Improvement of Biogas Generating by the Fermenting Barrel for Biogas Production from Organic Waste for Household Use

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Abstract. *This study was aimed to increase biogas generating from organic waste in the 120-liter fermenting barrel for household use by adding effective nutrients of molasses and glycerin. In the experiment, volumes of the organic waste were 1, 1.5 and 2 kilogram whereas the molasses and glycerin were added at 125, 250 and 500 grams respectively. The results revealed that the biogas volume from organic waste added with 500-gram molasses was averagely 1.17 and 1.46 times greater than those added with 250-gram and 125-gram molasses respectively. Likewise, the biogas volume from organic waste added with 500-gram glycerin was averagely 1.03 and 1.31 times greater than those added with 250-gram and 125-gram glycerin respectively. In conclusion, the biogas volume depends on the nutrient added volume and external temperature. The economic feasibility of the barrel for biogas production from organic waste was analyzed using the payback period (PB). The analysis results show that the barrel for biogas production from organic waste is economically feasible payback period =1 year and 3 months.*

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1. Introduction

Energy is an important factor in human life. Due to the increase in population, both developed and developing countries are facing mainly issues surrounding the future energy security and a better use of natural resources. In Thailand, there has been a government policy to promote the reduction and saving of energy use in all sectors which helps reduce the dependence on foreign energy and to support the production of alternative energy in various forms especially renewable energy such as solar energy, wind power, biodiesel, gasohol and biogas. As for the biogas, it can be produced from various types of organic waste. The Ministry of Energy recognizes and supports the efficient use of energy by focusing on alternative energy from the use of domestic raw materials which also helps solve environmental problems simultaneously. Thus, organic or compostable waste such as food waste, fruit peels, leaves, grass blades from garden trimming can be composted or produce biogas at 45-60%. On average, our food intake will cause about 0.1 kilograms of food waste per person at a time and the amount of the food waste awaiting disposal is increasing every year. Appropriate management and treatment can therefore be extremely helpful since the said waste is now combined with waste from other activities, causing various environmental problems such as foul odors, the spread of germs including the release of methane which causes global warming. Therefore, energy from biogas is another option that can be used as a renewable energy and organic waste can produce 60-70% of methane, more than methane produced from waste water [1]. The biogas, which is widely used in rural areas of many countries, comes from the composting of various waste such as banana peels, pineapple peels, fruits and vegetables and house waste [2-3]. [4] developed a biogas tank from organic waste and this can be used as a renewable energy source for household use. Also, [5] studied the effect of glycerin adding on biogas production from food waste in a 200-liter barrel. [6] examined the impact of adding vegetable and fruit waste and chicken manure in a continuous stirred tank reactor (CSTR). Moreover, [7] experimented on the co-digestion of dairy manure and food waste using the ratio of unfiltered cow manure to food waste. Therefore, this causes the concept of waste management at the source by using food waste to produce biogas because household waste may have a limited amount.

Based on the design principle that an average family has 2-4 people, each producing 0.5 kg of household waste per day, this paper presents increasing biogas generation both in higher volume and faster methanogenesis period, from 1-2 kg of organic waste per day in the fermenting barrel for household use, by adding effective nutrients in a ratio of not more than ¼ and worth the investment appropriately.

2. Material and method

An organic-waste-fermenting barrel

The organic-waste-fermenting barrel (Fig. 1), which was a 120-liter plastic one for a fermenting capacity of 90 liters, was designed and installed with 5 supplementary apparatuses fastened to the barrel's body by 2 outer and inner spiral tubes. An organic waste-filling apparatus (b) was a 2-inch diameter pipe connected to the other, wider pipe of 4 inches, with a closing lid. The sludge disposal apparatus (a) was made from a 1-inch diameter pipe bended to prevent itself from touching the floor, with a ball valve to open, close, remove unused sludge and use it as fertilizer. The stirring apparatus (c), which was made from a 3/8-inch diameter pipe built as a T-shape reaching the barrel bottom with a closing lid preventing biogas leakage on the top, was to stir organic waste, water, and the added nutrient until well and completely mixed. The water-level-keeping apparatus was a 1-inch diameter bended pipe with an open end outside the barrel (d) connected to the other long pipe in the barrel, and its open end outside was for draining the surplus fermented liquid. Finally, the biogas delivery apparatus (e) to the biogas-keeping barrel was a 12-inch-diameter bended pipe.

