Production of Biogas from Organic Waste and its Utilization as an Alternative Energy Source

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Abstract— *As a result of increase in human need for energy, the source of a new energy is necessary to replace the role of fossil fuel whose existence is beginning to scarce. The organic waste used for the production of biogas is an alternative energy, allowing reducing environmental pollution. The biogas test has been done by using digester fixed dome type made of fiberglass capacity of 5.5 m^3, equipped with an inlet for introduction of biogas raw material and an outlet for the release of residual biogas fermentation and an elbow iron mixing road. A soft PVC gas holder has capacity of 5.6 m^3. The digester is filled by organic wastes namely cow dung and grasses. Cow dung and water is added at the ratio of 1:2, then after methane production was stable, filling with grasses mixed with water. The results of the test show that organic waste get to produce biogas in blue flame, to be used as fuel to cook, to operate gas generator and for a infra red drying fuel. The Water Boiling Tests show that thermal efficiency is 57.9%, the fire power, 4.0173 watts, the burning rate 0.0688 gram/minute, the specific fuel consumption, 0.1248 kg/hour.*

Keywords— agitated digester, biogas production, organic waste, power generation, infra-red dryer

I. INTRODUCTION

The increasingly less reserve of petroleum is leading to increase in prices of refined fuel oil. Given increase in prices of refined fuel oil attributable to the upsurge of the world oil costs, the government is encouraged to deal with energy issues. One of efforts to tighten the refined fuel oil is to seek renewable source of alternative energy.

Most of need for fuel for low income population is satisfied by firewood, dried ups, and they are repeatedly chopping down trees in off-limits forests, thereby making natural conservation around the forest area in gradually danger. Based on the matters, it is necessary to try to use a source of renewable alternative energy. Biogas is a source of alternative energy having been developed, made out of diverse organic wastes by means of an anaerobic decomposition process. In general, the type of the resulting waste may be divided into two fold : one is organic waste consisting of kitchen waste, traditional market rubbish, livestock feces, agroindustrial waste, garden rubbish, agricultural waste and plantation. The second type is organic waste in the form of glass bottles, paper, cans, and plastics. The organic waste volume is, on average, more than inorganic waste, covering 60-70% of total waste volume (1).

Based on information from the Ministry of Environment, each individual produces, on average, 0.8 kg of waste per day. The average waste per person will continue to increase with the improved well-being and lifestyle. Assuming 220 million people in Indonesia, the waste discharged is at the rate of 176,000 tons per day, some 105,600 – 123,200 tons of them are organic waste.

So far, the management of organic waste is even using conventional techniques such as open dumping system management to the landfill, making it compost, burning it, or dump it into the river. The management of waste using those techniques tends to be environmentally less friendly and economically less valuable. The management in the open dumping system frequently creates new problems; i.e., generate pollutant gases such as H_2S and NH_3. The management of waste made into compost tends to be economically less valuable and burning it will cause the environmental pollution and respiratory troubles for humans. The management of waste by discarding it into the river will have direct impact being source of human diseases such as skin diseases and infectious diseases, while the indirect impact is a cause of the flood.

Looking at the drawbacks of such techniques, a more environmentally friendly management technique that able to produce products of high economic values is necessary. For this purpose, the management of organic waste as a source of alternative energy should be applied. A potential method is by applying anaerobic technology to the production of biogas.

Biogas technology was introduced in the 1980s; however, until now the development has not been encouraging, the existing obstacles include high construction costs, biogas digesters are not functioning due to leakage, requiring manual management (feeding/remove the stuffing of digester).

Biogas is gas produced from the fermentation of organic materials by anaerobic bacteria (bacteria being exist in anaerob conditions). The components of biogas are CH_4 50-70%, CO_2 30-45%, N_2 0.2%, H_2S 500 ppm, and 0_2 < 2% (2). Biogas is a fuel such like LPG which can be used for cooking and for power energy plant. Since it has a calorific value about 5,000-6,513 kcal/m^3 (3), the biogas is a source of environmentally friendly and renewable energy. The biogas digester output is slurry or residual sludge of fermentation which is useful as organic fertilizer for agricultural or plantation activities.

