The Biogas Production of Food Waste and Wastewater from Bang Ta Boon Estuary, Phetchaburi Province

Jutiporn I.[1,*] and Kodchasorn H.[2]

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ABSTRACT

This research is to study the biogas production system from food waste and effluent from Bang Ta Boon estuary, Phetchaburi Province, Thailand. The system design is based on suitability for the community. To study the parameters related to the production process of biogas from co-fermentation between animal manure, food waste, and community effluent within the fermentation tank system and also the thermal potential of biogas. Firstly, the proportion of biogas production was experimented at the laboratory level. The raw materials used for fermentation are cow dung, pig manure, chicken manure, food waste, and community effluent with different proportions to find out the optimal conditions for biogas production. Secondly, a biogas system was designed by using a 200-liter plastic tank and added a stirring system in the biogas fermentation tank. Thirdly, the production of biogas by fermentation of cow dung, food waste, and community effluent had the proportion of 1:2:1, the temperature used in the average biogas production system was 33 °C and the average of pH was 5.79. The average biogas volume throughout the experiment was 7,790.39 cm^3. The composition of biogas concentration was methane of about 58.5 percent, carbon dioxide concentration was 23.4 percent and the concentration of hydrogen sulfide gas was 682 ppm. The average thermal potential was 385.17 kJ per day. The potential for biogas production filled in organics loading of 100 kg per day could produce biogas throughout the experiment at 99.71 m^3/time or 909.85 m^3/year. In conclusion, the usage of liquefied petroleum gas is decreased by 454.93 kg per year with saving of 11,009.30 Thai baht (THB) per year with a payback period of 5 months.

1. INTRODUCTION

Phetchaburi is located in the west of the upper Gulf of Thailand in the south-central region. Phetchaburi's location is like a gateway to the southern border of Thailand and has a total area of approximately 6,225.138 km^2 or 3,890,711 rai, representing 1.2 percent of the country's total area (514,294.21 km^2). The approximate rectangle bordering with neighboring provinces which are in the north the Amphawa District, Samut Songkhram Province, and Pak Tho District Ratchaburi; South is with Hua Hin District, Prachuap Khiri Khan Province; East with the Gulf of Thailand coast; West is the Union of Myanmar.

The Department of Marine and Coastal Resources reported sea color change coastal phenomena 12 times in the environment of Phetchaburi during the first 6 months of 2015. Most of the characteristics are dark green, white or red-green colors (Figure 1), but it occurred for a short time and are not affecting the fish and livelihood depending on the fishery [1]. The occurrence of such a phenomenon comes from the wastewater drainage that causes the distribution of nutrients in the algae phosphate. Oxygen, sufficient sunlight and suitable temperature allow the algae to spread rapidly causing seawater to change color, so wastewater from industrial communities and aquaculture should be controlled before it is drained into the sea.

Fig.1. The occurrence of sea color change on the coast of the Gulf of Thailand.

[1]*Faculty of Engineering and Industrial Technology, Phetchaburi Rajabhat University, 38 Hardchaosamran Rd., Mueang, Phetchaburi 76000, Thailand.*
[2]*Faculty of Science and Technology, Rajamangala University Technology Rattanakosin, Salaya, Phutthamonthon, Nakhon Pathom 73170, Thailand.*
**Corresponding author:* Jutiporn I.; Tel: +66-83-035-2535; Fax: +66-3-270-8619 ; E-mail: jutipornintanin@gmail.com or jutiporn.int@mail.pbru.ac.th.

The water quality measurement station of the Pollution Control Department has announced that the average water quality is lower than the standard. The amount of dirt in the form of organic matter (BOD), total coliform bacteria (TCB) and the amount of fecal coliform bacteria (FCB), especially in the Phetchaburi river mouth cause the decrease of water quality index. Ban Laem District has a relatively high average bacterial load. This is caused by community wastewater including many fish processing establishments in Ban Laem Sub-district.