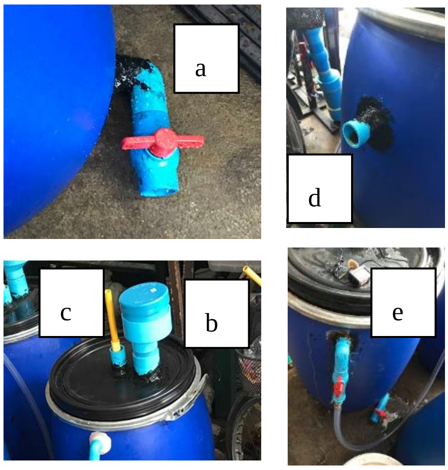

Fig. 1 Set of **120**-liter organic waste fermenting consisting of a) sludge disposal apparatus, b) organic waste-filling apparatus, c) stirring apparatus, d) water-level-keeping apparatus and e) biogas delivery apparatus to the biogas-keeping barrel

A biogas-keeping barrel

The biogas was transferred from the fermenting barrel through a 5/8-inch diameter rubber pipe to the 30-liter biogas-keeping barrel (Fig. 2) upside down in another 50-liter barrel filled with water preventing biogas leakage and all supplementary apparatuses were connected by 2 outer and inner spiral tubes. On the 30-liter biogas-keeping barrel (f), there was a supplementary biogas-filling apparatus made of T-shaped pipe and a ball valve used to take the biogas from the fermenting barrel to keep in it for further uses.

Fig. 2 Set of the 30-liter biogas-keeping barrel with the biogas-filling apparatus

Proportion in the fermenting barrel

Before the experiment, pig manure containing the microbes' capable biogas production and water were to be filled into the fermenting barrel at ¾ and ¼ of the barrel respectively; the mixture was to be stirred to be well mixed and the microbes were allowed to grow for 10 days.

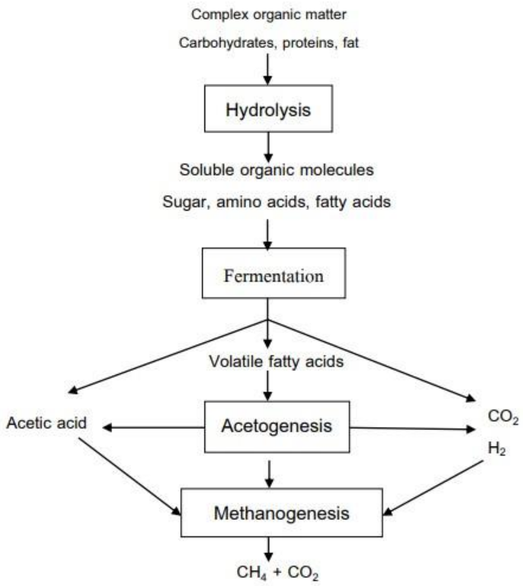

Fig. 3 Organic process degradation under anaerobic conditions [8]

Biogas production technology

Biogas, which results from the conversion of biomass by the anaerobic digestion (AD), comprises a mixture of different gases, mainly methane (60%), carbon dioxide (35%), and 1–5% other gases including hydrogen, nitrogen, ammonia, hydrogen sulphide, carbon monoxide, volatile amines and water. The process of the AD, which is a microbial degradation of organic waste in the absence of oxygen and requires bacteria, consists of 3 main phases as follows (Fig.3):

1. *Hydrolysis* is the digestion using enzymes to reduce molecules' sizes of such organic matters as protein, carbohydrate, and lipids so that they can go through the bacteria's tissues.