This study is designed to apply the technology to the production of household-scale biogas by utilizing organic waste derived from garden waste.

II. METHODOLOGY

A. *Biogas Digester*

Fixed dome digester used is made of fiberglass, 2.2 meters in height, 1.8 meters in diameter, capacity of 5.5 m^3. Fixed dome is a most popular model in Indonesia, where the installation of digester 3/4 is embedded in the ground, allowing the conservation of space, maintains the stability of digester temperature, and support the growth of methane bacteria.

Digester is equipped with an inlet for the introduction of biogas raw materials and an outlet for discharging the fermentation of residual biogas, made of PVC pipe, inlet of 31 mm in diameter and 19 mm in height spliced to PVC pipe of 16.5 mm in diameter, 30 mm in height, outlet of 4" in diameter, 22 mm in length. The outlet is operated based on the principles of hydrostatic pressure equilibrium.

Digester is equipped with a mixer, made of angle iron, 2 meters in height, and 1.5 meters in diameter. The purposes of the mixing are to prevent scum from formation, to reduce sedimentation, and to improve productivity. In addition, the mixing is generating exactly contact between a substrate and a population of bacteria, and produce a homogeneous condition and keep solid matters in suspension (4). Digester 2/3 is embedded in the ground, allowing the conservation of the land, thereby making the charging of the raw material easier and the temperature more stable.

B. *Agitated* Tank Biogas Material

Cow dung is collected in a plastic bag at capacity of 200 liters equipped with a mixer made of PVC pipe. The purpose of the mixing is to admix the whole organic waste – cow dung and water – to make the anaerobic digestive process faster. Manual mixing is made by spinning the mixer.

C. *Safety* Valve

This digester is equipped with a safety valve for regulating the gas pressure in the digester. It is made of PVC pipe, 3" in diameter, and 22 mm in height. This safety valve is using the principles of T pipe. When the gas pressure in the pipeline is higher than the water column, the gas will be coming out through the T pipe, allowing the reduction of the pressure in the digester.

D. *Gas* Holder

Gas holdet is made of soft PVC, 3.2 meters in length, 1.5 meters in diameter, and a capacity of 4 m^3. Digester is connected to the gas container by plastic tubing. Gas outlet is made of ½ inch plastic tubing. The gas container is placed on a height of 1.5 meters from the surface of the ground. The biogas is distributed by using the plastic tubing to the biogas stove. Furthermore, the biogas took in the gas container is distributed by using the plastic tubing to be used as fuel for cooking and generator to produce electricity.

E. The Filling up of Raw Material Biogas

Digester is filled up by cow dung and water is added. The cow dung is coming from cattle breeding of SMK II (STMPER) and Cikole. The water is added to the cow dung at a ratio of 1: 2 in order to obtain a dry weight about 9%. After the full filling up of digester has been completed and methane has been produced, the digester is filled with grasses and water is added at a ratio of 1:2.

F. *Measurement of Biogas Production*

The biogas produced is measured by a gas meter in specifications as follows: Q_{max} 6m^3/h, Q_{min} 40 dm^3/h, P_{max} 50 kPa, V 0.7 dm^3. While the gas meter used to measure the use of biogas for biogas stove and gas generator are as follows: Q_{max} 3 m^3/h, Q_{min} 16 dm^3/h, temperature -20ºC + 50°C, P_{max} 1.5 bar, V 1.2 dm^3.

G. *Utilization of Biogas for Cooking*

The biogas produced is used as fuel for cooking by using biogas stoves. To take advantage of biogas as a fuel stove required air pump to increase the pressure biogas. Air pump used has the following specifications: LP 60; 220 V/240 V; frequency, 50-60 Hz; output, 70 liters/min; power, 60 watts; and pressure, 0.04 mPa, is necessary.

