Biogas Production of Animal Manure with Wastewater From Toddy Palm Process with Circulate System for The Community: Case Study Phechaburi Province

K. Hussaro*, J. Intanin, and T. Sombat

Abstract— *To enhance biogas production and identify various sources of waste materials (wastewater from toddy palm process, chicken dung, pig dung, cow dung, and food waste) for the anaerobic co-digestion, pilot-scale were investigated in this research. Anaerobic co-digestion experiments using three different animal's manures with food waste and with/without wastewater from toddy palm process (WWTP) were conducted at 1:1:0.33 and 1:1 (optimal condition from lab-scale by biochemical methane potential, BMP, assay) of raw material ratio. There were conducted under mesophilic temperature (30-40 ℃) for 45 days on 200 L of digester with circulate system. This Results focusing on the comparative study of biogas production was evaluated in terms of biogas volume, the average cumulative biogas, and methane content. The biogas production (biogas volume, the average cumulative biogas, and methane content) was obtained from the anaerobic co-digestion with wastewater from toddy palm process, which was higher than obtained from the anaerobic co-digestion without wastewater from toddy palm. The raw material ratio of each digester was maintained as 1:1 of animal's manure: food waste on the both experiments. Cow manure with and food waste with WWTD with a C/N ratio of 31.62 was highest was 15.58 L of biogas volume with 70 % methane at 25th days and 308.96 L of the average cumulative biogas volume after 45th days. Cow manure, pig manure and chicken manure with WWTD with a C/N ratio of 31.62, 30.1, 27.47 were provided biogas volume higher than without WWTD consisting of 10.08 %, 9.79 %, and 8.54%, respectively. The results indicated that addition of WWTD with the widely used animals manure could lead to accelerated reaction, increased production and improved methane content. WWTD were successfully anaerobic co-digestion with animal's manure and food waste for methane production while it was failed when WWTD were used as a mono digestion. The results of the satisfaction evaluation for the technology transfer to the Wang Toddy Palm Community Enterprise Group, Phetchaburi Province showed that the participants were mostly satisfied. Anaerobic co-digestion for biogas production process technology in both lab-scale and pilot-scale were also financially and environmentally feasible.*

***Keywords*— Chicken dung, pig dung, cow dung, food waste, toddy palm process, wastewater, anaerobic co-digestion, and biogas production.**

1. INTRODUCTION

The Ministry of Energy in Thailand has set a target of 99,838 tons of oil equivalent by 2021, so individual renewable energy targets were set. The renewable and alternative energy development were determined from 2012 to 2021 with the proportion of renewable energy increased from 7,413 thousand tons of oil equivalent to 25,000 thousand tons of oil equivalent, respectively. It is representing 25% of total energy. Therefore, The Ministry of Energy in Thailand has implemented to develop renewable and alternative energy of 25% in 10 years. The energy demand was estimated to be increased by factors of two or three during this century. This demand is currently being met by coal and oil, which is depleting our resources and causing many of the environmental problems [1]. However, as the amount of organic wastes generated from human, animal, and agricultural activities increases, environmental pollution propels are also growing rapidly [2]. Biogas production has been set a target of 3,600 MW which are 600 MW produced from industrial waste and animal's manure and 3,000 MW produced from Napier grass power plant. Currently, there was a total capacity of 274.94 MW. Thailand has encouraged community participation to use and renew energy production widely, by encouraging the household biogas production level. Especially, implement their own household and promote of biogas pipe network in the system to the Community (Biogas Network). Biogas is a renewable energy that is produced from different types of biomass, including energy crops, municipal solid waste, sewage and waste from agriculture, livestock and some industrial activities [3].

The biogas production from a different organic material mainly depends on the content of substrates that can be converted into biogas, while their chemical compositions and biodegradability are the key factors for the biogas and methane productions [4]. Anaerobic digestion (AD) is a process which microorganism break down organic materials such as food craps and manure, in the absence of oxygen, into biogas and biosolids [5], which AD is often designed to achieve the maximum energy production, leading to a low stabilization of organic matter of the feed stocks. Consequently, digestates may be characterized by high labile organic matter content, thus, agricultural reuse may face agronomic and environmental issues [6]. The gas evolved from the anaerobic biological process is called biogas that is reproducible clean gas and can supply rural energy demand. Biogas, is a mixture of mostly methane (CH_4 (60-75%), carbon dioxide (CO_2, 25-50%) and some

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trace gases such as hydrogen sulfide (H_2S), hydrogen (H_2), nitrogen (N_2), and carbon monoxide (CO), that can be converted into electricity with internal combustion generators, turbines, fuel cells, and some other power generation facilities [7].

The co-digestion process, which can be defined as the simultaneous treatment of two- or more-organic waste streams by anaerobic digestion, offers great potential. Anaerobic co-digestion means combining various substrates simultaneously and probably produces a synergistic effect because of the contribution of nutrient complement. It is considered one of the most effect effective approaches for increasing the efficiency of biotransformation [8]. Recent research indicates that anaerobic co-digestion offers a promising alternative, particularly because it involves the dilution of potential toxic compounds, an improved balance of nutrients, synergistic effects of microorganisms, and better yields of biogas production. In fact, several co-digestion researches have been performed by using different organic fractions of industrial waste along with waste activated sludge to enhance biogas production [9]. However, co-digestion can prevent process failure, as 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 methane production is increased. As such, numerous organic substrates have already been successfully co-digested on lab-scale and industrial scale [10].