2. Acidogenesis is the digestion using acid-forming bacteria to reduce molecules' sizes of such organic matters as various acids and alcohols to become acetic acid.

3. Methanogenesis, the final phase, is the digestion of the acetic acid to become methane– the main component of the biogas using the bacteria.

Methanogenesis using cellulose as a pre-substance including hydrolysis and acidogenesis is shown in the chemical equations as follows:

1. Hydrolysis

$n(C_0H_{10}O_5) + H_2O \rightarrow n(C_0H_{12}O_0)$

2. Acidogenesis

$(C_0H_{12}O_6) \rightarrow CH_3CH(OH)COOH$

3. Methanogenesis

$4H_2 + CO_2 \rightarrow 2H_2O + CH_4$

$CH_3CH_2OH + CO_2 \rightarrow CH_3COOH + CH_4$

$CH_3COOH \rightarrow CO_2 + CH_4$

$CH_3CH_2\ CH_2COOH + H_2O + CO_2 \rightarrow CH_3COOH + CH_4$

All 3 phases of biogas production occur at the same time; therefore, they may affect one another. If the hydrolysis or acidogenesis is too much, the methanogenesis may be affected. Especially in the acidogenesis, if there is too much acid, it will affect the bacteria used for the methanogenesis. Theoretically, proper pH ranges between 6.8 – 7.2. The bacteria used for the AD are morphological. Temperature is critical to this type of bacteria; however, the appropriate is at 35°C and nitrogen or carbon from carbohydrates and proteins cannot be used. Balancing the bacteria number in the acidogenesis with that in the methanogenesis is also important because the work by the bacteria in the methanogenesis is a function of those in the acidogenesis [8].

Main Factors Affecting the Biogas Production

The production of biogas is influenced by many factors such as nutrients, pH of feedstock, temperature, flow rate of feed (loading rate) and retention time. These factors may slow or stall the process of biogas production if the values of the factors are not within a certain range [9]. Some of the factors are presented in this section.

1) Temperature

In the AD, temperature is critically important. According to previous studies, there are 2 ranges of the appropriate temperatures according to species of the mesophilic and thermophilic methanogens [10]. The optimum range of temperature for the mesophilic methanogens (bacteria) to work is around 20°– 45°C, but the most suitable range is 37°– 41°C. In these ranges of temperature, most bacteria in the fermenting barrel are mesophilic whereas the thermophilic work well between 50°–52°C and not beyond 70°C. In general, not only the mesophilic is greater than the thermophilic in number but also is more resistant to environment; therefore, the biogas production by the mesophilic bacteria is more stable. However, at higher temperature, the biogas production by the thermophilic bacteria is greater.

2) Carbon / nitrogen ratio(C/N Ratio) of raw organic waste

Typically, the C/N ratio of organic waste for biogas production ranges between 8– 30; however, the optimum C/N ratio of organic waste for biogas production is about 23. If the C/N ratio is very high, the nitrogen will be used by the methanogens (bacteria) to supplement themselves with proteins and will be depleted quickly resulting in less biogas. On the other hand, if the C/N ratio is very low, it will make a lot of nitrogen which gather to become ammonia which will further increase the pH. If the pH reaches 8.5, it will become toxic to the methanogens (bacteria), causing their number to decrease. Among various types of organic waste, animal manure has optimum C/N ratio followed by water lettuce, hyacinth and food waste.

From previous studies of the biogas production from organic matters, it is found that raw materials of large organic molecules such as carbohydrates, proteins and fats can be used. Adding food waste instead of animal waste is one way that can be done because both animal and food waste are of large organic molecules.

The role of the first group of microbes that produce enzymes to digest raw organic materials of large organic molecules such as carbohydrates, proteins and fats remain the same; however, digesting fats is harder than other organic substances because it requires temperatures higher than normal. Therefore, organic waste having a lot of fat should not be used to fill in the biogas production barrel.