The National Environment Board of Thailand has approved the framework to support environmental funds for the year 2014-2016. It consists of 7 general support frameworks and 2 proactive project support frameworks determining support for projects that promote community participation in waste and wastewater management at the point of origin. The scope of activity is from promoting of participation in activities of waste management by reducing waste at the source. To accomplish the recycling of waste 3Rs activities must be carried out to promote the management of organic waste and waste in the community such as composting, making fertilizer, and renewable energy, etc.

The government policy has determined that the resolution of waste management is a national agenda that must be resolved first by implementing the waste and hazardous waste management plan approved by the National Council for Peace and Order (NCPO). To eliminate accumulated residue at disposal sites in critical areas, appropriate waste and hazardous waste disposal methods must be established and regulations for solid waste and hazardous waste management and discipline also be formulated. Similarly, the people of the nation should focus on waste separation for reuse including recycling and the transformation into energy, which is a 5 year plan in line with provincial strategies. The strategy of the Ministry of Natural Resources and Environment deals with climate change to lead to stability, prosperity, and sustainability following government policy.

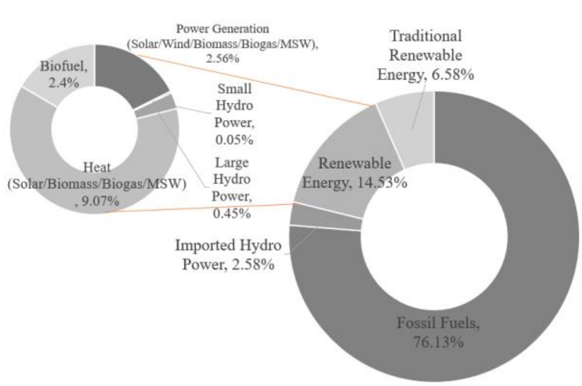


Fig.2. Alternative Energy Consumption in Thailand 2017.

Thailand's alternative energy consumption in 2017 [2], was 11,731 ktoe, an increase of 6.2% from the previous year and shared 14.53 % of the total final energy consumption. This affected the decrease of energy imports by 155,787.68 million Baht, and also decreasing CO_2 emission by 35.98 million tons, as shown in Figure 2.

Thailand Alternative Energy Situation 2018 reported [3] that the total heat energy consumption was 7,919 ktoe, up 8.2% from the previous year. Biomass was the greatest share 90.3%, followed by biogas, MSW and solar energy which shared 8.0%, 1.6%, and 0.1%, respectively as shown in Table.1.

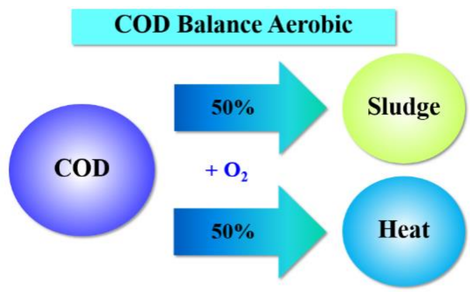
Table 1. The total heat energy situation of Thailand

Alternative Energy	**Heat (ktoe)**					**Growth rate (%)**
	2014	2015	2016	2017	2018	
Solar	5.1	5.7	6.7	9.3	10.1	8.6
Biomass	5,144	5,990	6,507	6,616	7,152	8.1
Biogas	528	495	593	634	634	0.0
MSW	98	88	75	63	123	95.2
Total	5,775	6,579	7,182	7,322	7,919	8.0

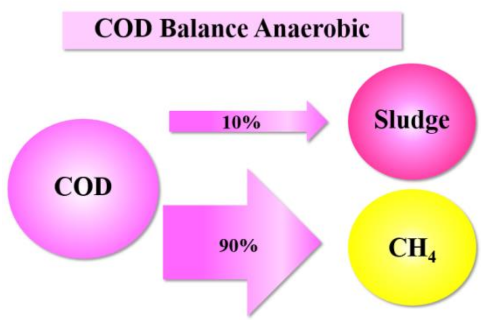
The main components of wastewater treatment of waste that contains organic substances use technology that relies on bacteria to decompose those organic substances. The system can be divided into 2 main categories, which are aerobic technology and anaerobic technology [4], as shown in Figure 3.

