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Anaerobic Decomposition Process Characteristics of Various Sizes of Garbage in a Lysimeter System

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Abstract
Garbage is produced daily in significant quantities especially in densely populated areas, creating serious environmental problems. On the other hand, the garbage has a high organic content and is a potential resource for producing renewable energy in the form of biogas. The implementation of an integrated approach to the environmental management gives hope to create a win-win solution to solve the strategic problem. The research work aims to characterize the biodegradation process of garbage in a lysimeter system. The lysimeters were intended to simulate the real conditions of landfill. The experiments were performed using 5 lysimeters filled with various sizes of garbage, consisting of powder (A), 0.1 – 0.9 cm (B), 1.0– 1.9 cm (C), 2.0 – 2.9 cm (D) and original shape (E). Observations were conducted for duration of 150 days focusing on the alteration of the fed material and the products of the conversion process. The research results showed that the process of biodegradation is unique to each garbage size variation. In the beginning phase, the biogas was dominated by methane gas (CH_4) in lysimeter A, while CO_2 was predominant in the other lysimeters. The smaller size of the garbage the larger volume of biogas was produced. In opposite, the larger size garbage was biodegraded, the faster garbage volume reduction and the higher leachate production will be.
Keywords: Garbage, biogas production rate, lysimeter, biodegradation process characteristics

1. Background

The management of garbage becomes a major concern in the highly populated cities. The tradional practices the garbage is collected without any sorting and sent off directly to a temporary shelters before being dumped in a permanent landfill. The currently available landfills are mostly operated on an open dumping system. Due to the high organic content of the garbage, most of the dumped garbage dumped will undergo an anaerobic degradation producing a gas, known as biogas (landfill gas). The biogas is a mixture of methane gas, carbon dioxide, and other gases in smaller portions. The nature and composition of the biogas makes it a potential harm in local and global scales. On a local scale the emission of biogas gives out a stench and various air pollutions at the area surrounding the landfill caused by trace substances such as hydrogen sulfide (H_2S), esteres, terpenes, mercaptan and FFA (Lombard, 2008). On the global scale, methane which is the main component of biogas (50 -70%) is a known greenhouse gas with a greenhouse gas effect 20-30 times more damaging compared to carbon dioxide (Porteous, 1992). Global methane emission from landfills contributes to 20-60 teragram (Tg). Densely populated nations with relatively simple garbage management such as China, Brazil, India, and Indonesia, are major contributors of methane emissions coming from landfills (Robinson *et al.* 2003; Thorneloe *et al.* 2002).
The biogas has a calorie value that can be used as a source of renewable energy with considerable economic value (Visvanathan and Trankler 2008; World Bank, 2008). The organic conversion of organic content from garbage into a source of alternative energy under a controlled environment can be seen as an approach to provide alternative energy and to manage city garbage that is viable on technical, social, and economic standpoints. This chosen method of recycling will not only give technical advantages in the struggle in environmental management but also has economic implications. These advantages can be utilized to not only manufacture a product with high economic value in the form of biogas for electricity and organic fertilizers, but also a significant financial potential in the form of the greenhouse gas trade (CDM/*clean development mechanism*). These economic advantages can be used as a resource to support the lasting implementation of good garbage management (*sustainable garbage development management).*

An attractive alternative to solve the aforementioned strategic problem (energy supplies) is to use resources that not been used effectively, namely the organic content in garbage. Garbage is produced daily in significant quantities especially in densely populated areas, creating serious environmental issues. On the other hand, garbage has a high organic content and is a potential resource in producing renewable energy in the form of biogas. The implementation of an integrated approach to environmental management gives hope to create a win-win solution to the strategic problem.
The government of Indonesia recognizes the un-sustainability of the existing waste management programs and is

attempting to remedy the situation. Solid waste management remains one of the biggest challenges facing the highly urbanized cities of Indonesia. An effective and sustainable waste management must, therefore, become a priority for the local authorities to prevent environmental degradation. Considering the high percentage of organic material in the waste stream, converting of the organic substances in garbage is considered to be a technically feasible solution to improve current waste management and to produce energy in form of biogas.