As for another group of microbes that produce the acids to digest raw organic materials of small organic molecules and to produce volatile acid require no air; therefore, the barrel for biogas production must be designed and built as a closed system without air [10].

3) pH

The optimum ranges of pH for biogas production are between 7.0 – 7.2. The pH depends on the AD phases. The pH level, during the acetogenesis stage, can be below 5 during the production of organic acids; thus, the overall AD stops and the bacteria die. Methanogens (bacteria) which are very sensitive to pH will not grow if the pH is below 6.5. At the final phase of the AD, the concentration of NH4 will increase according to the increase of nitrogen digestion resulting in pH increasing up to 8 or beyond. Then the production system becomes stable and the pH will be between 6.8 – 8 [11].

4) Stirring

Stirring sediment, water and organic waste is another important factor because it will allow bacteria to come into contact with organic waste thoroughly; it is to prevent the accumulation of organic waste at various points in the fermentation tank, and to help distribute heat at the same temperature throughout. Additionally, it makes the bacteria work more efficiently and resulting in faster and more biogas. Therefore, stirring increases the efficiency of the fermenting barrel for the AD. However, stirring in the fermenting barrel can be done in many other ways such as uses of a mixing propeller or a pumping draft tube and the recycling of sludge by pump [4].

Karim *et al* [12] studied effects of stirring on the biogas production using continuous stirred tank reactor (CSTR) of 3.7 –liter size with the mixtures of cow manure liquid and 5% 10% and 15% cow manure solids at the temperature of 35°C and hydraulic retention time (HRT) for 16.2 days. The result showed that the fermentation with stirring produces more gas than that without stirring by about 10-30% and the gas content will increase respectively according to the percentage ratio of cow manure solids used as raw materials. Therefore, stirring increases the efficiency of the fermentation process for raw materials containing solids.

Nutrients used to increase the biogas volume

1) Molasses

Molasses is important food that allows microbes to produce acids, to grow, and to help improve nutrient and smell properties of the fermented water. These microbes will decompose various elements in plants resulting in various useful substances such as proteins, amino acids, organic acids, growth hormones, enzymes and key nutrients.

2) Glycerin

Raw glycerin which is a by-product from bio-diesel production is clear, viscous, colorless, odorless and non-toxic liquid. It is a cheap substance and can be used in many ways. From previous studies, the raw glycerin is used as a digester in food industry. Adding the glycerin in the AD is to increase the pH because its pH is greater.

The experiments were designed into 3 cases: 1) molasses addition, at high outside temperature, 2) molasses addition, at low outside temperature, and 3) glycerin addition, at high outside temperature. All cases were repeated 3 times to find the average results.

3. Result and discussion

According to the previous experimental results, the sole volume of the organic waste results in less biogas production [13]; therefore, the nutrients of molasses and glycerine were added to accelerate the AD.

Results of pH and methane concentration

As shown in Table 1, the average pH from organic waste filled into the fermenting barrel together with molasses at external temperature 35.78 °C (molasses 1), with molasses at external temperature 33.73 °C (molasses 2), and glycerin are 6.68, 5.68 and 6.53 respectively. The average methane concentration is 55-60 %. The different of internal and external temperature between 4.22-4.35 °C.

Experiment of Household waste	T_{ext} (°C)	T_{in} (°C)	pH	Average Methane (%)
With molasses 1	35.78	31.44	6.68	57.43
With molasses 2	33.73	29.38	5.68	55.38
With glycerin	36.45	32.23	6.53	57.25

Table 1 Results of average pH and methane concentration

Results of the organic waste with added molasses

As shown in Fig. 4, 3 volumes of 1-kg, 1.5-kg and 2-kg organic waste were filled into the fermenting barrel together with 125-g, 250-g and 500-g molasses respectively for a day at average external temperature of 35.78 °C. The results revealed as follows: 1) The biogas volume resulting from 1-kg organic waste added with the 500-g molasses was 1.18 and 1.42 times greater than those added with 250-gram and 125-gram molasses respectively; 2) the biogas volume resulting from 1.5-kg organic waste added with the 500-g molasses was 1.14 and 1.34 times greater than those added with 250-gram and 125-gram molasses respectively; 3) the biogas volume resulting from 2-kg organic waste added with the 500-g molasses was 1.20 and 1.62 times greater than those added with 250-gram and 125-gram molasses respectively.