Biological wastewater treatment by microorganisms to treat wastewater can be divided into 2 major processes which are aerobic digestion technology and anaerobic digestion technology. Aerobic digestion technology digests organic matter decomposing into carbon dioxide and many microbial cells are created (about 50 percent of the organic matter in the wastewater is transformed into microbial cells) which has a reaction to decomposition. The advantage of this treatment process is the system is highly effective in treating wastewater. Nevertheless, there are disadvantages, which require a high cost of treatment. Because the air sprayed into the system and excess sludge must be eliminated. In addition, this treatment process cannot be used effectively with wastewater that has a very high amount of organic matter due to limitations in providing sufficient oxygen to the system [5].

Anaerobic digestion technology is approximately 80-90 percent of the organic wastewater decomposing into methane and carbon dioxide, collectively known as biogas. Microorganisms involved in the decomposition have relatively slow growth in the startup system and low efficiency in the treatment system. The longer hydraulic retention time (HRT) required belonging to the treatment system is very large. In addition, the system is not well adapted to environmental changes during disposal, sometimes hydrogen sulfide gas cause odor.



(a)



(b)

Fig.3. Digestion of COD in wastewater by using (a) aerobic process and (b) anaerobic process.

The composition of biogas is an important feature which influences the combustion of biogas. This affects the quantity and quality of heat that can be used in a heat application. Additionally, the concept of the biogas is characterized by the temperature level of the digesters which are usually heated with a fraction of the heat in order to allow bacteria fast decomposition of the material. Digesters of biogas plants are typically categorized into the following temperature levels [6];

- Psychrophilic: below 25°C
- Mesophilic: 25°C – 45°C
- Thermophilic: 45°C – 70°C

Thereby, some biogas with several digesters in series often use different temperature levels in the digesters. On the other hand, the biogas yield is increased if higher temperatures up to a certain maximum are applied. The optimum temperature has to be defined. The selection of the temperature level is influenced by the used feedstock, retention time, and the decomposition rate. The most important factor for the biogas plant for selecting the temperature level is usually the process stability.

The co-digestion process can be defined as the simultaneous treatment of two- or more-organic waste streams by anaerobic digestion that offers great potential. Anaerobic co-digestion combining various substrates simultaneously and probably produces a synergistic effect because of the nutrients complement. It is considered one of the most effective approaches for increasing the efficiency of biotransformation [7].

However, co-digestion can prevent process failure, as an in-depth selection of suitable co-substrates with complementary characteristics can favor position interactions by the introduction of additional micronutrients, and avoid inhibition by diluting concentrated wastes streams, thus increasing methane production. As such, numerous organic substrates already have been successfully co-digested on lab-scale and industrial scale [8].

Reducing the amount of wastewater from communities and fish processing establishments, especially around the estuary of the Phetchaburi River, requires using food waste and wastewater from the community to produce biogas. Additionally, it reduces the use of LPG in aquatic animal processing establishment and creating energy security considered sustainable to environmental solution as well.

2. MATERIALS AND METHODS

2.1 Raw materials and raw material preparation procedures

Animal manure used in the study to find suitable conditions for biogas production consisted of cow dung (CD), pig manure (PM), chicken manure (CM) as fresh manure that were collected from the same source every time.

Food waste (FW) from the community had to be sorted out because these inhibited the biogas system. For example, bones made the fermentation tanks of biogas systems to quickly fill up. Chili and meat are inhibitors of microorganisms, etc. Food waste was collected from the community of Phetchaburi Province, Thailand consisted of rice, vegetables, noodle, fish, and meat. Bones and other inorganic substrates were removed before disposal.