Toddy palm, is commonly known as Borassus flabellifer, palmyra palm, doub palm, tara palm or wine palm. It is a native plant in the Southeast Asia and Indian subcontinent, which including Nepal, India, Bangladesh, Sri Lanka, Cambodia, Laos, Burma, Vietnam, Malaysia, Indonesia, Philippines and Thailand. The toddy palm is also common in Thailand, especially in the central part provinces: Phetchaburi, Suphan Buri, and Nakhon Pathom and in the southern part province, Songkhla, where it is a prevailing part of the landscape. Toddy palm is very common in Phetchaburi Province. Sugar is produced in both households and communities. Toddy palm products are mostly to fruit, sap, and sprouts. In most of the fruit (sugar) is mainly directed to processed food, which waste water from toddy palm process (WWTP) and residues are not taken advantage. Proper management of toddy palm process has become a challenging problem as the production of wastewater has increased rapidly.

Food waste is a widely produced municipal solid waste with high yield, which are nutrient-rich organic material with a tremendous potential of renewable energy by anaerobic digestion (AD). However, the high moisture content of food waste makes it easier to become sour and smell, and the high contents of fat and protein in animal's manure and degradation compounds (such as, inhibitory long-chain fatty acids, ammonia or sulphides) affect the utilization of degradable components in the anaerobic process showed that at an early stage of AD, the soluble organics were converted to volatile fatty acids (VFAs) rapidly, resulting in a drastic pH drop and lower biogas production.

Therefore, AD of animal's manure often performs poor buffering capacity and lower biogas production. To stabilize AD process and increase methane yields, anaerobic co-digestion has been considered as an effective approach, that anaerobic co-digestion of food waste with other substrates (animals manure such as cow manure, pig manure, or chicken manure) could increase alkalinity and buffering capacity, reduce the inhibition cause by volatile fatty acids (VFAs) concentrations, and increase methane yield. An advantage of anaerobic co-digestion could be the possibility for achieving an improved carbon to nitrogen ratio (C/N ratio), the balance of other macro- and micronutrients, rapidly-degradable carbohydrates and slowly-degradable proteins and fats. An anaerobic co-digestion of different feedstocks has a main advantage the balance of nutrients carbon to nitrogen ratio (C/N ratio) equilibrium of digestion process. Thus, anaerobic co-digestion enhances process stability and performance of organic matter biodegradation, optimizing the biogas and methane yield [11].

This research was conducted to investigate the production potential of combination of different animal's manure (cow manure, pig manure, and chicken manure) with food waste and with/without wastewater from toddy palm process (WWTP), which was to assess the effect of different waste materials on the biogas prodction, and metahne content. Anaerobic co-digestion with/without WWTD was also evaluated as alternatives to improve the biogas production.

2. MATERIALS AND METHODS

2.1 Collection and Preparation of Substrates

Animal's manure can emit unpleasant odors, harmful aur pollutants, and greenhouse gases, including ammonia, hydrogen sulfide and particular matter, which can negatively impact the environment and human health. Animals manure also emits methane and nitrous oxide, two potent greenhouse gases. Wet animal's manure (Cow, Pig and Chicken manure) were obtained from a dairy farm near the Wang Toddy Palm Community Enterprise Group, Phetchaburi Province, Thailand during April 2017, and used as the main substrate in this research. Food waste was collected from the Wang Toddy Palm Community Enterprise Group, Phetchaburi Province, Thailand during April 2017, processing of average 98 kg/day of food waste, by screening and grinding, as a feedstock for an anaerobic co-digester. It consisted of rice, vegetables, noodle, fish, and meat. It was removal of bones and another inorganic substrate disposer.

Wastewater from toddy palm process (WWTP) was obtained in the fresh produce sugar toddy palm from the Wang Toddy Palm Community Enterprise Group, Phetchaburi Province, Thailand during April 2016, the WWTP was stored in a refrigerator under a temperature of 4 °C for later use. The waste water from toddy palm process is presented in Fig. 1.

Fig.1. Toddy Palm Process.

2.2 Anaerobic Co-digestion

2.2.1 Experimental design and set-up

The pilot experiment was conducted in two portions: one was co-digester of substrates (animals manure, food waste with/without wastewater from toddy palm) in 200 L and another was 150 L working volume using water displacement. The volume of the gas produced was measured by water displacement method which considers that the volume of generated gas equal that of the expelled water in the water tank. The cow manure (CM), pig manure (PM), chicken manure (KM) with food waste (FW) were fed into a 200 L semi batch digester. Each mix substrate was loaded in a 1:1 ratio, which CM: FW ratio (RM3), PM: FW ratio (RM2), and KM: FW ratio (RM1) were 1:1. Wastewater from toddy palm process (WWTP) was added with each mix substrate, CM: FW: WWTP ratio (RM6), PM: FW: WWTP ratio (RM5), and KM: FW: WWTP ratio (RM4) were 1:1:1:0.33. All experiments were applied as circulate system with EHELM pump (Compact Pump 600 11 W; 100-150 liter/hr.) and operated for 45 days at mesophilic conditions (31 °C). Each digester was connected to water tank (plastic tank 150 L) by means of a plastic pipe (gas pipe; PVC pipe) that conveyed the produced gas into the water tank, which both reactor of the gas pipe was inserted up to the topmost portion of anaerobic co-digester and water tank. The experimental set-up of anaerobic co-digestion is presented in Fig. 2.