H. *Utilization of Biogas to Run a Gas Generator*

The biogas produced is used to run a gas generator. Gas generator used has the following specifications : AJP 4000 E-type; rate voltage, 220 V; frequency rate, 50 Hz; rate output, 2.5 KVA; maximum output, 3.0 KVA; power generator, 3,000 watts.

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I. Utilization of Biogas to Run The Far Infrared Dryer

Biogas is used as fuel to run the dryer with the following specifications (5) : the type of far infrared dryer tray cabinet, dimension of length 2 meters; wide 2 meters; and height 2 meters.

Parts of wall made of styrofoam with a 40 mm thick insulating material to withstand the heat out of the dryer due to the heat transfer by conduction. Th inside styrofoam coated 304 stainless steel plate thickness of 1 mm as a reflector of electromagnetic radiation, while the outer walls using patterned alumunium plate orange peel with thickness of 0,8 mm. Floor section using T block with 20 mm thick and using the same layer as the walls. Dryers have two pieces of fan in the front and back, 1 piece exhaust fan, 2 piece of of intake air circulation holes in the door, 2 shelves and 1 control potel. Fans are used to flatten the hot air in the drying chamber, while the exhaust fan is used to absorb water vapor out of the drying chamber. As the type of heating used gasolec S8 as easily available and suitable for LPG and natural gas. Gasolec has a capacit 3,5 kw/hour with an operating pressure 350 – 1400 mbar (6). Infrared dryer is used to run the compressor with the following specifications maximum working pressure 9 kg/cm^2, water test pressure 14,7 kg/cm^2, capasity 22 l.

J. Testing the methane content

Testing the methane content is done simply by means of flame.

K. Water Boiling Test

The water boiling test is designed to determine the capability of biogas. The test is established in a biogas stove at room temperature using biogas to boil 2 liters of water in a pot. Once the water in the first pot is boiling, the test is done by replacing the pot in the second phase. The Water Boiling Test is delivering data on thermal efficiency, fire power, burning rate and specific fuel consumption (7).

L. Thermal Efficiency Test

Efficiency is the percentage of usable heat than the heat generated by a cookware during the test, the equation used is as follows (7) :

$$\eta_{overall} = \frac{(m_w.c_p + m_{pa}.c_{pa})(T_2 - T_1) + m_s.H_{fg}}{m_f.E}$$

Note:

η = Overall efficiency of gas burner
m_w = Mass of water under heat (kg)
m_{pa} = Mass of pot of water under use (kg)
c_p = Heat of water type (kj/kg)
c_{pa} = Heat of pot type (kj/kg)
T_2 = Temperature of boiling water (°C)
T_1 = Initial temperature of water (°C)
m_s = Mass of water under evaporation (kg)
m_f = Mass of fuel under application (kg)
H_{fg} = Latent heat of water evaporation (°C)
E = Low caloric value of fuel (kj/kg.bb)

M. Fire Power Test

This test is designed to determine the amount of power generated by a stove to cook. The power is derived from the multiplication of the mass of the fuel by caloric value of the fuel divided by time. Thus, the power generated by a stove is derived from the mass of the fuel under application and the caloric value of fuel (biogas) and the length of time to cook (7).

To determine the amount of fire power, the following equation is used:

$$P = \frac{m_f.E}{\Delta t} (KW)$$

Note:

P = Fire power (KW)
m_f = Consumption of fuel during time t (kg)
E = Low caloric value of fuel (kj/kg).
Δt = Time of testing (second)

N. Burning Rate

This is a measure of the rate of fuel consumption while bringing water to a boil. It is calculate by dividing the equivalent fuel by the time of the test (7).

$$R_{cb} = \frac{f_{cd}}{\Delta t_c}$$

Note :

Rcb = Burning rate (grams / minute)
f_{cd} = Biogas consumed (grams)
Δt_c = Time to boil (minute))