The research aims to characterize the biodegradation process of garbage in lysimeter system and quantify the products associated with it process such as biogas and leachate. The biodegradation process is characterized by measurements of biogas production, biogas composition, garbage stockpile depletion rate, and leachate production. The lysimeters were intended to simulate the real conditions of landfill.

2. Research Methodology

1.1 Material and Equipment

The materials used in the experiments were organic garbage in various sizes, cow dung as the starter, and chemicals for laboratory analysis. The equipment's and instrumentations used for the experiment consisted of five lysimeters, garbage shredder, shift, scale, gas holder, Gas Chromatography type GHG 450, thermometer, bamboo stakes, electrical drill, measuring tape, 10 ml syringe, silicone gel, plastic bags, bucket, and standard laboratory glassware for laboratory analysis.

1.2 Method

The applied sampling method was grab sampling. The garbage samples were taken from the landfills of Gunung Sindur, South Tangerang, Banten Province, Indonesia. Each sample was composite sample taken from five sampling points. The garbage sample was sorted based on its organic and inorganic category. The organic garbage was used for experiments.

The experiment was started with the physical preconditioning of the garbage material. The organic garbage samples were cut using a shredder into desired sizes. Table 1 shows the physical characteristics of the materials used for the experiments. One liter of dilute cow dung was used as a starter for each lysimeter. The cow dung was diluted with water at a ratio of 1: 1 to facilitate the fast mixture with the garbage material.

Table 1. Physical characteristics of the fed material into each lysimeter

Lysimeter	Treatment Material Size (cm)	Quantity of the fed Input Organic Garbage (kg)
A	Powder	27.60
B	0.1 - 0.9	38.50
C	1.0 - 1.9	35.50
D	2.0 - 2.9	37.40
E	Original size	41.30

Some process parameters were measured during the experiment time of 150 days. Biogas production were measured everyday by observing the gas volume accumulated in the gas holder attached to the lysimeter. The gas composition was monitored by taking samples of the biogas from the gas holder hose at 30^{th} day, 60^{th} day, 90^{th} day, 120^{th} day, and 150^{th} day of the experiment. The gas sampling was conducted by using a 10 ml syringe plunged into the gas outlet tube followed by securing the needle using cork. The gas samples were analyzed for the concentration of methane (CH_4), carbondioxide (CO_2), hidrogen sulfida (H_2S), nitrogen oxide (N_2O), oxygen (O_2) with a Gas Chromatography type GHG 450. The garbage stockpile depletion rate was measured using a simple conventional way of sticking in a bamboo stake into the lysimeter. The leachate production rate was monitored by removing the leachate produced through a tap at the bottom of the lysimeter. The produced leachate was measured using a graduated cylinder. The bulk density was determined using measuring the organic garbage weight divided by the volume of the garbage in the lysimeter.

3. Results and Discussion

3.1 Characteristics of Garbage Used as Test Material

The garbage used for the experiments were organic garbage. The characteristics of the garbage used in the research are presented in Table 2. The portion of organic substances in the garbage is relatively high and varies between 71.0 and 82.6%. The bulk density was in the range of 0.4-0.6 g/cm^3.

Table 2. Characteristics of the garbage at various sizes in the lysimeter

	Unit	Lysimeter (size of the garbage)				
		A (powder)	B (0.1-0.9 cm)	C (1.0-1.9 cm)	D (2.0-2.9 cm)	E (Original size)
Organic substances	%	75.2	77.0	71.0	74.8	82.6
Inorganic materials	%	24.8	23.0	29.0	25.2	17.4
Moisture	%	72.10	80.25	82.91	83.47	86.6
Solid materials	%	27.90	19.75	17.09	21.63	13.34
Bulk Density	g/cm^3	0.532	0.642	0.576	0.613	0.401

The characteristics of the garbage, namely size, organic material portion and the moisture, are important factors determining the characteristics of the bioconversion process in the lysimeter. This is related with the physical and chemical characteristics of garbage as the growing and breeding media of methane producing bacteria. The physical properties influence the stability of the acidogenesis bacteriaand methanogenesis bacteria. The bacteriaare responsible for the conversion of organic matters (carbohydrate, protein, and lipids) to fatty acids and then the methanogenic bacteria will convert it into methane and carbondioxide (Gamayanti *et al.* 2012). As stated by Yani *et al.* (2013), the physical and chemical nature of media as the place of microbial consortium growth is crucial in the biological process. Furthermore, the organic materials in the garbage act as source of the biogas production after the hydrolysis process of the materials (Dasgupta and Mondal 2012).