2.2.2 Analytical Methods

The characteristics of CM, PM, KM, and FW used in this research, in terms of total solids (TS), volatile solid (VS), and pH, which the measurement of total solid (TS) and volatile (VS) were done according to the Standard Methods (APHA, 2005) and pH was measured using pH meter. Namely the substrates were initially characterized by determining total and volatile solids (VS/TS) as well as pH. Total solids (TS) were determined by drying at 105 °C for 24 h, and then volatile solids (VS) were operated by placing those samples in a 550 °C for 1 h in accordance with APHA Standard Method 2540 (APHA, 2005). The chemical composition (carbon content, nitrogen content, and carbon to nitrogen ratio (C/N ratio)) of WWTP were measured in accordance with the Standard Methods (APHA, 2005). The biogas composition was analyzed by using a portable BIOGAS 5000 (Geotech), which there were determined the methane (CH_4) and carbon dioxide (CO_2) content. The pH and temperature of the substrated mixture in the digesters were measured every day by pH meter and data logger (Amron, ZR-RX25), respectively [13].

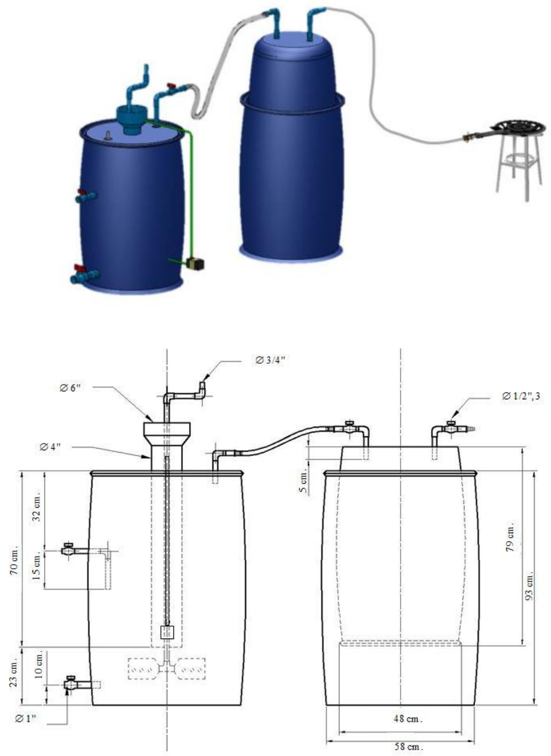

Fig. 2. The Experimental Set-up of Anaerobic Co-digestion with Circulate System.

3. RESULTS AND DISCUSSION

3.1 Characteristics of Substrates

The chemical composition characteristics of waste water from toddy palm process are shown in Table 1. The range of carbon (C), hydrogen (H), and nitrogen (N) in WWTP were 42.30, 5.62, and 0.89, respectively. The carbon content indicates presence of energy rich molecules in substrate for microbial metabolic energy necessity. The C/N ratio is one of the most critical parameters in biodegradability of organic substances in aerobic as well as anaerobic degradation process [12]. The WWTP was characterized by high carbon to nitrogen ratios (C/N ratio, 47.53) in comparison with the C/N ratios of animal’s manure (as shown in previous research) [13]. The optimum C/N ratios have been reported a value in the range of 15-30, which there were affects the biogas production. Namely, it was confirmed that higher C/N ratios cause nitrogen deficiency for microbial growth and then lack of nitrogen leads the process to lower methane production yield due to deactivation of methanogens and possible failure of the entire process. However, anaerobic co-digestion of these more than two substrates can be a solution to improve the imbalance C/N ratios of mono substrate. The high C/N ratios in WWTD compared to animals’ manure enables it to adjust the C/N ratios in anaerobic digestion using them as co-substrates.

Table 2 showed the characterization of each substrate: CM, Cow Manure; PM, Pig Manure; KM, Chicken Manure; FW, Food Waste, which the substrates used during the semi-batch anaerobic co-digestion experiments. The C/N ratios in substrates ranged between 10.51 (KM), 17.53 (PM), 22.15 (CM), and 25.59 (FW). The CM, PW and FW were characterized by optimum range of C/N ratios (20-30) in compared with the other hand research [4]. The nutrient balance is important aspect in microbial activity in anaerobic digestion and C/N ratios should be in appropriate range (20-30) as suggested by other research [13]. The TS of feedstock was: 14.99; CM, 24.13; PM, 25.5; (KM), and 26; (FW). The high TS load in substrate suggests the presence of total organic load. The high VS/TS ratio was the suitability of substrate for anaerobic digestion of degradation mechanism. The TS and VS represents total mass of organic load in substrate, which the TS content showed great differences among the four substrates, which the TS content of food waste was higher than other substrates and being particularly low in CM, reason why this substrate was very suited as dilution media for mixtures. The TS content affects the performance and stability of anaerobic digestion in association with the organic loading rate, and the parameters influencing the mass transfer rates within the digesters. In addition, the pH of feeding was found within the desirable ranges of pH required for hydrolytic activity in anaerobic digester. The pH value of CM, PM, KM, and FW were determined to be 7.12, 7.4, 7.6, and 4.94, respectively, indicating that the most substrates performed within range of pH to obtain maximal biogas production in anaerobic digestion is 6.8-7.2 [4].

