of MSW is varies greatly, but often MSW refers to the waste that come from household activities.

Increasing the volume of solid waste generated is a serious problem in urban areas around the world. This situation become worst due to the high rate of population growth and economic development that cause change of human being life pattern to be more consumptive. All of these is resulting a very large generation of MSW that pose a threat to the environment (Kumari, 2016).

So far, many research related to degradation organic matter in MSW landfill has been done, but most of the research were conducted in-temperate region, of which the climate condition is very different compare to tropical region. Since, the MSW landfill emissions are influenced by many factors, including precipitation, evapotransportation, moisture content, density, landfill capacity, waste composition and waste age (Sarto et al. 2016). Therefore, the emission of MSW landfill in temperate climate region would be quite different compare to MSW in tropical region.

The research related on MSW have been done in four Asian countries (China, India, Srilanka and Thailand) was provided information the composition of MSW in these countries, where of them have almost similar MSW composition. This result is probably due to similarity climatic and cultural conditions.

The aims of this research is to investigate the effect of leachate recirculation on landfill gas production, leachate generation in tropical climate and the parameters that affect the performance of the landfill simulator reactors (LSRs) to greenhouse gases emissions. Results of this research would be useful as reference to improve the landfill operation and management in tropical climate. This research can also provide a strategy to minimize the greenhouse gases emissions from MSW landfill in tropical climate countries which identified with high precipitation and relative constant temperature throughout the year.

Material and Methods

Sample Preparation
The MSW used as a sample in this research was collected from Blang Bintang Regional Landfill in Aceh Besar district. The landfill site is located at Peurumping village, Montasik, Aceh Besar district (5°31'09.8"N 95°28'44.3"E), which is around 17.5 km Southeast of Banda Aceh city. The Blang Bintang Regional Landfill was constructed to receive MSW generated from Banda Aceh and Aceh Besar District area and it has been operated for about 10 years. This landfill has a total area of around 200 ha equipped with giant landfilling cells, leachate treatment pond, and other supporting facilities. The landfill was built with the support of the United Nations Development Programme (UNDP), German Technical Cooperation Agency (GTZ), the United Nations Children's Fund (UNICEF), and The Agency for Rehabilitation and Reconstruction of Aceh and Nias (BRR) after the tsunami disaster 2004 under multi donor fund scheme.

All samples for this research were taken from the landfill is fresh MSW that just unloaded from waste collection vehicle. Approximately 2 tons of waste was collected and characterized between the organic and inorganic matters. Most of the waste consisted of organic and inorganic matters, such as plastic sheet, rubbers, textiles, woods and unidentified waste. The sample later on was transported to the laboratory in Banda Aceh for further preparation before emplaced into the landfill simulation reactor (LSR).

The organic waste was collected from the Blang Bintang Regional Landfill was sieving by using screen has opening size 5 cm to have a particle sizes of around 1 to 5 cm. Then, the waste is gently mixed and separated into 4 parts to ensure each the LSR accept the same waste characteristics. While the oversize waste particle treated furthermore to be smaller through cutting and re sieving process.

Landfill Simulator Reactor (LSR) Set-up
Four LSRs made of high density polyethylene (HDPE) pipe a 50 cm outside diameter, 2.5 cm wall thickness and 150 cm of height have been used in this research. Each LSR has a total volume of approximately 0.57 m$^3$. The top and bottom lids of the LSR were made with similar material to ensure its could be easily connected and kept the LSRs under air tight condition. A port for biogas collection was installed on the top lid, while another port was installed at the bottom lid for the leachate drained
purpose. In addition to biogas collection port, a showerhead has also been installed on the top lid for leachate recirculation or fresh water adding to simulate the rainfall.