3.2 Biogas Production

In the lysimeter, the organic content of garbage will mainly be degraded by anaerobic bacteria. In the biological degradation process, the microbes consume biodegradable organic matter as an energy source and convert it into smaller simpler chemicals used in the microbe's growth and reproduction. Due to the anaerobic condition, the end-products are methane and carbon dioxide. These anaerobic garbage conversions are a complex process involving many stages and many microbes at each stage (Boenke *et al.* 1993). Figure 1 shows the accumulated biogas production during the bioconversion process experiments. The maximum biogas production was in treatment A. It can be seen that the production of biogas started at 3rd day of the process. The formation continued to rise until 60th day. It was stable during the bioconversion process testing, except the gas production at the treatment E (original size) that increased steadily until the end of the bioconversion testing of 150th day.

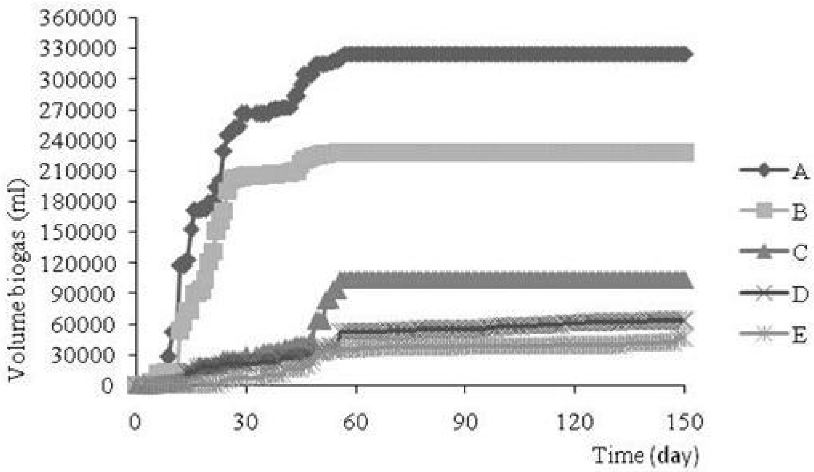

Figure 1. Biogas production in lysimeter fed with various sizes of garbage

The different gas productions can be explained by using the characteristics of the fed materials. The size of the material influences strongly the biogas production. The smaller the materials size of the fed garbage the higher the biogas production. This is due to the fact that the acidogenesis and methanogenesis process is effected the surface area of material, the smaller the material surface area the better the methanogenesis process and the higher the biogas production. Table 3 shows the relationship between the sizes of the fed garbage and the maximum biogas production. The results confirmed the previous findings (Fantozzi and Buratti 2011) that the conversion of garbage in slurry form gave a higher biogas production compared to the bioconversion using an initial state of garbage. Another important factor in anaerobic process is water content of the fed organic material. Visvanathan and Trankler (2008) reported that water content influences the biological decomposition process, especially in the mixing, nutrient availability, and maintaining a constant temperature. The water content is also important to the methane fermentation process because it is used as the nutrient solvent for the microorganisms prior to being assimilated. Thorneloe*et al.* (2002) pointed that the water content not only is vital for the bacteria mobility but also influences mass transport inside the garbage and the balance of the volatile fatty acids by the acidogenic bacteria and the conversion of acids into methane by the methanogenic bacteria

Table 3. Biogas production at various sizes of feed

Pre-treatment (Size of the fed materials)	Quantity of Feed (kg)	Moisture Content (%)	Biogas Volume (ml)
A (powder)	27.60	72.47	325.000
B (0.1-0.9 cm)	38.50	79.67	228.000
C (1.0-1.9 cm)	35.50	80.25	103.225
D (2.0-2.9 cm)	37.40	82.91	52.730
E (Original size)	51.30	86.60	41.340