O. Specific fuel consumption

Specific fuel consumtion can be defined for any number of cooking tasks and should be considered the fuel required to produce a unit output, wether the output is boiled water. In the case of the cold start high power Water Boiling Test, it is a measure of the amount of biogas required to produce one liter of boiling water starting with cold stove (7).

$$SC_h = \frac{f_{hd}}{P_{ht} - P}$$

Note :

SC_h = Specific fuel consumption (grams fuel / grams water)
f_{hd} = Equivalent biogas consumed
P_{ht} = Weight of pot with water before test (grams)
P = Weight of pot with water after test (grams)

III. RESULTS AND DISCUSSION

Based on the results of the chemical analysis, cow dung have chemical composition as follows: pH, 8.0; the content of water, 76.25%; total nitrogen, 1.38%; total organic carbon, 34.42%; phosphate, 1.6%; and C/N ratio, 25. While the chemical composition of grasses as follows the content of water, 80,82 %; total nitrogen, 1.76 %; total organic carbon, 87,95 %; phosphate, 0,92 %; and C/N ratio, 49,9.

The optimum C/N ratio for the methane forming organism is 25-30 (8). If the C/N ratio in the material is high, it will be making the process of radical changes longer, leading to less production of methane. According Jewel (1982) when the amount of C in the material is very much high C/N ratio), the N will be ran out in advance, so that C are left in great quantities, thereby making the bacteria cease from active. The balance of carbon (C) and nitrogen (N) in the organic substance will be simply determining the microorganisms living and activities (9). A factor affecting the C/N ratio value of cow dung is the feeding of woof. To achieve ideal C/N ratio, the weeds need to be added. Carbon in carbohydrate and nitrogen in protein, nitric acid, ammonia, are the main substances for anaerobic bacteria. Carbon is used as energy and nitrogen to build structural cells of the bacteria.

The content of water in cow dung used as a raw material for production of biogas is 76.25 % and dried matter is 23.75%, while grasses the content of water is 80,82 % and dried matter is 19,12 %. In the processing of cow dung as input for digester, the cow dung and grasses is diluted at a ratio of cow dung / grasses and water = 1:2. The use of water is twice more than the amount of cow dung / grasses under mixing, because of the content of dried matter is high and methane bacteria needs water in large quantities for the process of biogas formation. According Kim (2011) in Triakuntini et al. (2012), the normal activity of the methane microbe requires about 90% of water and 7-10% of dried matter and fermentation input (10). This condition can be realized by using dilution by water at a ratio of 1:1 or 1:2. If the water is every little, the acetic acid would be accumulated; thereby inhibiting the fermentation process and a crust is formed and, in turn, hinder the gas formed into the surface.

pH of cow dung is 8.0, this value is qualifying for the production of biogas; according to Van Lier in Zhao (2011) the anaerobic microbe is active at optimum pH of 6.5 – 8 (11). If pH is below 6.5, it can be toxic to the methane forming bacteria; otherwise, it will be leading to the end product, CO_2, as the main product. Rather, when the pH is more than 8, it can be inhibiting microbe. The pH value during the observation, the inlet around 7 to 7.48, whereas at the outlet from 7 to 7.34.

A. The Temperatures of Digester and Ambient

Temperature is one of important factors in the process of biogas fermentation, as the temperature affects the optimal development of biogas forming microorganism. As ESCAP argues it, the temperature is essential for the process of fermentation, as it is related to the ability of bacteria in processing biogas. Optimum ambient temperature is ranging from 30-35°C (8).