Table 1. Chemical Composition of Wastewater from Toddy Palm Process (WWTP)

Characteristic	Wastewater from Toddy Palm Process (WWTP)
Carbon (% as received)	42.30
Hydrogen (% as received)	5.62
Nitrogen (% as received)	0.89
Sulfur (% as received)	0.04
Oxygen (% as received) by calculate	36.72
Lower Heating Value (cal/g as received) by calculate	3,521.00
Carbon to Nitrogen Ratio (C/N Ratio)	47.53

The feeding (RM1-RM6) characteristics of C/N ratios were presented in Table 3, which was 17.65; RM1, 21.56; RM2, 23.82; RM3, 27.47; RM4, 30.1; RM5, and 31.62; RM6. An anaerobic co-digestion mixture was use two and three substrates to balance the C/N ratios of feeding to optimize anaerobic process, trying to be as close as possible to the optimal range [13].

Table 2. The Characterization of each Substrates: CM, Cow Manure; PM, Pig Manure; KM, Chicken Manure; FW, Food Waste

Substrates	pH	Total Solid (TS) %	Volatile Solid (VS) %	VS:TS Ratios	C/N Ratios
Cow Manure	7.15	14.99	14.85	0.99	22.15
Pig Manure	7.40	24.13	19.95	0.83	17.53
Chicken Manure	7.60	25.50	18.98	0.74	10.51
Food Waste	5.94	26.00	24.50	0.94	25.59

Table 3. The C/N Ratios of each co-digester (two substrates; RM1-RM3 and three substrates; RM4-RM6)

Substrates	Carbon to Nitrogen Ratios (C/N ratios)
RM6	31.62
RM5	30.10
RM4	27.47
RM3	23.87
RM2	21.56
RM1	17.65

3.2 Biogas Production in Anaerobic Co-digestion from Two and Three Substrates (RM1-RM6)

In this experiment, two and three substractes co-digestion of cow, pig, and chicken manure, food waste with/without WWTP were conducted in a bath digester with circulate sytem as a control with mesophilic bacteria temperature range (30-40 °C) for 45 days. Biogas volume collected from two substrates co-digester (CM:FW, PM:FW, and KM:FW = 1:1) was presented in Table 4 and Fig. 3. The result showed a dramatic incresed in production after naerly 11 days of all the experiment. From the comparison of biogas volume at differneted mixing substrates of food waste with cow, pig, and chicken manure for the same ratio at 1:1 showed that the feed with cow manure: food waste (CM:FW=1:1; RM3) with a higher biogas volume than the feed from pig manure:food waste (PM:FW=1:1; RM2) and chicken manure (KM:FW=1:1; RM1). The optimal biogas volume at differenced mixing substrates of RM3, RM2, and RM1 for the same ratio at 1:1 (at 25^{th}

days) were 14,005.72, 13,510.3, and 12,078.95 ml, respectively.

Therefore, the added of animals manure mixing with food waste can siggnificantly enhance biogas volume production and also improve by C/N ratio of feeding. The C/N ratios resulting from mixtures were shown in Table Table 3. Whereas the mixture food waste with cow maure (1:1) still presented as optimal for anaerobic co-digestion, which showed the values of 23.87. This experiment suggested as optimal for anaerobic co-digestion, which there were suggested values with other research close to 20-30 [13].

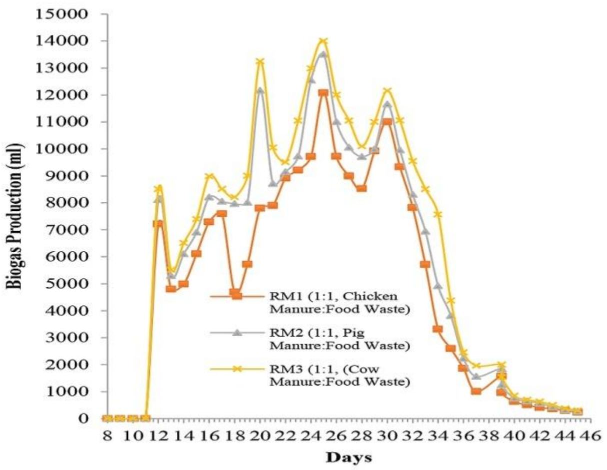

Fig.3. Biogas Volume from RM1 (Chicken Manure: Food Waste=1:1), RM2 (Pig Manure: Food Waste=1:1), and RM3 (Cow Manure: Food Waste=1:1).

Table 4. Biogas Volume from RM1 (Chicken Manure: Food Waste; KM: FW =1:1), RM2 Pig Manure: Food Waste; PM: FW=1:1, and RM3 (Cow Manure: Food Waste; CM: FW=1:1)

Days	Biogas Volume (ml)		
	RM1	RM2	RM3
1-11	0	0	0
12	7,211.13	8,115.9	8,510.12
13	4,800.29	5,299.26	5,519.31
14	4,990.16	6,110.95	6,512.28
15	6,108.93	6,910.33	7,391.79
16	7,291.21	8,210.59	8,990.05
17	7,594.58	8,054.54	8,513.71
18	4,690.15	7,970.21	8,210.51
19	5,721.93	8,016.61	9,001.50
20	7,800.13	12,170.16	13,251.03
21	7,900.10	8,715.02	10,054.15
22	8,910.24	9,152.15	9,510.29
23	9,209.10	9,726.16	11,049.43
24	9,715.79	12,550.91	12,991.04

Table 4. Biogas Volume from RM1 (Chicken Manure: Food Waste; KM: FW =1:1), RM2 Pig Manure : Food Waste; PM : FW=1:1, and RM3 (Cow Manure : Food Waste; CM : FW=1:1) (Cont.)