3.3 Biogas Composition

In lysimeter system organic materials are decomposed anaerobically into methane ($CH_{4)}$, carbon dioxide (CO_2) and small quantities of N_2, H_2, H_2S, H_2O, and traces of other substances (Indira, 2007, Visvanathan and Trankler 2008, Felik *et al*. 2012). In the anaerobic decomposition, for example, one mole of glucose is converted into three moles of methane. However, in practice, the composition of the biogas produced is influenced by various factors, including physical and chemical composition of the substrate, as well as operation time (Romli *et al*. 2014, Timothy1998). Tables 4 shows the biogas composition of biogas produced in lysimeterA, B, C, D and E during the bioconversion process. The potion of CH_4 varied greatly between 11 and 68% depending on depending on the size of the garbage loaded into the lysimeter and the process stability. The biogas contained small quantities of H_2S, N_2O, and O_2 by 0.8 - 1.7%, 0.1 - 1.4%, and 0.1 - 0.9%, respectively.

Table 4. CH_4 and CO_2 gases in biogas produced in lysimeter during the testing of the bioconversion process

Time (day)	Unit (%)	Lysimeter (size of the loaded garbage)									
		A (powder)		B (0.1-0.9 cm)		C (1.0-1.9 cm)		D (2.0-2.9 cm)		E (Original size)	
		CH_4	CO_2	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2	CH_4	CO_2
30	%	58.6	36.1	13.6	45.7	19.5	44.2	14.3	46.7	11.0	42.1
60	%	33.5	38.9	57.1	36.3	21.9	44.4	38.3	41.2	18.2	36.5
90	%	29.5	42.6	27.1	40.1	61.1	31.9	66.2	24.3	45.7	44.9
120	%	28.3	32.1	26.7	41.9	38.7	33.1	43.4	24.2	68.1	30.1
150	%	24.7	68.3	24.5	42.1	32.4	36.4	41.3	25.4	56.4	40.4

3.4 Garbage Stockpile Depletion Rate

Figure 2 is shows the garbage stockpile depletion rate of various size of garbage during the bioconversion process. The maximum depletion rate was observed is in lysimeter E, where the filled garbage was at its original size. The bulk density of the garbage inside the lysimeter influences the stockpile depletion rate. The low bulk density in lysimeter E resulted in rapid depletion of the garbage stockpile. The smaller the material sizes the slower is the rate of stockpile depletion as seen in lysimeter A. The smaller size of the material results in the higher bulk density of the material leading to a slower stockpile depletion rate. Figure 2 shows the stockpile depletion rate in the lysimeter filled with various size of garbage.

The larger material sizes tend to the faster stockpile depletion rate due to the biodegradation process followed by the faster increase of the bulk density. Chauzy *et al.* (2005) reported that the anaerobic biodegradation process is effected by the feed bulk density in the bioreactor. In the biological degradation the microbes consume organic biodegradable matter as an energy source and convert it to simpler molecules and produce energy for the microbial growth. In the anaerobic condition the garbage dissociation produce methane and carbon dioxide. The anaerobic conversion is complex involving many stages with its specific types of microbes at each stage. Shearer (2001) described the garbage stabilization process in an anaerobic process undergoes five phases, which are lag phase, transition phase, acid formation phage, methane formation phase, and maturation phase. Each phase is signified by a spesific leachate characteristics.

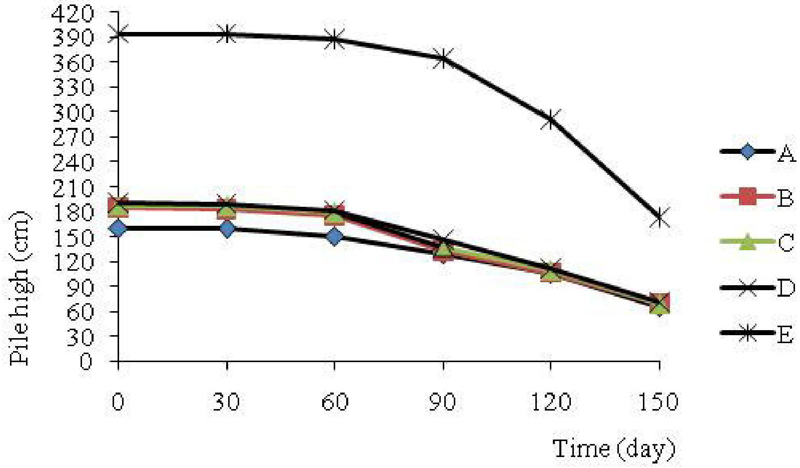

Figure 2. Stockpile depletion rate in the lysimeter filled with various size of garbage