The biogas outlet port is connected to the eudiometer which is use to measures volume the gas landfill volume generated. A silicone tube is used to connect between the eudiometer and gas analyzer (Multitec 540, Sewerin) to determine the landfill gas composition. The leachate outlet port is connected to U-type silicon tube to prevent intrusion the ambient air into the LSR after the leachate draining out. An external plastic container has capacity 10 litter was placed to collect the drainage leachate and re-circulate it's into the LSR depending on LSRs operation mode. Four thermocouples were installed at a distance 20 cm from the bottom of the LSR to measure the temperature inside of the LSR. In order to reduce the heat loss from the LSR to ambient air, each LSR was covered by two layers of blanket made of synthetic wool and aluminium foil. There was no an electrical device used to maintain the LSR temperature to simulate the real landfill temperature which is influenced by climate conditions.

Prior the LSR filled with the waste, the gravels layer having a particle size ranging from 1-2.5 cm was emplaced for around 10 cm of high as the leachate drainage layer. The gravel layer was covered by geo-textile sheet to prevent the gravel pore from clogging by waste materials. At the top of the LSR, around 15 cm from the top lid an empty space was provides as headspace. The detailed configuration of the LSR is illustrated in Figure 1.

![Figure 1. Experimental set-up of landfill simulator reactor.](image)

The LSRs were filled with 250 kg (wet weight) of MSW in layers of approximately 30 cm and compacted by using a hydraulic press to an apparent density of 750 kg/m³. Additionally, each LSR was fed with a 50 L of mature leachate taken from the leachate pond of Blang Bintang landfill to stimulate methanogenic and leaching conditions. The LSRs were operated under different modes, namely with and without leachate recirculation mode. The first two LSRs donated as LSR-C1 and LSR-C2 were operate under with leachate recirculation mode, while two remained LSR donated as LSR-D1 and LSR-D2 were operate under without leachate recirculation mode. The LSRs C, a fresh water was added instead of discharged leachate to maintain the moisture content inside LSR. The amount of fresh water was added approximately 1.8 L per day. This amount was determine based on average the precipitation rate in Banda Aceh. On the contrary, the leachate discharged was pumping back into the LSR D to stimulate the LSR operate under the leachate recirculation mode. The volume of leachate recirculation was set similar to fresh water added in LSR C. In case the leachate volume generated is less than 1.8 L after subtracted for laboratory analysis purpose, the fresh water was added to maintain desired amount of leachate recirculation.
Analytical Procedures

During the experiment, the gas volume produced was measured using eudiometer and the gas composition (CH₄, CO₂, O₂ and H₂S) was determined by using gas analyzer (Multitec 450, Sewerin Inc). The leachate samples were analyzed for pH using pH meter (HI 9126, Hanna Instruments), electrical conductivity (EC) using conductivity meter (Model 541, Corning Pinnacle), BOD₅ using BOD sensor (BOD system, VELP Scientifica). The COD and NH₄ were analyzed using visible ultraviolet spectrophotometer (UV-1800, Shimadzu Corp.), whilst the heavy metal content of the leachate was analyzed by using atomic absorption spectrophotometer (AA-6300, Shimadzu Corp.). The volume and composition of gas were measured daily. In addition to gas analysis parameter, the temperature inside LSR as well as leachate temperature, leachate pH and EC were also measured on daily basis. While the BOD₅, COD, NH₄ and the heavy metal content were analyzed once a week.

Results and Discussion

1. Reactor Operation

Although initially this research was carried out by using 4 LSRs in order to have duplicate of each operation mode, however, in this section only one of each LSR will be discussed herein. This is happened because one of each LSRs has technically problem that caused not work properly. One LSR that are operated under without leachate circulation was blocked, so volume the leachate produce was not enough to be analyze in the laboratory. Whereas one the LSR operated under with the leachate circulation mode has leakage that cannot identified to be repaired. Therefore, the landfill gas cannot be collected to be determine its volume and composition from the beginning experiment.