Days	Biogas Volume (ml)		
	RM1	RM2	RM3
25	12,078.95	13,510.31	14,005.72
26	9,719.10	11,010.83	12,010.25
27	8,995.26	10,058.42	11,049.05
28	8,522.90	9,713.38	10,097.26
29	9,915.65	9,995.04	11,003.40
30	11,000.09	11,659.78	12,156.45
31	9,335.71	9,961.35	11,055.58
32	7,827.28	8,315.46	9551.1
33	5,711.29	6,941.61	8,512.38
34	3,310.30	4,918.39	7,569.47
35	2,597.10	3,815.11	4,377.80
36	1,859.27	2,235.30	2,458.11
37	1,000.04	1,561.28	1,960.91
39	1,576.43	1,845.1	2,000.18
39	964.18	1,254.74	1,543.26
40	631.16	753.18	850.11
41	508.15	650.45	702.16
42	410.33	570.23	630.34
43	364.13	431.22	500.00
44	295.29	320.00	380.00
45	233.11	276.30	300.00

In an anaerobic co-digestion with three substrates (CM : FW : WWTP, PM : FW : WWTP, and KM : FW : WWTP = 1:1:0.33) conducted in a bath digester with circulate sytem as a control with mesophilic bacteria temperature range (30-40 °C) for 45 days, were demonstrated in Fig. 4 and Table 5. It was found that when fed WWTP of all experiments at two substrates, biogas volume were higher with RM6 (CM : FW: WWTP = 1:1:0.33) than RM5 (PM : FW : WWTP = 1:1:0.33) and RM4 (KM : FW : WWTP = 1:1:0.33), which on day 25th, the highest biogas volume of RM6, RM5, and RM4 were 15,576 ml, 14,976.88 ml, and 14,300 ml, respectively. In the process of digestion (fermentation) the produced biogas product, ratios of feedstock co-digestion are critical. Cow dung, pig dung and chicken dung with WWTD (RM6-RM4) with a C/N ratio of 31.62, 30.1, 27.47 were provided biogas volume higher than without WWTD consisting of 10.08 %, 9.79 %, and 8.54% of biogas volume, respectively. In particular C/N ratios are critical, and at a ratio of 20-30 is optimal. The C/N ratios in RM6 and RM5 were about

31.62 and 30.1, respectively, which were close to optimal range of C/N ratios. Therefore, the C/N ratios in two substrates (RM1-RM3) were lower than three substrates, this relatively low content of carbon hinders continuous biogas production in the digestion of two substrates, and can easily cause accumulation of ammonia nitrogen, resulting low biogas production. Therefore, in these research, an anaerobic co-digestion of three substrates by adding wastewater from toddy palm (WWTP) to animals manure and food waste (RM4-RM6), which was performed so that imbalances in C/N ratio in feeding, the increased carbon content also reduced the buffering capacity of the system against H_2S toxicity.

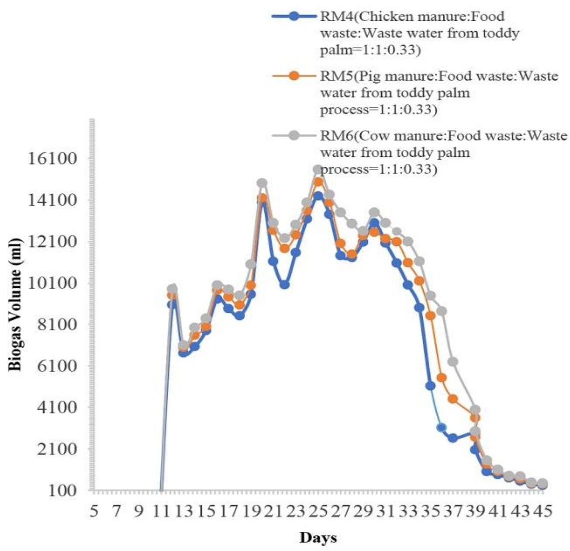

Fig.4. Biogas Volume from RM4 (Chicken Manure: Food Waste: Wastewater from Toddy Palm Process = 1:1:0.33), RM5 (Pig Manure : Food Waste : Wastewater from Toddy Palm Process = 1:1:0.33), and RM6 (Cow Manure : Food Waste : Wastewater from Toddy Palm Process = 1:1:0.33)

Table 5. Biogas Volume from RM4 (Chicken Manure: Food Waste: Wastewater from Toddy Palm Process; KM: FW : WWTP =1:1:0.33), RM5 Pig Manure : Food Waste : Wastewater from Toddy Palm Process; PM : FW : WWTP = 1:1:0.33, and RM6 (Cow Manure : Food Waste : Wastewater from Toddy Palm Process; CM : FW : WWTP = 1:1:0.33)

Days	Biogas Volume (ml)		
	RM4	RM5	RM6
1-11	0	0	0
12	9,045.81	9,510.36	9,811.21
13	6,726.15	6,999.00	7,104.50
14	7,039.93	7,572.15	7,949.09
15	7,811.26	8,002.49	8,398.11
16	9,325.57	9,745.23	9,995.86
17	8,861.01	9,429.92	9,786.35
18	8,515.41	9,041.42	9,500.00

Table 5. Biogas Volume from RM4 (Chicken Manure: Food Waste: Wastewater from Toddy Palm Process; KM : FW : WWTP =1:1:0.33), RM5 Pig Manure : Food Waste : Wastewater from Toddy Palm Process; PM : FW : WWTP = 1:1:0.33, and RM6 (Cow Manure : Food Waste : Wastewater from Toddy Palm Process; CM : FW : WWTP = 1:1:0.33) (Cont.)