3.5 Leachate Production Rate

The leachate production rates from various sized of the fed garbage are given in Figure 3. It is apparent that the leachate production rose rapidly at the beginning of the bioconversion process until 30th day. The increase of leachate production rate indicates an ongoing degradation of organic matter by the microorganisms living in the system. These microorganisms use the organics and nutrients available as an energy source.

Water content and material size are important variables in the anaerobic degradation process in term of leachate production (Suprihatin *et al.* 2008). The highest leachate production was observed at lysimeter E given with an accumulated volume of 27,680 ml and the lowest leachate production accoured at lysimeter A with an accumulated volume of 11,780 ml. This clearly illustrates that the material size influences the degradation process of the material and the leachate production. The larger size and the higher water content of the feed resulted in increased leachate production. Lombard (2008) stated that the organics in leachate are difficult to biologically degrade substances. However, the liquid product of the degradation process of garbage has the potential to be used as liquid fertilizer. According toGijzen (1987), the leachate contains several macronutrients for plants, such as nitrate (NO_{3}-), ammonium (NH_4), phosphate (PO_4^{3-}), potassium (K), calcium (Ca), magnesium (Mg) and sulfate (SO_4^{2-}), as well as micro-nutrients for plants, such as iron (Fe), manganese (Mn), copper (Cu) and zinc (Zn).

Mulasari *et al.* (2014) reported that the piled-up unattended garbage will decompose and produce a liquid termed as leachate. The composition of garbage leachate will be influenced by the types of garbage in the stockpile, composition of the garbage, the microbes responsible for the process, and the water balance in the system. The concentration of N, P, and K in the leachate can be used as an indicator of nutrient availability for the bacteria thriving in the leachate.

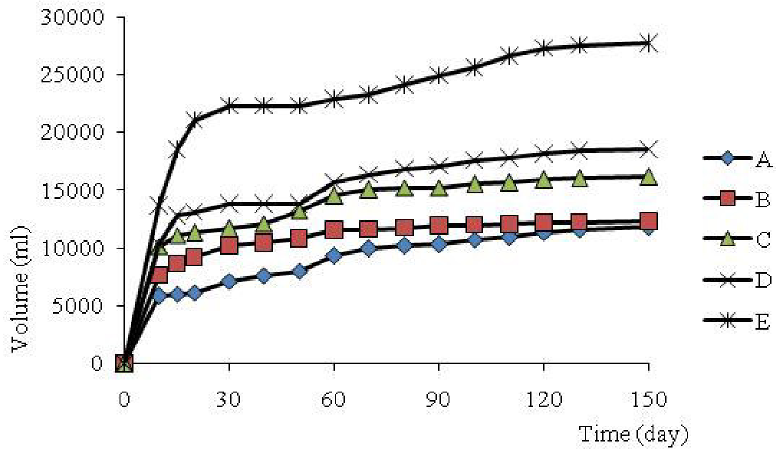

Figure 3. Leachate production rate in lysimeter filled with various size of garbage

4. Conclusions

The biodegradation process of garbage in a lysimeter depends on the size of the fed organic material. The larger size of the garbage leads to the faster rate of stockpile depletion and the higher leachate production rate. The biogas production was greater when the fed materials were smaller. The garbage size effects also the biogas composition. During the beginning phase the portion of methane gas dominates at the process in lysimeter A (powder size), while the portion of CO_2 dominates in the other lysimeters. The anaerobic process produces leachate as by-product. The liquid product contains several macro- and micro nutrients for plants and therefore has the potential to be used as liquid organic fertilizer. The recovery of organic carbon and nutrients of the waste into biogas as source of energy and leachate as soil improver and fertilizer can be seen as a potential resource to support the lasting implementation of sustainable garbage management.

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