2. Physical and Chemical Parameters

The physical and chemical parameters of leachate were measured every day, its include volume leachate, pH and electrical conductivity (EC). The pH measurement was carried out by using a pH meter, while the electrical conductivity was carried out by a conductivity meter. The electrical conductivity measurement was aimed to investigate the leaching process. The high electrical conductivity of leachate is indicated better the liquid distribution across LSR. The measurements results for 120th operational days were presented in Figure 2. The pH value of leachate during 120th day operation did not change significantly. The pH value leachate of LSR C at the beginning of the operation was 5.4, while the pH leachate of LSR D was 5.7. A low pH value indicates that the degradation process of organic compounds has been started since the beginning of the operation. This can be happen because the solid waste used in this research is the organic waste which has been separated from other fractions and the addition of leachate to stimulate the degradation of organic compounds is going well. A low pH value occurs due to the accumulation of volatile fatty acid (VFA) produced at the acidogenesis stage. Then, VFA compounds are converted to acetic acid by acetogenic bacteria at the stage of acetogenesis (Anggraini et al. 2013).

Twenty days later, the pH leachate of LSR C and D was increased slowly to 7.3 and 7.5, respectively. This increase in pH value indicates that the methanogenesis stage is begins, the process of forming CH₄ from acetic acid by methanogenic bacteria. This is confirmed by the increasing concentration of CH₄ in the landfill gas produced (see Figure 3). Furthermore, the pH of leachate LSR C and LSR D was relatively constant at 7.3 and 7.5, respectively. This shows that the rate of conversion of organic compounds into VFA and acetic acid was equivalent to the rate of conversion of acetic acid into CH₄. The results obtained are in accordance with the results of (Syafrudin et al. 2011) which states that in the initial conditions, the activity of microorganisms in decomposing organic compounds causes pH to approach acid, and then the pH returns to increase after entering the phase of methanogenesis.

Whilst for electrical conductivity, the LSR C was increasing in the beginning of operation then decreases until the last day of operation. The increase electrical conductivity was occurred until the 15th day of operation. The highest and lowest electrical conductivity of LSR C was 19.78 mS/cm and 4.85 mS/cm, respectively. This can be caused by the addition of water into the reactor which results in the dissolution of salts contained in the reactor and leach out with the leachate. In contrast, the electrical conductivity of leachate from LSR D continues to increase until the 120th day of operation. This probably due to the accumulation of salts by leachate recirculation. The highest conductivity of leachate from LSR D about 19.12 mS/cm was obtained on the 120th day of operation.
3. Biological Parameter

The biological parameters were included gas production, gas composition, BOD and COD concentrations. The measurements of volume and composition of landfill gas produced were carried out every day, while the BOD and COD concentrations were carried out once a week from the first day of operation until the 120th day. The measurement results of volume and composition of landfill gas produced can be seen in Figure 3. Gas production from both LSRs has a similar trend from the beginning to the 120th day of operation. However, landfill gas produced LSR C was higher than LSR D, Wagiman (2007) claiming this can be caused the organic compounds in LSR D has been reduced indicated that decreasing of the COD value. The values were 3.520 and 3.200, respectively. In term of composition, the CH4 concentration of LSR C has a relatively stable until the last day of operation, while LSR D has little bit declining from the day 60 until day 120th. The highest CH4 composition of LSR C was 59% found on 60th day, and 60% on 63rd day for LSR D. The composition of CH4 of LSR C and D on 120th day was 59% and 56%, respectively. According to Septiropa (2012), the leachate circulation can pretend moisture of the waste in the reactor and gave the kind effect to the anaerobic bacteria growth to produce CH4. In addition, the composition of the CO2 produced is relatively stable for the two LSRs with compositions ranging from 35 to 40%.