Days	Biogas Volume (ml)		
	RM4	RM5	RM6
19	9,552.63	9,995.28	11,005.03
20	13,985.92	14,205.47	14,917.28
21	11,143.71	12,641.00	12,999.43
22	10,020	11,760.38	12,260.54
23	11,569.11	12,414.52	12,910.99
24	13,186.34	13,593.19	13,990.65
25	14,300.00	14,976.88	15,576.00
32	11,060.19	12,087.94	12,575.56
33	10,005.39	11,068.31	12,099.15
34	8,911.69	10,198.48	11,145.98
35	5,140.14	8,521.86	9,488.00
36	3,120.51	5,532.59	8,732.54
37	2,611.92	4,508.21	6,300.91
39	2,851.00	3,598.33	3,990.11
39	2,055.72	2,661.97	2,951.34
40	1,010.59	1,361.31	1,550.00
41	850.00	1,000.00	1,100.45
42	699.00	750.23	800.00
43	542.00	644.90	776.78
44	399.65	430.00	480.20
45	341.12	400.00	442.56

3.3 Methane Content in An Anaerobic Co-digestion from Two and Three Substrates in (RM1-RM6)

The methane content (CH_4) in different feed stock from two substrates is given in Fig. 5 and Table 6. The CH_4 content was slow during first week of anaerobic co-digestion. Methane content of around 35-65 % were achieved with the RM3, while RM2 and RM1 produced around 31-64 % and 30-61 %, respectively. The highest CH_4 content at 25^{th} days of RM3, RM2, and RM1 were obtained 65 %, 63 %, and 61%, respectively. While, there was highest CH_4 content about 70, 69.5, and 68.5 in RM6, RM5, and RM4, respectively, as shown in Fig. 6 and Table 7. In these results, it was found that increased in CH_4 content in three substrates feed stock than two substrates in feed stock. Methane content of around 39-70 % were achieved with the RM6, while RM5 and RM4 produced around 40-69.5 % and 39-68.5 %, respectively.

The differences methane content between two substrates (RM1-RM3) and three substrates (RM4-RM5) co-digestion may be due to higher C/N ratios applied in three substrates anaerobic co-digestion, which were close to optimal range of C/N ratios [13]. The adding of wastewater from toddy palm process (WWTP) to feed stock (0.33 by weight) showed higher methane content compared to the without WWTP in feed stock.

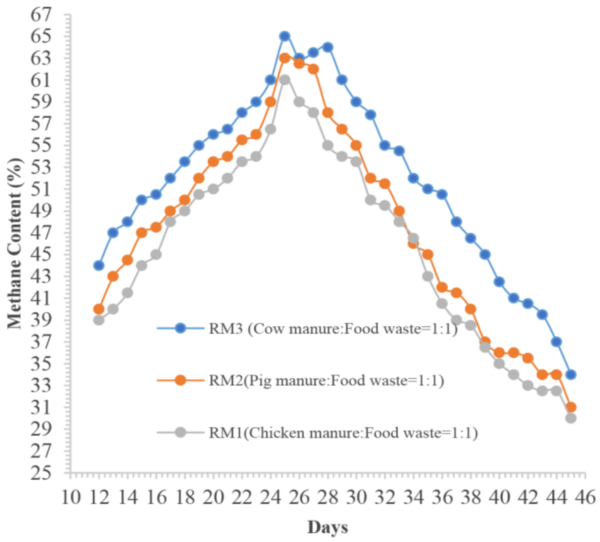

Fig.5. Methane Content from RM1 (Chicken Manure: Food Waste = 1:1), RM2 (Pig Manure : Food Waste = 1:1), and RM3 (Cow Manure: Food Waste = 1:1).

Table 6. Methane Content from RM1 (Chicken Manure: Food Waste; KM: FW =1:1), RM2 Pig Manure: Food Waste; PM : FW = 1:1, and RM3 (Cow Manure : Food Waste; CM : FW=1:1)

Days	RM3	RM2	RM1
1-11	0	0	0
11	42.00	39.50	36.00
12	44.00	40.00	39.00
13	47.00	43.00	40.00
14	48.00	44.50	41.50
15	50.00	47.00	44.00
16	50.50	47.50	45.00
17	52.00	49.00	48.00
18	53.50	50.00	49.00
19	55.00	52.00	50.50
20	56.00	53.50	51.00
21	56.50	54.00	52.00
22	58.00	55.50	53.50
23	59.00	56.00	54.00
24	61.00	59.00	56.50

Table 6. Methane Content from RM1 (Chicken Manure: Food Waste; KM: FW =1:1), RM2 Pig Manure: Food Waste; PM: FW = 1:1, and RM3 (Cow Manure: Food Waste; CM : FW=1:1) (Cont.)