This shows that molasses can be used as a factor to improve biogas production efficiency. The increase of the added molasses volume results in longer methanogenesis and greater biogas output.

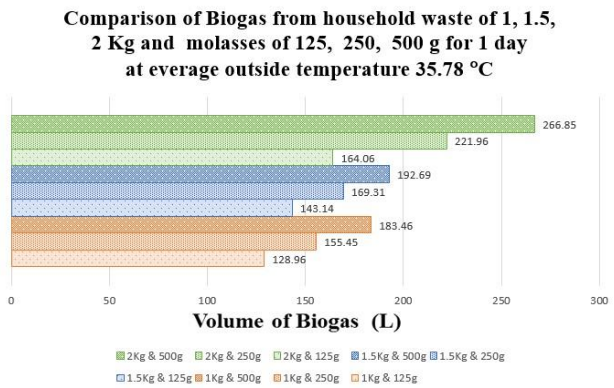

Fig. 4 Graphic comparison of the biogas resulting from filling 3 volumes of 1-kg, 1.5-kg and 2-kg organic waste together with 125-g, 250-g and 500-g molasses respectively for a day at average external temperature of 35.78 °C

Results of the organic waste with added glycerin

As shown in Fig. 5, 3 volumes of 1-kg, 1.5-kg and 2-kg organic waste were filled into the fermenting barrel together with 125-g, 250-g and 500-g glycerin respectively for a day at average external temperature of 36.45 °C. The results revealed as follows: 1) The biogas volume resulting from 1-kg organic waste added with the 500-g glycerin was 1.04 and 1.26 times greater than those added with 250-gram and 125-gram glycerin respectively; 2) the biogas volume resulting from 1.5-kg organic waste added with the 500-g glycerin was 1.02 and 1.22 times greater than those added with 250-gram and 125-gram glycerin respectively; 3) the biogas volume resulting from 2-kg organic waste added with the 500-g glycerin was 1.03 and 1.47 times greater than those added with 250-gram and 125-gram glycerin respectively.

This shows that glycerin can be used as a factor to improve biogas production efficiency. Increasing of the added glycerin volume results in longer methanogenesis and greater biogas output.

Due to its higher pH, the glycerin added as a co-digester therefore increases the pH in the AD. [14] reported that 6% glycerin added to the organic mixture of pig manure and maize silage resulted in higher methane production; however, the 8% and 15% glycerin resulted in the lower methane production.

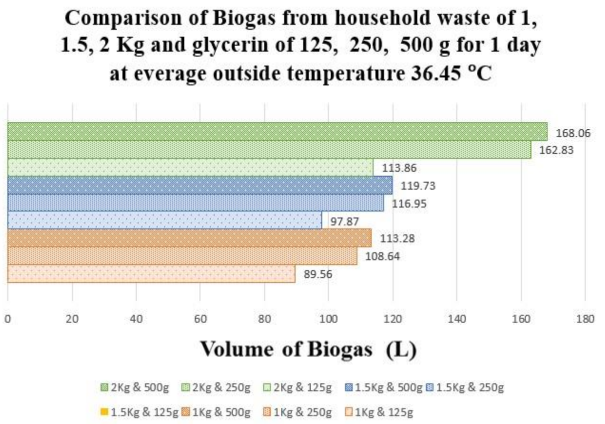

Fig. 5 Graphic comparison of the biogas resulting from filling 3 volumes of 1-kg, 1.5-kg and 2-kg organic waste together with 125-g, 250-g and 500-g glycerin respectively for a day at average external temperature of 36.45 °C