The BOD/COD ratio of leachate production was present in the Figure 5. BOD/COD ratio from both LSRs has a similar trend, it has low. But, the BOD/COD ratio was increasing after the days 80th. According to Farastika et al. (2017) this can be caused the organic compounds have entered to the methanogenesis phase, where in this phase there are microorganism has convert the acetic acid to the methane. And BOD/COD decrease by reducing the acetic acid and organic compounds in leachate. Otherwise, the pH will increase together with reducing acetic acid. The lowest concentration of BOD/COD of LSR C was in days 80th; it has 283 mg/l and 480 mg/l. Where as in LSR D, the lowest concentration of BOD/COD was in days 80th and 90th, it has 300 mg/l and 570 mg/l. Based on the
Regulation Minister of Environment Republic of Indonesia P.59/2016, the BOD values from this research has exceeded to the quality standard of waste water, it has 152.2 mg/L and about the COD values from this research, if it compared with the Regulation Minister of Environment Republic of Indonesia No. 82/2001 also exceeded to the quality standard of waste water, it has 300 mg/L. Therefore, the leachate produce from landfill has to be treated (Sari and Afdal 2017).

Figure 4. BOD/COD concentration in the leachate from the LSR which operated without leachate circulation (left) and by leachate circulation (right).

According to Samudro and Mangkoedihardjo (2010), the BOD/COD ratio of the leachate can illustrate the level of biodegradability organic compounds. The BOD/COD ratio are an indicator that showing the rate of degradation from the organic compounds by microorganism. A higher BOD/COD ratio indicated that the degradation of organic compounds takes place rapidly. In such conditions it can be assumed that the main component of waste is organic compounds that can be degrade by microorganism. Otherwise, if the BOD/COD ratio is lower, the degradation of organic compounds takes place slowly and the main component of waste is non-organic compounds which are difficult to degrade by microorganism.

The evolution of the BOD/COD ratio of leachate produced of the study is presented in Figure 5. From the figure can be seen that the BOD/COD ratio of leachate from LSR C and LSR D has similar tendencies. The BOD/COD ratio of leachate from both LSR has a tendency to increase with operating time. This finding in line with the general concept of degradation organic compound. Whereas all organic compounds are degraded from complex structure to be more simple structure, so that the rate of degradation of organic compounds takes place quickly by the time and the BOD/COD ratio of leachate become higher.

Although BOD/COD ratio both LSR has similar tendency, however the increasing of both LSR of them were at different rate. This is probably due to the differences the leachate recirculation mode. In the LSR D, recycling the leachate could be increase the organic load by accumulate of dissolved organic compounds. The leachate recirculation can also cause accumulation of toxic compounds which can inhibit the growth of microorganisms. Where as in LSR C, the leachate produced was not re-circulated into the reactor so the organic load become lower than LSR D. The BOD/COD ratio of leachate from LSR C and LSR D on the last day of operation was 0.064 and 0.054, respectively.

Acknowledgments
The authors wish to thank Syiah Kuala University, Banda Aceh of the Republic of Indonesia for their important contributions to the development of this work.

Conclusions
Based on the results and discussion, the following conclusions can be drawn:

The reactor which operated without leachate circulation is LSR C that produced higher landfill gas than LSR D which operated by leachate circulation. This can be caused accumulation of toxic compounds which can inhibit the growth of microorganisms in the reactor which operated by leachate circulation. pH of the leachate from both LSR has a similar tendency; they have tended to be below neutral pH on days 20th, then increased and relative stable until the end of operation. Increasing of pH
from the leachate occurs due to increased activity of methanogens which convert acetic acid to the methane. The highest pH value of LSR C and D was 7.3 and 7.5, respectively. The EC from both LSR has different tendency. It has an increasing trend and then decreased until 120th day of operation, for LSR C. while LSR D continuous to increase until 120th day of operation. this can be caused by the accumulation of salt in the reactor caused by leachate circulation. The similar phenomena occur in the evolution of the BOD/COD concentration, BOD/COD ratio from both reactors. The lowest BOD/COD concentration in the reactor which operated without leachate circulation (LSR C), it's about 283 mg/l and 480 mg/l, whilst the highest BOD/COD ratio also from LSR C, it's about 0,064.

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