Days	RM3	RM2	RM1
25	65.00	63.00	61.00
26	63.00	62.50	59.00
27	63.50	62.00	58.00
28	64.00	58.00	55.00
29	61.00	56.50	54.00
34	52.00	46.00	46.50
35	51.00	45.00	43.00
36	50.50	42.00	40.50
37	48.00	41.50	39.00
38	46.50	40.00	38.50
39	45.00	37.00	36.50

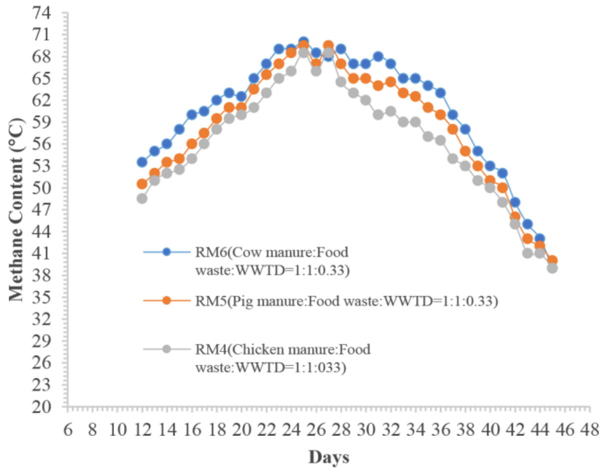

Fig.6. Methane Content from RM4 (Chicken Manure: Food Waste: Wastewater from Toddy Palm Process = 1:1:0.33), RM5 (Pig Manure: Food Waste: Wastewater from Toddy Palm Process = 1:1:0.33), and RM6 (Cow Manure: Food Waste: Wastewater from Toddy Palm Process = 1:1:0.33).

3.4 The pH Value in Anaerobic Co-digestion from two and three substrates (RM1-RM6)

It is known that pH is a very important parameter with direct impact on the performance of anaerobic digestion systems. It is known that the activity of methanogenic and acidogenic microorganisms are different with respect to the optimal nutritional requirements and optimal pH. The optimal pH for methanogenesis is around 7.0, while it is between 5.5 and 6.5 for hydrolysis and acidogenesis [14]. According to the literature [13], the optimum pH for anaerobic digestion is around 6.8-7.2. As can be seen in Fig. 7, the monitoring profiles of pH value, for mixtures of RM1-RM6, the pH in RM6, RM5, RM4, RM3, RM2, and RM1 were approximately between 6.5-7.3, 6.3-7.2, 6.25-7.2, 6.15-6.9, 5.79-6.8, and 5.89-6.7, respectively. The pH in three substrates feed stock (RM4-RM6 was nearly neutral (about 6.25-7.3), which a good buffer capacity of the digester and substrate dilution may have enabled the operation of the digester without the necessity of externally adjusting the pH.

Table 7. Methane Content from RM4 (Chicken Manure: Food Waste: Wastewater from Toddy Palm Process; KM: FW: WWTP =1:1:0.33), RM5 Pig Manure: Food Waste: Wastewater from Toddy Palm Process; PM: FW : WWTP = 1:1:0.33, and RM6 (Cow Manure :Food Waste : Wastewater from Toddy Palm Process; CM : FW : WWTP = 1:1:0.33)

Days	RM6	RM5	RM4
1-11	0	0	0
12	53.50	50.50	48.50
13	55.00	52.00	51.00
14	56.00	53.50	52.00
15	58.00	54.00	52.50
16	60.00	56.00	54.00
17	60.50	57.50	56.00
18	62.00	59.50	58.00
19	63.00	61.00	59.50
20	62.50	61.00	60.00
21	65.00	63.50	61.00
22	67.00	65.50	63.00
23	69.00	67.00	65.00
24	69.00	68.50	66.00
25	70.00	69.50	68.50
26	68.50	67.00	66.00
27	68.00	69.50	68.50
28	69.00	67.00	64.50
29	67.00	65.00	63.00
30	67.00	65.00	62.00
31	68.00	64.00	60.00
32	67.00	64.50	60.50
33	65.00	63.00	59.00
34	65.00	62.50	59.00
35	64.00	61.00	57.00
36	63.00	60.00	56.50
37	60.00	58.00	54.00
38	58.00	55.00	53.00
39	55.00	53.00	51.00
40	53.00	51.00	50.00

Table 7. Methane Content from RM4 (Chicken Manure: Food Waste: Wastewater from Toddy Palm Process; KM: FW: WWTP =1:1:0.33), RM5 Pig Manure: Food Waste: Wastewater from Toddy Palm Process; PM: FW : WWTP = 1:1:0.33, and RM6 (Cow Manure :Food Waste : Wastewater from Toddy Palm Process; CM : FW : WWTP = 1:1:0.33) (Cont.)

Days	RM6	RM5	RM4
41	52.00	50.00	48.00
42	48.00	46.00	45.00
43	45.00	43.00	41.00
44	43.00	42.00	41.00
45	39.00	40.00	39.00

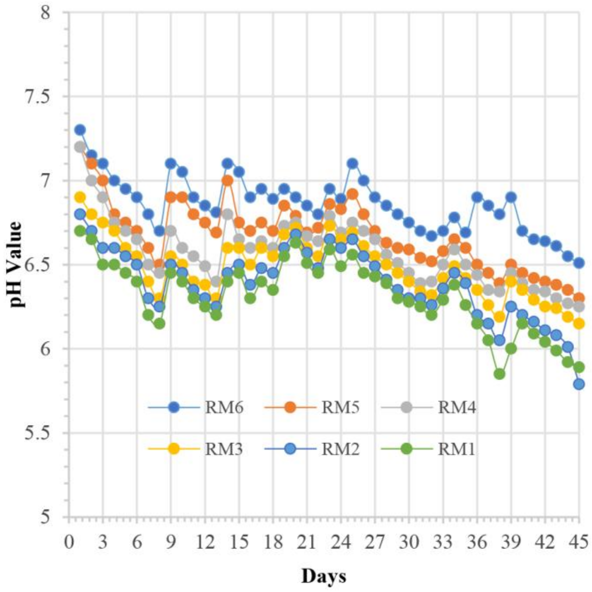

Fig.7. pH Value from RM1, RM2, RM3, RM3, RM4, RM5, and RM6.