Results of the organic waste with added molasses at different outside temperature

As shown in Fig. 6, 3 volumes of 1-kg, 1.5-kg and 2-kg organic waste were filled together with 125-g, 250-g and 500-g molasses respectively for a day at average external temperature of 33.73 °C. The results revealed as follows: 1) the biogas volume resulting from 1-kg organic waste added with the 500-g molasses was 1.06 and 1. 25 times greater than those added with 250-gram and 125-gram molasses respectively; 2) the biogas volume resulting from 1.5-kg organic waste added with the 500-g molasses was 1.03 and 1.11 times greater than those added with 250-gram and 125-gram molasses respectively; 3) the biogas volume resulting from 2-kg organic waste added with the 500-g molasses was 1.03 and 1.05 times greater than those added with 250-gram and 125-gram molasses respectively.

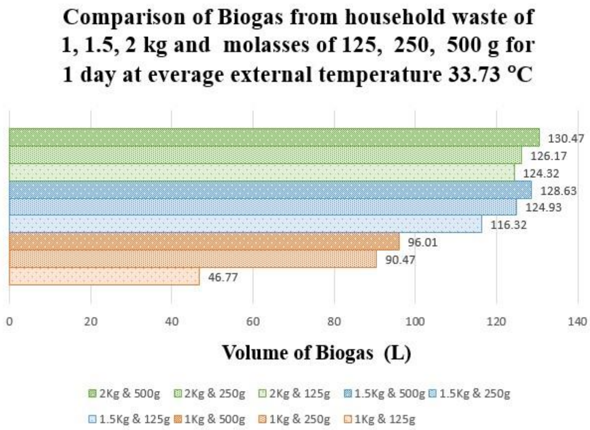

Fig. 6 Graphic comparison of the biogas resulting from filling 3 volumes of 1-kg, 1.5-kg and 2-kg organic waste together with 125-g, 250-g and 500-g molasses respectively for a day at average external temperature of 33.73°C

Moreover, as shown in Fig. 7, it can be seen that higher external temperature can increase the biogas, 1.32-2.75 times; however, it should be between the appropriate ranges of temperature [10].

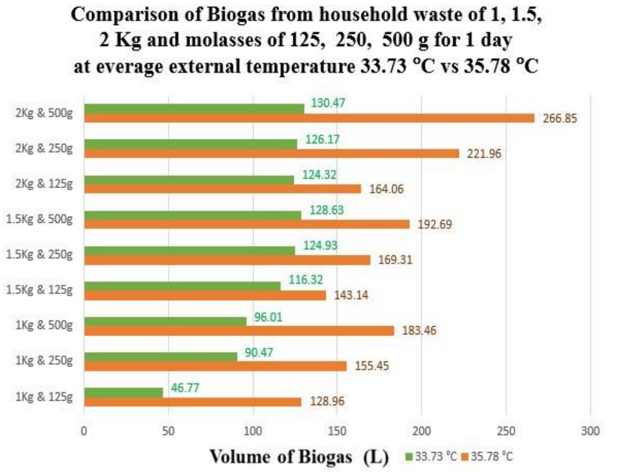

Fig. 7 Graphic comparison of the biogas resulting from filling 3 volumes of 1-kg, 1.5-kg and 2-kg organic waste together with 125-g, 250-g and 500-g molasses respectively for a day at average external temperature of 35.78 ° and 33.73 °C

Results of the organic waste with added molasses and glycerin

From Fig. 8, it can be seen that molasses can increase the amount of gas more than glycerin. The same amount of nutrition, the result from molasses can increase gas 1.28-1.59 times of the result from glycerin.

