Determination of Household Green Waste Fractions to Methane and its Economic Value

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Abstract. The methane gas produced at the landfills has become one of the main causes of the global warming. On the other hand, solid waste has potentials as a new energy. One of the well-known methods in processing solid waste into a new energy is methanation or anaerobic fermentation process. This paper considers calculation of the solid waste fraction of green waste that can be released as methane from traditional market. The gas volume is measured by using U-pipe filled with water. The difference of water height in the U-pipe is used to calculate the formed biogas volume which can be generated from the solid waste processing by using anaerobic fermentation. The profits are obtained from the use of methane as the source of electricity energy and the profit of selling compost from the fermented trash residue. The results of this research show that the solid waste fraction which can be released as methane has the value range 0.11% - 0.18%, the benefits that can be generated from anaerobic process for organic solid waste are 300,899,290.00 IDR annually for electricity energy and 24,432,222,254.00 IDR annually for compost.

1. Introduction
An increase in population has occurred very rapidly and it is followed by a rapid increase in the amount of household waste with a lot of green waste proportion [1]. This waste forms complicated problems considering that there is no sophisticated waste management system, especially in Indonesia right now. The solid waste treatment system currently in use is open dumping. Management of this method raises a variety of problems, such as: a very pungent odour, the need for a very large area of land for its storage, unpleasant sight, health problems to community because of the pile [2]. The open dumping waste management system causes problems everywhere. The landfill produces a large amount of methane gas emissions.

Methane is one of the compounds classified into greenhouse gases [3]. Methane gas emissions have an effect on temperature increases reaching 20 - 25 times higher than carbon dioxide emissions [4]. The molar concentration of methane gas in the Earth's atmosphere in 2011 reached1803 ppb [5]. Methane gas generated from landfill at the Final Disposal Site (FDS) can apparently be used as a new energy source. This methane gas can be stored as electrical energy to be converted to generators. The converted energy is stored in the form of direct current (DC), such as batteries.
Developed countries are fully aware of the potential of waste to be processed into new energy sources. They have done research and the research continues today. As for developing countries (including Indonesia), it is too late to realize this. In fact, developing countries actually have an increase in population greater than developed countries, which means that the amount of waste is increasing rapidly too [6]. Research that has been done in Indonesia focuses more on the optimal conditions that must be used so that the biogas production process can take place effectively and efficiently. In reality, setting the conditions as is done in the laboratory today, it is less likely to be applied directly at the Final Disposal Site. Communities will not be able to regulate pH, temperature, pressure, and other operating conditions when disposing or piling up garbage in landfills. The existing technology in Indonesia does not allow for the regulation of operating conditions in the landfill. The above problems cause the process of methanation of waste is still less well known and not fully utilized by the people of Indonesia [6].

Until now, studies on energy conversion have used quite complex calculations. This is a source of new problems, where the community becomes difficult to accept and understand the potential of this new energy source. Knowledge of the process of methanation of waste is needed to create a new awareness that it turns out that waste can be treated simply and produce no small amount of profit economically. This paper considers the calculation of solid waste fractions of green waste collected from traditional market to methane. This value is then used to calculate the amount of benefits that can be obtained from waste treatment by anaerobic fermentation. These benefits come from the use of methane as a source of electrical energy and compost sales profits from fermented residual waste.

2. Material and Method
The raw material used in this paper is green waste taken from waste disposal at the traditional market, Simpang Dago Market in Bandung, Indonesia located with latitude and longitude locations (-6.884072, 107.613951). The waste represents the real condition of the waste that will be delivered to the final disposal site. Figure 1 shows the diluted green waste taken from the market.

![Figure 1. Garbage samples with 4x dilution that has undergone decay](image)

To conduct the experiment of methane release from the waste, the equipment used in this research is to support in conducting total solid analysis. The equipment consists of porcelain cup, digital scales, oven, stirring rod, glass bottle with a volume of 1 L as a biogas reactor, plastic hose.

2.1. Research methods
This research was conducted in three stages, namely preliminary research, primary research, and data processing using Microsoft Excel software.

- Preliminary research: calculate the total solid of the remaining green waste to be used as feed to reactor, followed by dilution until it reaches the desired total solid condition, which is half of the initial total solid and a quarter of the initial total solid.
Main research: determine the effect of the amount of total solid on the amount of biogas formed from the feed in the form of green waste.