3.5 Temperature in Anaerobic Co-digestion from two and three substrates (RM1-RM6)

Temperature is one of the main influential parameters which affect the performance and stability of anaerobic digestion. Suitacle operating performance, stability and less sensitivity to inhibitors are considered as the advantages of mesophilic operations (about 30.5 °C - 37°C). On the other hand it is reported that anaerobic digestion process conducted under mesophilic temperature regime was more stable than the one operated under ambient temperature [15]. As can be seen in Fig. 8, the average temperature of anaerobic co-digester at during 45 days for RM6, RM5, RM4, RM3, RM2, and RM1 were 35.4 °C, 34.4 °C, 33.9 °C, 33.7 °C, 33.6 °C, and 32.9 °C, respectively.

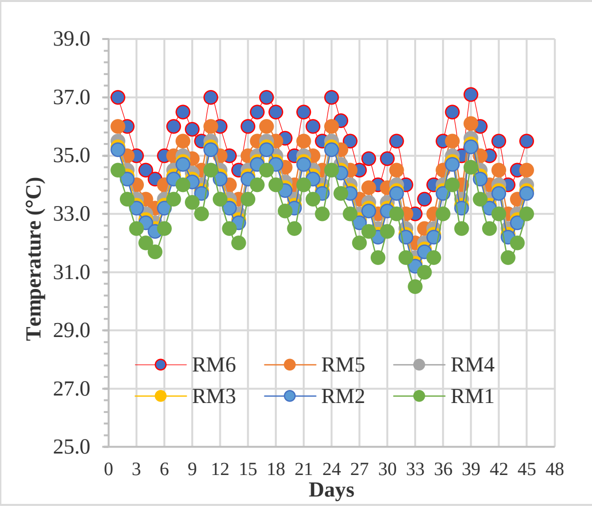

Fig.8. Temperature of digester from RM1, RM2, RM3, RM3, RM4, RM5, and RM6.

3.6 Economic Analysis of Two and Three Substrates (RM1-RM6)

To investigate the economic analysis of the suggested biogas production from anaerobic co-digestion by calculation payback period, as following [13]:

Payback period = Total fixed costs / {(Capacity/day) x (LPG price)}

1 kg of LPG = 1.82 L

Total fixed costs = 4,000 Baht (including fermentation and measurement biogas system)

Capacity of biogas production (L)/ days (RM6) = Cumulative biogas production (L) / HRT

Capacity of biogas production (L) / day (RM6) = 308.56 (L) /45 (days) = 6.86 L/days

Average biogas production/day = 6.86 L/days/1.82 = 3.77 kg of LPG

LPG price in the market is not compressed in tank was 11 Baht/kg. Therefore:

Payback period = 4,000 Baht / (3.77 kg of LPG/days x 11 Baht/kg) = 96.52 days or 3.22 month

The payback period of RM1-RM6 was represented in Table 8, which were 5.26-month, 4.49-month, 4.09-month, 3.76-month, 3.46-month, and 3.22-month, respectively. It was found that three substrates feed stock (RM4-RM6) has lower value of payback period than two substrates feed stock (RM1-RM3), this means that significant WWTP can be attained operating at 1:1:0.33. It is also clear that the parameter with higher biogas volume and methane content influence in the C/N ratios is optimal co-digestion. The results of the satisfaction evaluation for the technology transfer to the Wang Toddy Palm Community Enterprise Group, Phetchaburi Province showed that the participants were mostly satisfied. Anaerobic co-digestion for biogas production process technology in pilot-scale was also financially and environmentally feasible.

Table 8. Payback Period of RM1-RM6

Parameter	RM6	RM5	RM4	RM3	RM2	RM1
Cumulative Biogas Production (L)	308.56	287.3	263.94	242.22	220.80	188.79
Capacity of Biogas Production (L/day)	6.85	6.39	5.87	5.38	4.91	4.19
HRT (days)	45	45	45	45	45	45
Parameter	RM6	RM5	RM4	RM3	RM2	RM1
Average Biogas Production (kg)	3.77	3.51	3.22	2.96	2.69	2.31
Payback Period (Month)	3.22	3.46	3.76	4.09	4.49	5.26

4. CONCLUSIONS

Experimental results showed that the alternate feeding could be used for the anaerobic co-digestion with circulate system of wastewater from toddy palm process (WWTP) with animal's manure (Cow manure; CM, Pig manure; PM, and Chicken manure; KM) and food waste was operated at mesophilic (30-40 □C) for 45 days. The RM6 (CM: FW: WWTP =1:1:0.33) was proved to successfully operate at higher average biogas volume (308.56 L) with a highest CH4 content (70 %) at 25th days, which occurred to the optimum range of C/N ratios (31.62). Namely, an anaerobic co-digestion of these three substrates can be a solution improve C/N ratios of each substrate, which for animal's manure, C/N ratios are too low, and its carbon deficiency retards its efficient anaerobic digestion. By adding about 30-40 % of WWTP to animal's manure; upon its addition, the C/N ratio of the mixture increased to optimal C/N ratio (about 20-30) as a result, the biogas production enhanced. Cow dung, pig dung and chicken dung with WWTD with a C/N ratio of 31.62, 30.1, 27.47 were provided biogas volume higher than without WWTD consisting of 10.08 %, 9.79 %, and 8.54% of biogas volume, respectively. Thus, the anaerobic co-digestion of cow manure and food waste with WWTP were successful more than without WWTP.

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