Community effluent (CE) were collected from aquatic animal processing establishments that are discharged into the river. However, the measurement values have passed legal standards.

2.2 The analysis equipment of the biogas production

To find the optimum conditions for biogas production in the analysis include a tester to determine the amount of oxygen needed by microbes to decompose organic matter in the water (Biochemical oxygen demand: BOD). The Organic substances by chemical (Chemical oxygen demand: COD) and analyzers to find the potential to produce methane by biochemistry (Biochemical methane potential: BMP) test methods are as follows:

2.2.1 Biochemical oxygen demand: BOD

Lovibond BOD analyzer model BD600 is test equipment for the amount of oxygen needed by microbes to decompose organic substances in water or BOD (Biochemical oxygen demand: BOD).

Fig.4. Biochemical oxygen demand (BOD) analyzer.

2.2.2 Chemical oxygen demand: COD

Lovibond COD model MD200 is test instrument for determining the amount of oxygen used for decomposing organic matter by chemical (Chemical oxygen demand: COD).

Fig.5. Chemical oxygen demand (COD) analyzer.

2.2.3 Biochemical methane potential (BMP) analyzer

The biochemical methane potential analyzer measures the amount of methane gas (CH_4), carbon dioxide (CO_2) and hydrogen sulfide (H_2S) by using the BLUESENS BMP analyzer, model Yield Master.

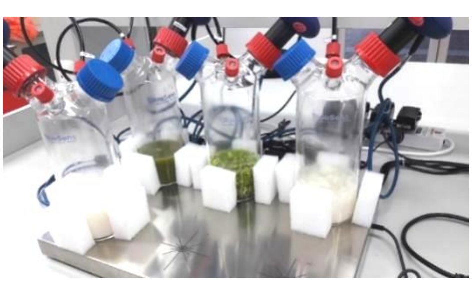


Fig.6. Biochemical methane potential (BMP) analyzer.

2.2.4 Biogas composition measurement

The composition analyzer of the biogas produced which consists of measuring the amount of methane gas (CH_4), carbon dioxide (CO_2) and hydrogen sulfide (H_2S) by using the Biotech Composition Analyzer Brand Geotech model BIOGAS 5000.

Fig.7. Biogas composition measurement analyzer.

2.2.5 The temperature measurement

The temperature controlled measurement inside the fermentation tank and outside the fermenter was done using the data logger Omron ZR-RX25, T type thermocouple.

Fig.8. The temperature measurement equipment.

2.2.6 The pH measurement

The pH controlled parameters measurement of the fermentation tank was measured by the pH meter brand Testo, model Testo 206 PH 1.

Fig.9. The pH measurement equipment.

2.3 The potential of biogas production from food waste and

community effluents

A study of the potential of biogas production from food waste and community effluents was done by evaluating the thermal potential. Assessing the thermal potential of biogas will use the concentration of biogas produced each day to calculate the heat value. The economic analysis of biogas production determine the economic effects of biogas and the payback period of the project.

Furthermore, finding the economical results of biogas will be compared with LPG. A cubic meter of biogas can replace 0.5 kilograms of LPG gas. The payback period of the project can be found from the cost of building the system compared to the economical results.

3. RESULTS AND DISCUSSION

The results of the study of suitable conditions for biogas production included test results of pH, Total Solid (TS), Volatile Solid (VS), raw materials, oxygen content required by microbes. To decompose organic matter in water or BOD (Biochemical Oxygen Demand (BOD), the amount of oxygen used to decompose organic substances by chemical or COD (Chemical Oxygen Demand Ratio: COD), the ratio of Carbon to Nitrogen ratio (C/N) and the potential to produce methane by biochemical methods (Biochemical Methane Chance: BMP) were used. Test results are as follows;

3.1 Basic conditions of raw materials

The characteristics of raw materials shown in Table 2. The results were pH, Total Solid (TS), Volatile Solid (VS), Carbon to Nitrogen ratio (C/N ratio), Biochemical oxygen demand : BOD) and COD (Chemical oxygen demand: COD). The raw materials (RM) were cow dung (CD), pig manure (PM), chicken manure (CM), food waste (FW), and community effluent (CE).