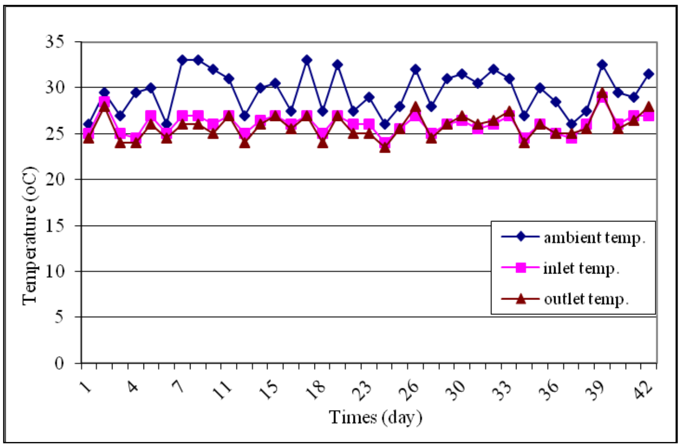

Fig.1: Ambient temperature and the temperature of stuffing in the digester during observation

As shown in Figure 1, the temperatures of inlet digester is in the range of 24.5-28.5°C, outlet, 24-28°C, and the ambient, 26-33°C, including the optimal temperature of digestion for biogas forming bacteria. According Rouf (2011), the optimum methanogenic bacteria are active at temperatures between 25-30°C (12). According Price (1981), microorganisms response to temperature changes in temperature cause in reaction speed, change in population of bacteria causes selection or mutation in the microorganism (13) .

B. Production of Biogas

The production of biogas is starting at 1 day after the full charging of digester and gas may be burned; eventhough the flame is yellowish blue in color and the pressure of gas is still very small and, therefore, can not be used as fuel. Biogas can be used as fuel at day 4, on the condition of the gas holder contains half. This hows that the biogas containing methane gas is high enough to be used as fuel. The production of biogas shows an increase until day 12, as shown in Figure 2. On the 13rd day, the biogas has reduction. This reduction is indicative of the organic waste need to be charged into the biogas digester, resulting in longer increase biogas production, because the substrat that has been fermented to be replaced by new waste still fresh. Charging raw material once a week, in the first week until week three of charging using com manure. Charging grasses done from week 4 until stable biogas production. Production of biogas from cow dung is higher than the grasses. Production of biogas from cow dung in the second week of 10.156 m^3, in week 3 of 9.208 m^3. While production biogas from the grasses at week 4, 9.775 m^3, week 5 amounted to 9.904 m^3 and the 6 th week increase to 7.423 m^3. This is due to cow dung containing the C/N ratio better than the grasses at 25, while the grasses at 49,9. Production of biogas average per day to 1.383 m3 of cow dung, to grasses of 1.291 m3. Arifin research results (2011) conducted in boarding Saung Balong Majalengka showed that the production of biogas from cow dung of 1.51 m^3 per day (14).

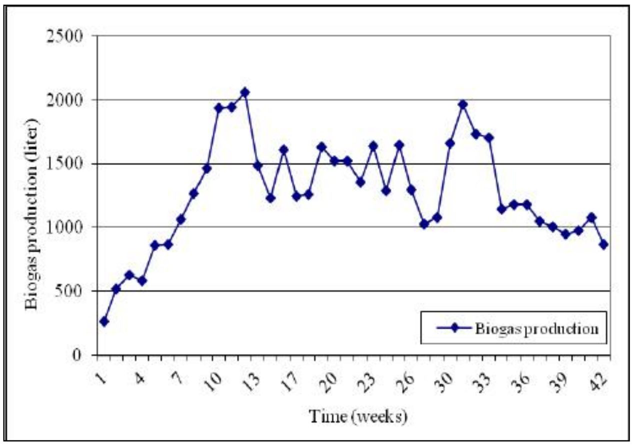

Fig.2: Biogas production during the observation

The content of methane is put to the simple flame test. The biogas may be burned properly if the content of methane has reached 57%, generating the blue flame (15). Meanwhile, according to Hessami in Alpen Steel (16), the biogas is well inflammable if the content of methane has reached at least 60%. According to Jewell (1982) the color of flame generated by the combustion of biogas may be used as an indicator to determine the content of CO_2 in the biogas (9). The blue flame is indicative of high methane. The yellow flame indicates the content of CO_2 is more than normal; i.e., it is more than 48%. When the gas is not inflammable, the content of CO_2 is extremely high.