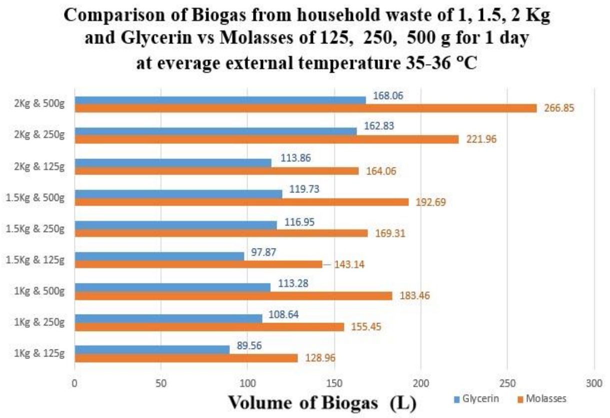

Fig. 8 Graphic comparison of the biogas resulting from filling 3 volumes of 1-kg, 1.5-kg and 2-kg organic waste together with 125-g, 250-g and 500-g molasses vs glycerin respectively for a day at average external temperature of 35-36 °C

From Fig. 9, comparing the amount of nutrients given, the amount of gas produced depends on the amount of household waste. The molasses gave the same increase ratio of 1.72 times when the percentage of sugar increased from 12.5% to 25%, but the ratio of gas with glycerin decreased from 1.82 to 1.54 times when the glycerin percentage increased from 12.5% to 25% which corresponds to the work of [14].

From the result, using molasses and glycerin as nutrition sources to increase and speed up the biogas by producing gas with an average methane content of 55-60%, pH is 5.68-6.68 and an average gas of more than 100 L / day, which is more than the fermentation from a 200-liter tank [13] and can reduce the fermentation time from 12-15 days to 10 days and also can reduce the gas generation time from 24 hours to 10-15 hours.

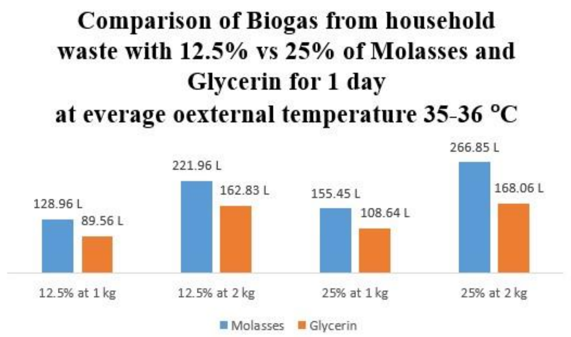

Fig. 9 Graphic comparing of the amount of biogas obtained from organic waste respectively for a day at average external temperature of 35.78 °C

Comparing Result of Biogas Production from Other Research.

Table 2 shows a comparison of type and condition of biogas generating, organic loading rate: OLR (g VS/l.d) and Biogas production rate (l/l.d) from other research with this research.

Type and condition [References]	Input material	OLR (g VS/l.d)	Biogas production rate (l/l.d)
Single stage fermentation tank 5 liters, CSTR, size, 3.75 liters, thermophilic fermentation (55 °C), semi-continuous operation [15]	Cattle manure, household waste and sludge from waste water	1.5	0.72
One-stage fermentation tanks 3000 liters, CSTR fermentation mesophilic (37 °C), operates a semi-continuous system [16]	household waste	3.7	2.7
One-stage CSTR fermenter, 5 liters, 3.5 liters mesophilic fermentation (35 °C), semi-continuous system operation. [8]	Chicken manure and household waste	0.87	0.8
CSTR single-stage fermentation tank 2 liter, 1.8 liter mesophilic fermentation (36 °C), semi-continuous operation [17]	Cattle manure and household waste	1.0	0.72
One-step fermentation system, 1000 liters, 750 liters mesophilic fermentation conditions (30-37 °C) [4]	household waste	0.72	0.53
	Pig and Cattle manure	0.80	0.44
One-step fermentation system, 120 liters, 90 liters mesophilic fermentation conditions (30-37 °C) Household waste 2 kg with nutrition 500 gram [This research]	Pig manure household waste and molasses 1	2.45	2.96
	Pig manure household waste and molasses 2	2.15	1.45
	Pig manure household waste and glycerin	1.85	1.86

Table 2 Comparison of biogas production from other research with this research.