Table 2. Characteristics of raw materials

RM	pH	%TS	%VS	C/N	BOD	COD
CD	7.14	25.21	24.65	22.21	9,500	19,000
PM	7.36	26.12	20.12	18.23	37,000	17,000
CM	7.52	26.13	19.23	11.21	4,950	10,740
FW	6.11	25.82	23.20	26.52	7,500	15,060
CE	6.89	10.27	8.21	10.52	2,000	3,000

BOD is the amount of oxygen that bacteria use to decompose organic matter in 5 days at a temperature of 20 degrees Celsius. The value represents the amount of organic matter that is easily digested mainly from organic substances such as washing food scraps, some types of oil, etc. causing spoilage water. COD is the total amount of oxygen needed to cause oxidation of organic matter in water into carbon dioxide and water or the substitute for organic substances that are easy and difficult digest including some inorganic substances such as nitrate chloride sulfide, most commonly tested since the measurement takes 2-3 hours, the COD is usually greater than the BOD. The ratio between BOD and COD in most wastewater is constant. If the BOD: COD value is high, it is appropriate to use biological treatment methods.

The standard value of BOD is 20 mg/liter and the standard value of COD is 120 mg/l according to the Pollution Control Department's regulation regarding the determination of water source type in the Phetchaburi river as published in the Government Gazette, Book 116, Section 72, D, showing that the Phetchaburi river, from the Phetchaburi river, Ban Laem Sub-district, Ban Laem District, Phetchaburi Province (Km.0) until the end of Phetchaburi Village, Village No. 1, Ko Kla Om, Tha Laeng District, Tha Yang District, Phetchaburi Province (km 61) is in the group of water quality Level 3.

3.2 Carbon to nitrogen ratio (C/N ratio) of raw materials

The Carbon to Nitrogen ratio (C/N ratio) is the ratio of carbon to nitrogen of organic substances that can be used to produce biogas is range 8-30. However, the most suitable ratio for biogas production is about 20-25. If the C/N ratio is high it will be used by Methanogen bacteria to supplement the protein by itself and will run out quickly resulting in less gas.

Table 3. Carbon to nitrogen ratio of raw materials

Condition	CD	PM	CM	FW	CE	C/N ratio
1	1	-	-	1	1	19.75
2	1	-	-	2	1	21.44
3	1	-	-	1	2	17.44
4	-	1	-	1	1	18.42
5	-	1	-	2	1	20.45
6	-	1	-	1	2	16.45
7	-	-	1	1	1	16.08
8	-	-	1	2	1	18.69
9	-	-	1	1	2	14.69

Nevertheless, if the C/N ratio is low it will result in a lot of nitrogen and coalesce into ammonia affecting the increase of pH value. Conversely, if the pH value is up to 8.5, it will become toxic to bacteria causing the number of Methanogen to decrease. Also, if the C/N ratio is outside the range 8-30, it will cause the proportion of gas produced into other gases such as higher carbon dioxide. Therefore, the experimental condition 2 is a proportion of CD: FW: CE with the 1: 2: 1 ratio and the experimental condition 5 is the proportion of

PM: FW: CE with the ratio 1: 2: 1. The potential for effective biogas as the C / N ratio is in the range of 20-25 shown in Table 3.

3.3 Biochemical methane potential (BMP) potential

The potential for methane production by Biochemical methane potential (BMP), the control of the pH value is shown in Figure 10.