Processing with software: calculate economic benefits obtained from the methanation process of organic wet waste at the Final Disposal Site (FDS).

The procedure for calculating total solids from green waste can be seen in figure 2. The dilution procedure for feed is described figure 3. The procedure for analysis total solids from green waste residues can be provided by the equations which will be displayed later.

**Figure 2.** The procedure for calculating the total solid from the sample is left over green waste

1. 200 grams of green waste are mashed and weighed using a cup
2. Put the cup in the oven and weigh the sample every 30 minutes
3. Wait until the mass of the sample is constant for 5 times
4. Perform total solid analysis of the samples

**Figure 3.** Procedure for diluting the bait in the form of leftover green waste

1. 2×200 grams of green waste are mashed and weighed using a cup
2. In different cup, the addition of water is done until the total solid value becomes a quarter of the previous value
3. Water is added until the total solid value is half of the previous value
2.2. Main research
The main research was carried out by varying the amount of total solid that is: without treatment, diluted to a value of half of the initial total solid, and diluted to a value of a quarter of the initial total solid. The acquisition of biogas volume is measured by calculating the area of the volume of water increased in the hose. Pictures of equipment tools can be seen in figures 4a and 4b and the main research procedures can be seen in figure 5.

Figure 4a. Simple biogas reactor, to illustrate [7]  

Figure 4b. Anaerobic fermenters for experiments

Figure 5. Main research procedure

2.3. Mass methane and total solid calculations
A typical biological reaction as described in [8], the main components of biogas consist of methane (\(CH_4\)), carbon dioxide (\(CO_2\)), and hydrogen sulfide (\(H_2S\)). Methane is a nonpolar compound and has very low solubility in water at room pressure and temperature [9], while carbon dioxide and hydrogen sulfide have polar properties so they tend to dissolve in water. The solubility of carbon dioxide and hydrogen sulfide in water is used in the design of water scrubbing to reduce the content of both compounds in biogas purification [10].

In this paper, it is used a hose filled with water which also functions as a column (water scrubbing) to absorb carbon dioxide and hydrogen sulfide which are formed as side compounds. Methane (with very low solubility in water) is assumed to be completely retained in the fermenter so that it does not dissolve and does not diffuse into columns containing water, whereas carbon dioxide and hydrogen
sulfide are assumed to dissolve completely into water and diffuse into free air at atmospheric pressure. The effectiveness of water scrubbing in reducing carbon dioxide and hydrogen sulfide content is not discussed in this paper.

The volume of methane produced can be obtained from the difference in the height of the water in the hose before and after the experiment is carried out. The volume is calculated using the following simple equation.

$$V = \frac{1}{4} \times \pi \times d^2 \times \Delta h$$

(1)

The methane mass is then obtained by entering the volume value of methane into the van der Waals equation

$$\left( P + \frac{a}{\bar{V}^2} \right) (\bar{V} - b) = RT$$

(2)

where

| Variable | Description |
|----------|-------------|
| $V$      | Volume of methane gas produced (mm$^3$) |
| $d$      | Inner diameter of the water hose (mm) |
| $\Delta h$ | Water level difference (mm) |

| Constant | Description |
|----------|-------------|
| $P$      | System pressure (pressure at a certain depth at landfill) = 1.5 atm |
| $T$      | System temperature= 30°C |
| $R$      | $= 0.0821 \text{ L.atm/(mol.K)}$ |
| $a$      | $= 2.283 \text{ L}^2\text{bar/mol}^2 = 2.253 \text{ L}^2\text{atm/mol}^2$ |
| $b$      | $= 0.04278 \text{ L/mol}$ |

Moisture content in solids can be determined by calculating the total solid of the sample. The equation used in calculating total solid is given by:

$$\text{total solid} = \frac{\text{final sample weight}}{\text{initial sample weight}} \times 100\%$$

(3)

2.4. Data processing with software

Data processing is performed to analysis whether waste processing with parameters obtained from the main research is economically beneficial or detrimental. Other parameters needed to process this data were obtained by gathering information from the Bandung City Government, previous research, and other relevant sources. Operating Conditions the assumptions used in processing this data are [11]:

- The price for each ton of methane gas is $ 5.00/CO_2$ equivalent.
- Waste entering the landfill is not subject to special treatment.
- Circumstances at the landfill in the form of daily conditions in the form of pH in the range of 6.7-7 and temperatures in the range of 30-45°C

Other parameters used in this experiment were obtained from the results of previous studies and from the survey literature in Thailand [12]:


• MSW (Municipal Solid Waste): Represents the amount of waste received by landfills. Used in tons/year.
• Comparison of molecular weight between methane and carbon is 16:12.
• GWP (Global Warming Potential): This price shows the conversion factor from methane to CO₂. Methane GWP is worth 21.