The formation of biogas by the anaerobic fermentation is a process consisting of three stages: hydrolysis, acydogenesis, and methanogenesis. The first is the hydrolytic process by which the organic materials such as carbohydrate, lipid and protein are degraded by hydrolytic microorganisms to be such dissolved compounds as carboxylic acid, keto acid, hydroxyl acid, ketone, alcohol, simple sugar, amino acid, H_2 and CO_2. Organism having a role in the fermentation is *Bacteroides ruminicola*. The reactions are as follows (17) :

$$C_6H_{12}O_6 + 2H_2O \longrightarrow 2CH_3COOH + 2CO_2 + 4H_2$$
(acetic acid)

$$C_6H_{12}O_6 \longrightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2$$
(butyric acid)

$$C_6H_{12}O_6 + 2H_2 \longrightarrow 2CH_3CH_2COOH + 2H_2$$
(propionic acid)

In the next stage, acydogenesis or acidification, the dissolved compounds are converted into fatty acid in short chain which are, generally, acetic acid and formic acids. Also, it is changing a low molecular compound molecular into alcohol, organic acid, amino acid, CO_2, and H_2S by acydogenic microorganism of desulfovibrio genus. The reactions are as follows (18):

$$CH_3CH_2COOH \longrightarrow CH_3COOH + CO_2 + 3H_2$$
(acetic acid)

$$CH_3CH_2CH_2COOH \longrightarrow 2CH_3COOH + 2H_2$$
(acetic acid)

The last stage is methanogenesis, by which fatty acids in short chain is modified into H_2, CO_2, and acetate. Acetate will be undergoing decarboxylation and reduction of CO_2; afterwards, it is together with H_2 and CO_2 producing the end products, methane and carbon dioxide. Organisms having role are methanogenetic bacteria, for examples, *Metanobacterium formiciccum*, *Metanobacterium mobile*, *Metanobacterium ruminantium*, *Metanobacterium sohngenii*, *Metanobacterium prpionicum*, *Metanobacillus omelianski*, *Metanococcus mazaei*, *Maethanococcus vanbiellii*, *Metanosarcina metanica* (8). The reactions are as follows:

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

$$2H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$

C. Biogas application test as fuel for cooking

To turn on biogas stove need to use air pump to suck the biogas into the gas burner. The specifications of air pump used are as follows: LP 60, 220 V/240 V, 50-60 Hz frequency, 70 liters/ min output, 60 watts power, 0.04 mPa pressure. The results of biogas test as a fuel for cooking shows that consumption of biogas for the use of gas burner is 580-800 liters per hour, depending on the size of the flame. Researches by Martono (19) showed that consumption of biogas for the use of gas burner is 200-450 liters/hour, while for the large gas burner is 1000-3000 liters/hour. Meanwhile, the researches by Widodo (20) suggest that a gas burner need for 300 liters/hour to flare up at a pressure of 75 mm H_2O. Biogas produced is blue in color, odorless, and does not emit smoke. This is evidence of shrinking the biogas accommodating plastic representing decline in the composition of methane. Meanwhile, when the content of methane is high, the biogas accommodating plastic will be inflated and the burst of fire in the biogas stove is nice and blue in color.