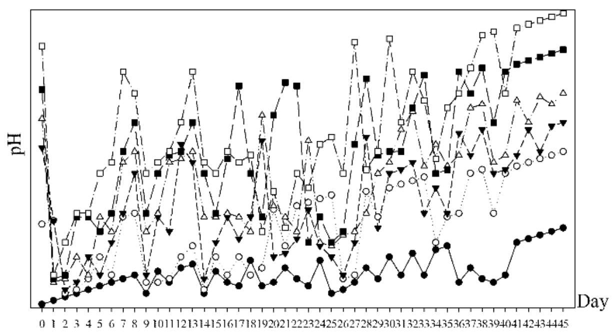


Fig.10. The result of the pH control.

3.4 The structural design of a biogas production system

The digester system has been designed as a 200-liter tank water with an immersion system. The system is designed for use in communities that do not require a lot of installation space like other systems and can be moved as needed. The researcher designed exactly according to the design and consistent with the parameters used in the design, as shown in Figure 11.

Fig.11. The design of the biogas production system.

3.5 The results of biogas production from food waste and community effluents

The results of biogas production from food waste and community effluents are composed of quantitative and qualitative measurements. The quantitative measurement is the measurement of the volume of biogas produced. The qualitative measurement is the measurement of the composition of biogas to analyze its quality on suitability for heat usage. It consists of measuring the amount of methane gas (CH_4), carbon dioxide (CO_2) and hydrogen sulfide gas (H_2S) and the controlled conditions consisting of acidity (pH) and temperature. Biogas production from cow dung, food waste and community wastewater at a ratio of 1: 2: 1 is the production of biogas in a 200 liter biogas production system, and the proportion of biogas production is a selection from the results. The experiment was done for finding the most suitable proportion for biogas production. The results are as follows:

3.5.1 Volume of biogas production

The experiment of biogas production from cow dung, food waste and community wastewater at the ratio 1: 2: 1 has the volume of biogas obtained as shown in Figure 12. Biogas occurs on the 18^{th} day of the fermentation and trend increases. The maximum volume of biogas on the 27^{th} day was 22,258.25 cm^3 and gradually decreased until the 40^{th} day of fermentation, with the average biogas volume throughout the experiment at 7,790.39 cm^3.

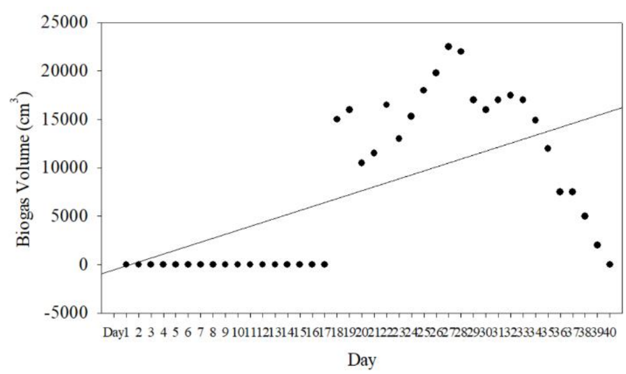


Fig.12. Biogas volume from cow dung, food waste and community effluent at a ratio of 1: 2: 1.

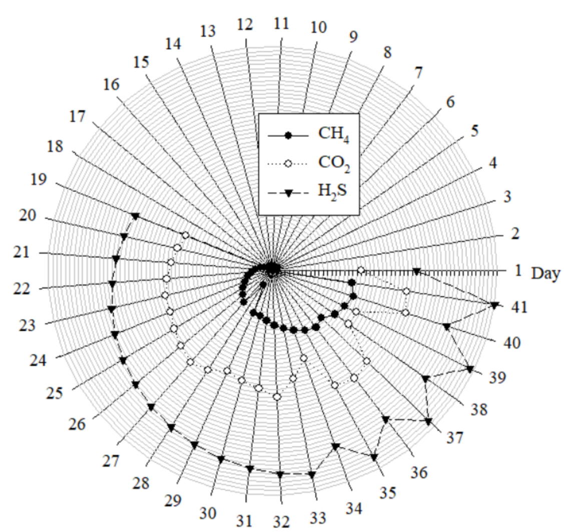


Fig.13. Biogas composition from cow dung, food waste and community effluent at a ratio of 1: 2: 1.