3. Results and Discussions

3.1. Selection of total solid as a trial variation
Several factors influence the process of biogas formation, to illustrate, temperature, pH, COD value, comparison of carbon and nitrogen values, type of starter, and total solid. In fact, quite a lot of obstacles are encountered when having to control these factors in the field. Therefore, total solid is used as the only factor that is considered sufficient to influence this methanation process. Another reason for the choice of total solid is that the rainfall that is quite volatile in Indonesia causes the total solids in waste in cities to change in value. Acquisition of methane with total solid as a trial variation is given in the following results. The following graph shows the profile of the difference in fluid level that changes due to the formation of methane with respect to time of observation.

![Graph showing liquid level curve](image)

**Figure 6.** Comparison of liquid level curve shows methane production for samples with various dilutions

From the graph in figure 6, the acquisition of methane over the time of observation forms an S-curve. At the beginning of the observation, the rate of methane formed is quite slow. The rate of methane formation has increased quite rapidly on the 10th day to the 18th day which then slowed down again in the following days. At first glance, the change in total solid to half and a quarter of the initial conditions shows the results which are quite influential on the rate of methane production. At lower total solids, the curves that are formed are more linear, where the rate of methane that is formed is fast enough in the initial stages. In the final stage, the characteristics of the curves that occur are the same as the conditions without dilution, that is, the rate of reaction seems to slow down.

The conclusion above is only done with a rough approach. A detailed discussion of the reaction rates due to differences in total solids is not elaborated further because it is beyond the scope of the research. From the final height on the curve above, the calculation is based on the volume of the tubular water hose so that the volume of methane formed is obtained. The conversion of methane volume to mass is determined using the van der Walls equation. This is because this research does not discuss in detail about the molecular properties of methane. Another reason is that methane is the simplest and non-polar hydrocarbon compound so that the use of more complex equations does not give much different results. The final acquisition of the volume of methane formed has increased significantly with a reduction in
total solid. Further observations show a reduction in total solid from half to a quarter giving the same final result.

Subsequent calculations use the smallest percentage of methane acquisition from the experimental results, which is equal to 0.12% (as an average result in experiments without dilution by duplication) in table 1. This is so that the results obtained next show minimum benefits that can be obtained from the organic wet waste methanation process.

| MSW  | Dilution | H (cm) | Methane (cm³) | Methane (mol) | Methane (grams) | % Methane from Trash |
|------|----------|--------|--------------|--------------|-----------------|---------------------|
|      | 0x       | 26     | 264.51       | 0.016        | 0.26            | 0.13                |
|      | 200 grams| 23     | 233.99       | 0.014        | 0.23            | 0.11                |
|      | 2x       | 35     | 356.08       | 0.022        | 0.34            | 0.17                |
|      |          | 37     | 376.42       | 0.023        | 0.36            | 0.18                |
|      | 4x       | 35     | 356.08       | 0.022        | 0.34            | 0.17                |
|      |          | 37     | 376.42       | 0.023        | 0.36            | 0.18                |

### Table 1. Calculation of % methane from waste

#### 3.2. Waste composition data collection

Waste composition data was obtained through a survey from the city government of Bandung. Table 2 shows data on the composition of waste in the city of Bandung for the years 2006 - 2007.

| No | Composition  | % Weight | Weight (ton) | Vol. (m³) | % Vol. |
|----|--------------|----------|--------------|-----------|--------|
| 1  | Wet Garbage  | 59.5     | 1115.6266    | 3592.5    | 47.9   |
| 2  | Paper        | 11.9     | 223.125      | 2235      | 29.8   |
| 3  | Textiles     | 0.5      | 9.375        | 112.5     | 1.5    |
| 4  | Plastic      | 12.6     | 236.25       | 697.5     | 9.3    |
| 5  | Broken Split | 1.4      | 26.25        | 60        | 0.8    |
| 6  | Metal        | 1.5      | 28.125       | 292.5     | 3.9    |
| 7  | Etc          | 12.8     | 236.249      | 525       | 7.0    |
|    | Amount       | 100      | 1875         | 7500      | 100    |

Every year the volume of waste in the city of Bandung has increased significantly. Each resident has the potential to produce 3 L of waste per day. Of the total garbage in Bandung, around 66% came from households. Industry is the second waste producer with production of 11% per day, followed by market waste, commercial waste, and garbage from the sewer. Such a lot of waste when processed properly can produce benefits in various ways. Methane gas produced from anaerobic fermentation can be used further to be used as electrical energy. Residue from fermented waste can be processed into compost.