D. Water Boiling Test

The Water Boiling Test is designed to determine the combustion power of biogas under test. The results of the Boiling Water Test suggest the consumption of biogas to boil 2 liters of water is 143 liters; the time required is 9 minutes and 14 seconds, from the initial temperature of 28°C to the final temperature of 99°C, no any soot in the bottom of pot. In light of the time to boil the water, the biogas can compete with other fuels such as kerosene. To cook 2 liters of water requires 9 minutes and 52 seconds, from the initial temperature of 21°C to the end temperature of 96°C, resulting in soot in the bottom of pot. Meanwhile, to cook the water using LPG take 6 minutes 29 seconds, from the initial temperature of 23°C to the final temperature of 98°C, no any soot in the bottom of pot. The Water Boiling Test generate thermal efficiency of 22.9% - 83.3%, the average is 57.9%, the fire power is 1.79 - 2.71 KW, the average is 2.21 KW, the burning rate is 0.0688 grams/minute, and specific fuel consumption of biogas is 0.359 - 1.078 kg/hour, the average is 0.1248 kg/hour. Syamsuri et al (2015) research result showed that the test using burner diameter of 2 to 4 was obtained power fire of 0,4744 to 0,55 KW, the fire power of 1,21 to 2,052 KW, thermal efficiency of 56,81 to 61,64 % (21). While Sudarmanta (2012) research results showed that the specific fuel consumption of 0,3451 kg/hour, the thermal efficiency of 50,591 % (22). Thermal efficiency is the magnitude of energy received by a pot as compared to energy released by the combustion of biogas. The thermal efficiency of biogas produces satisfactory results.

The gas burner power is heat supplied by the fuel during the test. The equation of power showed the consumption of fuel is directly proportional to the capacity. Therefore, when the biogas stove has a big power, the consumption of fuel is high, as well. Rather, when the biogas stove has small power, the consumption of fuel is, of course, low.

E. Gas generator test

Biogas can be used as fuel to run a gas generator. The gas generator being used has a capacity of 3000 watts; the consumption of biogas is 1053 liters per hour. Researches by Martono (18) showed that, to run a diesel machine per bhp requires biogas some 420 liters/hour. According to ESCAP (8), 1 m^3 of biogas can run a motor 2 HP for 2 hours and generate 1.25 kwh electricity.

F. Infra Red dryer test

The biogas produced can be used as fuel for Infra Red dryer. Infra Red dryer has a wavelength of 25-1,000 μm or approaching microwave. The drying process by Infra Red technology is very efficient because the radiation of heat is directed through inner molecule and breaks the bond of water molecules in the material molecules without any intermediary medium (air) as did in the processes of convection and conduction. In the Infra Red, the resultant product have high quality in the efficient process than drying by convection and conduction, the dried product did not experience a significant change in color, the aroma of product is even strong. The infra red dryer capable of drying 12 kg of cassava slices of water content 57,12 % to 14,865 % during 3 hours for drying at a temperature of 60 ºC. The consumption of biogas is 5,484 m^3, whereas, when LPG is used, the consumption of fuel is approximately 1.5 kg.

IV. CONCLUSION

The conclusion that can be drawn from the use of organic waste for the
Production of biogas is as follows: the production of biogas is improved with the time of observation, the content of methane is quite high, the biogas stove can be fired up in a blue flame, the gas generator and the far infra red dryer might be ran. The consumption of biogas for lighting up the biogas stove is ranging from 580-800 liters per hour, for the gas generator is 1757 liters per hour at 3000 watts, and for the Far Infra Red dryer of 2 m in length, 2 m in wide, and 2 m in height to dry 12 kg of cassava slices required about 2.653 – 3 m^3 of biogas. Biogas can be an alternative substitute of kerosene for day-to-day purposes.

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REFERENCES

[1] Putra, SE., Limbah Organik Tradisional sebagai Sumber Energi Alternatif bagi Masyarakat, 2010.
[2] Monnet, An Introduction to Anaerobic Digestion of Organic Waste, Chemical Engineering Journal, 2003.
[3] United Nations, Updated Guidebook on Biogas, Development Energy Resources Development Series No. 27, New York, USA, 1984.