3.5.2 Biogas composition

The biogas composition are methane gas, carbon dioxide gas, and hydrogen sulfide gas, respectively. As shown in Figure 13. The biogas occured on the 18th day with the highest concentration of methane gas at 58 percent, the concentration of carbon dioxide gas is 25 percent and hydrogen sulfide gas is 0.8 percent.

3.5.3 Relationship of parameters with the composition of biogas from cow dung and food waste

The biogas production from cow dung, food waste and community waste water have many factors that affect the occurrence of biogas. The relationship of the parameters with the composition of biogas that affect the process of the composition of biogas is shown in Figure 14.

The relationship of parameters and composition of biogas that methane concentration is higher than carbon dioxide concentration because the pH is related to the composition of biogas. The theory of the optimum acidity is 7.00-7.20. The methane concentration occurring in biogas is at 58 percent, carbon dioxide concentration is 27 percent. Nevertheless, the experiment found that the average acidity is 4.98, the acidity is alkaline-like that it is possible for the occurrence of biogas process in the state of Acidogenesis and the hydrogen sulfide gas begins to rise in the 33rd day of fermentation.

3.5.4 Temperature for the operation of a biogas system

The optimum temperature for the work of microbes in cow dung in the production of biogas from cow dung, food waste and community waste at a ratio of 1: 2: 1 will be in the mesophilic temperature range. The temperature is around 20-45. The operating temperature for biogas production from cow dung, food waste and community effluents at an average ratio of 1: 2: 1 is 33 degrees Celsius.

3.5.5 The acidity in the biogas production system

The optimum pH for biogas production is between 7.0-7.2. Controlling the system condition for the pH level within the range is very difficult because the pH in the fermentation tank depends on the range of fermentation. The acid-forming bacteria produce large amounts of acid and reduce the pH and reach a stable state on the 14th day of the fermentation, with the acidity of 4.79.

3.5.6 The potential of biogas production from food waste and community effluents

The thermal potential of biogas in each day of production from the data collected from biogas content and biogas composition has found that the amount of biogas produced per day is 0.0223 m^3 per day. The methane concentration in biogas is 58.5%. Pure methane has a heating value of 39.4 MJ/m^3. Therefore, the thermal potential of biogas is 385.17 kilojoules per day.