#### 3.3. Calculation of energy production

The initial input for this calculation is the mass of organic wet waste in Bandung at 1,115,6266 tons / day. In this calculation, the machine's operating costs are used to convert waste to energy in the amount of 480,150,000 IDR/year. Assume, the technology used comes from COMFAC III to produce electrical energy in Hawaii. The electricity that can be sold is 781,049,290.00 IDR/year so that it produces a profit of 300,899,290.00 IDR/year.

In this calculation the conversion factor from waste to methane is used at 0.12% which was obtained from the experiment. This value is the average of the first experiment and duplication which is the lowest value of the entire experiment conducted. The conversion factor of biogas to electrical energy is set at 2.22 kWh/year, where 0.45 m³ of biogas is needed to produce 1 kWh of electrical energy [13].
The price of electricity used is 720.00 IDR/kWh. This price is the price of electricity for housing in the Central Java region with 900 VA power. In this calculation of electricity production, there are several other factors which are not taken into account. For example, the capital costs of this waste conversion technology are not included. Another factor which is quite influential is the variety of electricity prices in Indonesia.

3.4. Calculation of compost production

After the waste has been fermented and biogas taken, the waste is removed from the fermenter and is known as sludge. This sludge still contains organic materials which can be used further as compost. The World Bank issues standards for the quality of compost products with the parameters listed in Table 3. Composting can be done in two ways, namely aerobic and anaerobic. Almost all composting systems in Indonesia have been carried out with aerobic systems. This is due to slogans and appeals from the government which say that anaerobic waste management is very dangerous because it produces methane gas as a greenhouse gas. A false appeal like this should be fixed early on. Anaerobic waste management is actually not dangerous as long as it is done properly and structured. Even processing this way yields additional benefits from the methane gas produced.

Table 3. World Bank Standard for compost products

| Parameter           | Score |
|---------------------|-------|
| Water content (%)   | <45   |
| Ratio C/N           | <20   |
| Cr (mg/kg BK)       | <45   |
| Cu (mg/kg BK)       | <150  |
| Pb (mg/kg BK)       | <150  |
| Zn (mg/kg BK)       | <400  |

Kompas Daily Report [14] reported years ago, there were 225,017.40 m³ of waste accumulated from unloaded waste. Of this large amount of waste, only 75 m³ is recycled and composted. Meanwhile, the rest is thrown away without further processing. This shows that public awareness about the potential of waste to be further processed to be composted is still lacking. In fact, the benefits gained from the production of compost are quite large. In [15], the percentage of composted waste in one city of Indonesia has increased to 20%. The paper also shows that the biggest benefit gained from anaerobic organic wet processing turns out to be the production of compost.

The results of this study indicate that with compost production costs of 350 IDR/kg and compost selling prices of 500 IDR/kg will generate a profit of 24,432,224,254.00 IDR/year. The selling price of compost used here is the price that has been affected by government subsidies. Compost sold to the general public and the medium scale agricultural industry can reach 1000.00 IDR/kg. This of course will provide benefits far doubled. In the compost production calculation, a composting factor of 0.4 is used. The weight of compost obtained is only 0.4 out of the total waste produced by compost. This is because the weight of the waste will shrink during the composting process. The value of the composting factor varies, depending on the method of processing the compost itself.

4. Conclusion

The paper discusses the determination of solid waste fractions of green waste which can be released as methane. Under conditions without setting physical parameters (pH, C/N ratio, temperature) the fraction of organic wet waste that can be released as methane ranges from the range of 0.11% to 0.18%. The economic potential of anaerobic organic wet processing was gained from the electrical generation and the compost production. Adding water content to organic waste will increase the acquisition of methane to a certain extent. The solid waste fractions of green waste can be optimized by making an appropriate setting for a number of physical parameters.
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