The result of biogas production from household waste and pig manure, with molasses as nutrients, the OLR and Biogas production rate is increased when the external temperature is higher. The OLR and Biogas production rate of household waste added molasses is higher than household waste added glycerin. Moreover, a one-step fermentation tank when operating a semi-continuous system can increase the amount of biogas produced from household waste and pig manure sufficient for use in daily household cooking.

Table 1 and Table 2 found that Biogas production of the system when OLR is increasing, the amount of methane gas increase as well.

Analytical Result of Economic Feasibility

Table 3 shows comparison of cost of nutrition, production rate and energy per unit mass. So the molasses should be selected because it can produce the most biogas with the fastest methanogenesis period and one-time filling molasses can result in the longest methanogenesis period.

Experiment of Household waste	Cost of nutrition (Baht)	Production rate (L/KgVS)	Energy per unit mass (MJ/kg)
With Molasses1			
1Kg & 125g	1.25	128.96	28.79
1Kg & 250g	2.50	155.45	29.29
1Kg & 500g	5.00	183.46	29.29
1.5Kg & 125g	1.25	95.43	29.80
1.5Kg & 250g	2.50	112.87	29.79
1.5Kg & 500g	5.00	128.46	30.30
2Kg & 125g	1.25	71.57	31.31
2Kg & 250g	2.50	110.98	30.81
2Kg & 500g	5.00	133.43	31.82
With Glycerin			
1Kg & 125g	8.50	89.56	25.25
1Kg & 250g	17.00	108.64	28.28
1Kg & 500g	34.00	113.28	27.27
1.5Kg & 125g	8.50	65.25	26.26
1.5Kg & 250g	17.00	77.97	26.77
1.5Kg & 500g	34.00	79.82	27.78
2Kg & 125g	8.50	56.93	29.29
2Kg & 250g	17.00	81.42	28.79
2Kg & 500g	34.00	84.03	30.30

Table 3 Comparison of Cost of nutrition, Production rate and Energy per unit mass

Moreover, in terms of their prices/kilogram between molasses and glycerin, molasses costs 10 baht only meanwhile the glycerin costs 68 baht.

Therefore, the molasses is the best selection for improved biogas production. As for heat in comparison, biogas is about 30 MJ/kg meanwhile LPG is 45.5 MJ/kg. If household fuel demand of biogas is 60 L/day and 1 m3 of biogas can be substitute of LPG 0.46 kg. LPG price is at 24.2 baht/kg and the cost of fuel equipment is 1530 baht/set; then we can save on fuel cost at 3.34 baht/day. The economic feasibility of the barrel for biogas production from organic waste was analyzed using the payback period (PB). The analysis results show that the barrel for biogas production from organic waste is economically feasible payback period =1 year and 3 months.

4. Conclusion

The research improved a 120-liter biogas barrels for household biogas production. The barrels were designed to be suitable for the study and monitoring of the system. Biogas production barrel and assembling fermentation barrel were designed by adding propeller sets to increase fermentation efficiency and adding gas barrel lock to avoid gas loss. The fermentation of organic waste to produce biogas in a barrel is a conversion of biomass into biogas through the AD. Nevertheless, the biogas production efficiency can be improved by adding molasses and glycerin. Household expenses can drop after using the barrel for biogas production from organic waste. According to the experimental results, the methanogenesis depends on the major factors of the biomass volume and the added nutrients to help the microbial degradation by bacteria and the minor ones of the temperature and the HRT. The barrel for biogas production from organic waste can be really used by any households able to produce organic waste at 2 kg per day and then the household energy cost can drop at 3.34 baht per day. The analysis results show that the barrel for biogas production from organic waste is economically feasible with the payback period = 1 year and 3 months.

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Biography

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