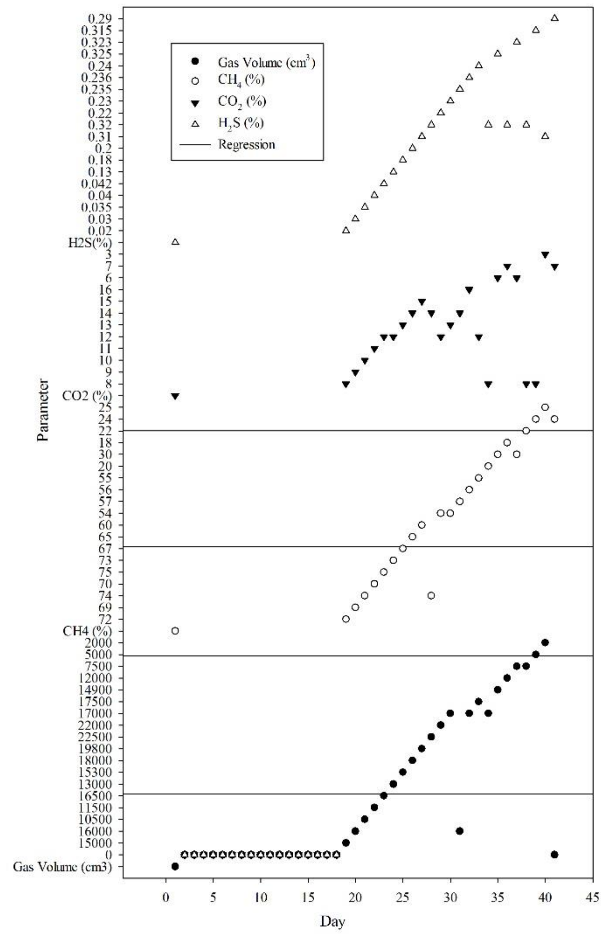


Fig.14. The relationship of the parameters of biogas production from cow dung, food waste, and community wastewater at the ratio of 1: 2: 1.

The experimental data, by adding organic loading of a kilogram of food waste per day and a kilogram of community waste water throughout the test for 35 days will get the total biogas volume throughout the test of 0.7790 cubic meters. The organic loading of food waste will get the total biogas volume as 99.71 m^3. Therefore, biogas can be produced throughout the 40-day trial for 99.71 cubic meters. Therefore, the volume of biogas produced per year are 909.85 m^3/year. In conclusion, the potential of biogas production is 909.85 m^3/year.

4. CONCLUSION

This research is to study the biogas production system from food waste and effluent from Bang Ta Boon estuary, Phetchaburi Province, Thailand. The system design is based on suitability for the community and to study the parameters related to the production process of biogas from co-fermentation between animal manure, food waste, and community effluent within the fermentation tank system and also the thermal potential of biogas. The biogas production by fermentation of cow dung, food waste, and community effluent had the proportion 1: 2: 1 with the average temperature control was 33 °C and the average of pH was 5.79. The biogas volume throughout the experiment was 7,790.39 cm^3. The composition of biogas was methane concentration 58.5 percent, carbon dioxide concentration 23.4 percent and the concentration of hydrogen sulfide gas was 682 ppm. The thermal potential was 385.17 kJ per day. The potential for biogas production by filling in organics loading of 100 kg per day could produce biogas throughout the experiment at 99.71 m^3/time or 909.85 m^3/year. In conclusion, through this biogas production, usage of liquefied petroleum gas can be decreased by 454.93 kg per year with savings of 11,009 Thai baht (THB) per year and a payback period of 5 months.

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REFERENCES

[1] Planning and Evaluation Division (2015) , *Thailand 6 months of Pollution State Year 2015,* Pollution Control Department of Thailand, pp.25

[2] Department of Alternative Energy Development and Efficiency, Ministry of Energy. 2017. Thailand alternative energy situation. In *Thailand Renewable Energy Report, Vol.15, January-December 2017.* ISSN: 1686-5170.

[3] Department of Alternative Energy Development and Efficiency, Ministry of Energy. Thailand alternative energy situation 2018. In *Thailand Renewable Energy Report, Vol.16, January-December 2018.* ISSN: 1686-5170. p.7

[4] Department of Alternative Energy Development and Efficiency of Thailand (2008), *Biogas*, Ministry of Energy.

[5] Teodorita A., Dominik R., Heinz P., Michael K., Tobias F., Silke V., Rainer J., 2008. *Biogas Handbook.* Denmark: University of Southern Denmark Esbjerg.

[6] Dominik R., Rita M., Rainer J., 2012. *Sustainable Heat Use of Biogas Plants A Handbook.* Germany: WIP Renewable Energies.

[7] Li, R., Duan, N., Zhang, Y., Liu, Z., Li, B., Zhang, D., Lu, H. and Dong, T. 2017. Co-digestion of chicken manure and microalgae chlorella 1067 grown in the recycled digeste: Nutrients reuse and biogas enhancement. *Waste Management.*

[8] Vrieze, J.D., Plovie, K., Verstraete, W. and Boon, N. 2015. Co-digestion of molasses or kitchen waste with high-rate activated sludge results in a diverse microbial community with stable methane production. *Journal of Environmental Management* 152: 75-82.