[4] Hadi, A. and El-Azeem, A., Effect of Heating, Mixing and Digester Type on Biogas Production from Buffalo Dung, Jurnal Agriculture Faculty, Suez-Canal University Mesir, 2008.
[5] Afifah, N., Rahayuningtyas, A., Haryanto, A., Kuala, S.I., Pengeringan Lapisan Tipis Irisan singkong Menggunakan Pengering Infrared, Potgan Media Komunikasi dan Informasi, Vol 24, No. 3, 2015, hal. 167 – 246.
[6] Gasolec, Specification of Gasolec S 8, unpublished.
[7] Bailis, R., Ogle, D., Mac Carty, N. And Still, D., The Water Boiling Test (WBT), for the Household Energy and Health Programme, Shell Foundation, 2007.
[8] ESCAP, Updated Guidebook on Biogas Development, Energy Resources Development Series No. 27, Economic and Social Commision for Asia and the Pasific, united Nasions, Bangkok, New York, 1985.
[9] Jewell, W.J., Adams, B.A., Eckstrom, B.P., Fanfoni, K.J., Kabrick, R.M. and Sherman, D.F., The feasibility of Biogas Production on Farms, Department of Agricultural Engineering Cornell University, Ithaca, New York, 1982.
[10] Triakuntini, E., Sudarno, Sutrisno, E., Pengaruh Pengenceran dan Pengadukan Pada Produksi Biogas Dari Limbah Rumah Makan Dengan Menggunakan Starter Ekstrak Rumen Sapi, Jurusan Teknik Lingkungan, Fakultas Teknik, Universitas Dipenogoro, Semarang, 2012.
[11] Zhao, C., Effect of temperature on Biogas Production in Anaerobic Treatment of Domestic Wastewater UASB System in Hammarby Sjostadsverk, 2011.
[12] Rouf, Ari Abdul, Pemanfaatan Limbah Kotoran Ternak sapi untuk Biogas Skala Rumah Tangga, BPTP, Gorontalo, 2011.
[13] Price, E.C., Cheremisnoff, P.N., Biogas Production and Utilization, ANN Arber Science, 1981.
[14] Arifin, M., Saepudin, A., Santosa, A., Study of Biogas for Power Generation at Pesantren Saung Balong Al Barokah, Majalengka West Java,Journal of Mechatronics, Electric Power and Vehicular Ctechnology, Vol. 02, No. 2m pp. 73 – 78, 2011.
[15] Hermawan, B., Lailatul, Q., Candrarini, P., Evans, S.P., Sampah Organik Sebagai Bahan Baku Biogas, Jurusan Kimia FMIPA UNILA, Lampung, 2001.
[16] Alpen Steel, Bahan Baku Biogas Berasal dari Sampah Organik, unpublished.
[17] FAO, China : Azola Propagation and Small Scale Biogas Technology, Roma, Italy, 1978.
[18] Fry, Methane Digester for Fuel Gas and Fertilizer, The New Alchemy Institute, Massachusetts, 1974.
[19] Martono, D.H., Pengolahan Sampah Menjadi Energi, Indonesian Solid Waste Association, InSWA, Jakarta, 2009.
[20] Widodo, T.W., Asari, A., Ana, N. Dan Elita, R., Rekayasa dan Pengujian Reaktor Biogas Skala Kelompok Tani ternak, Balai Besar Pengembangan Mekanisasi Pertanian, Jurnal Enjiniring Pertanian, 2006.
[21] Syamsuri, Suheni, Wulandari, Y., Taufik, Analisa Performasi Kompor Biogas dengan Volume Penampung Biogas 1 m^3 yang Dihasilkan dari Reaktor dengan Volume 5000 liter, hal. 151 – 162, Prosiding Seminar Nasional Sains dan Teknologi Terapan III, Institut Teknologi Adhi Tama Surabaya, 2015.
[22] Sudarmanta, B., Unjuk Kerja Kompor Berbahan Bakar Biogas Efisiensi Tinggi Dengan Penambahan Reflektor, Jurusan Teknik Mesin, Fakultas Teknologi Industri, Surabaya, 2012.