CHAPTER IV

RESULT AND DISCUSSION

The results and discussion has discussed the digestion results on the influence of particle size and total solids on biogas production. Further, the economic evaluation of biogas production from the different particle size has been discussed. The economic analysis of this study was based on assumptions made from the literature review and experimental results.

Anaerobic digestion tests on the influence of particle size and total solids on biogas production.

Before assesings the influence of particle size and total solids of the food waste on the biogas production. The physical and chemical composition of food waste were analysed and the results of the analysis are discussed below.

Physical characteristics of Food Waste

Figures 10 and 11 show the physical composition of the food waste and it contained a large amount of the organic materials such as rice, noodles and meat which are easily biodegradable. The biodegradability of the biogas substrate is a very important parameter used for the design of the anaerobic digestion (AD) systems. It influences the amount of methane that can be produced. In addition, previous studies have indicated that the rate and extent of the digestion in AD process depends on the physical composition of the substrates [6]. The results obtained from the analysis of the physical composition of food waste showed that food waste generated at the university is a suitable substrate for biogas production however, as it is with most of the Asian food, the food waste contained more chillis and peppers. Previous studies have stated start that the presence of these two items will reduce the pH level in the digester below the required level. Further, it also had small portion of non degradable materials such as tooth picks and bones. Therefore, it was necessary to sort out the food waste before conducting the anaerobic digestion test.

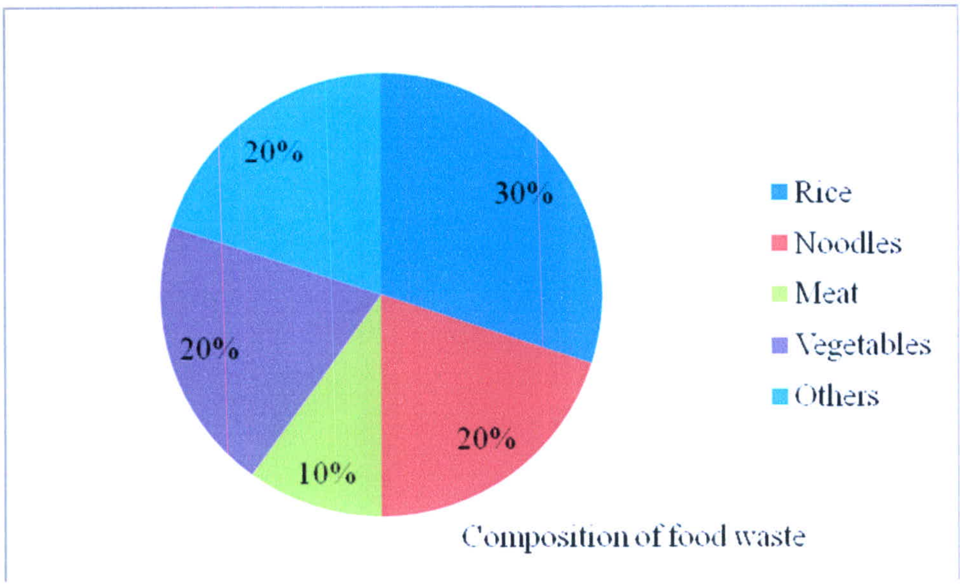

Figure 11 Physical compositon of food waste

Figure 12 Physical characteristics of food waste in picture

Chemical composition of Food Waste

Table 10 indicates the result of the chemical composition of food wastes. C/N ratio is the relationship between available carbon and nitrogen in the organic material. Based on this result, the food waste contained C/N ratio of 15, however the optimum C/N ratio of biogas production ranges from 20-30. The low C/N ratio that was observed in these results might reduce biogas production because nitrogen available in the organic waste will accumulate in the form of ammonia thereby decreasing the pH in the digestive [15]. In this case, it is recommended to mix the food waste with the feedstock such as animal dung and biomass to improve its C/N ratio. The wastes also contained pH levels which were lower than the optimal level of 7-7.2, therefore it is recommended that prior to anaerobic digestion, the pH has to be adjusted to make a conducive environment for the microbial activities and to prevent the total process failure of the system [14]. Nevertheless, other chemical parameters such as COD, BOD, VS and MC were highly suitable for biogas production. Moisture availability helps in the movement of water and growth of the bacteria and at the same time helps in the transportation of the nutrients [11]. Almost 98 % of the solids in the food waste were volatile solids. These solids are easily degradable during anaerobic digestion [15]. This means the waste would be easily degraded by the microorganism. COD is the amount of chemicals that are present in the organic waste that can be oxidized. It has been estimated that 1 kg of COD is equivalent to 0.43 m^3 CH_4. Based on the research findings the waste contained more COD suitable for oxidation. BOD is the measurement of the oxygen that is available and can be used by microorganisms while consuming organic matter [34]. Similarly, the results indicated higher levels of the BODs in the food waste.

Table 10 Chemical characteristics of food waste

Item	Value
pH	3.95
Moisture Content (%)	77.17
Carbon nitrogen ratio	15.49
Biological oxygen demand (mg/kg)	103,889
Chemical oxygen demand (mg/kg)	278,388
Volatile Solids (%)	98.47
Total Solids (%)	22.83

Influence of Particle size on daily volume of biogas

Figure 12 indicates the daily yield of biogas production using anaerobic digestion test of different food waste particle size. The maximum biogas yield of 400 mL per day was observed with sample A and B which contained ground food waste. Less biogas yield of about 210 mL/day was produced from sample C which had non ground food waste. This clearly indicates that grinding food waste prior to biogas production had higher effect on the volume of biogas. Furthermore, this study observed that it took about four days to produce biogas from samples with non ground food waste. Using this information, this study recommends the grinding of food waste either manually or electricity prior to the anaerobic digestion to increase biogas yield.

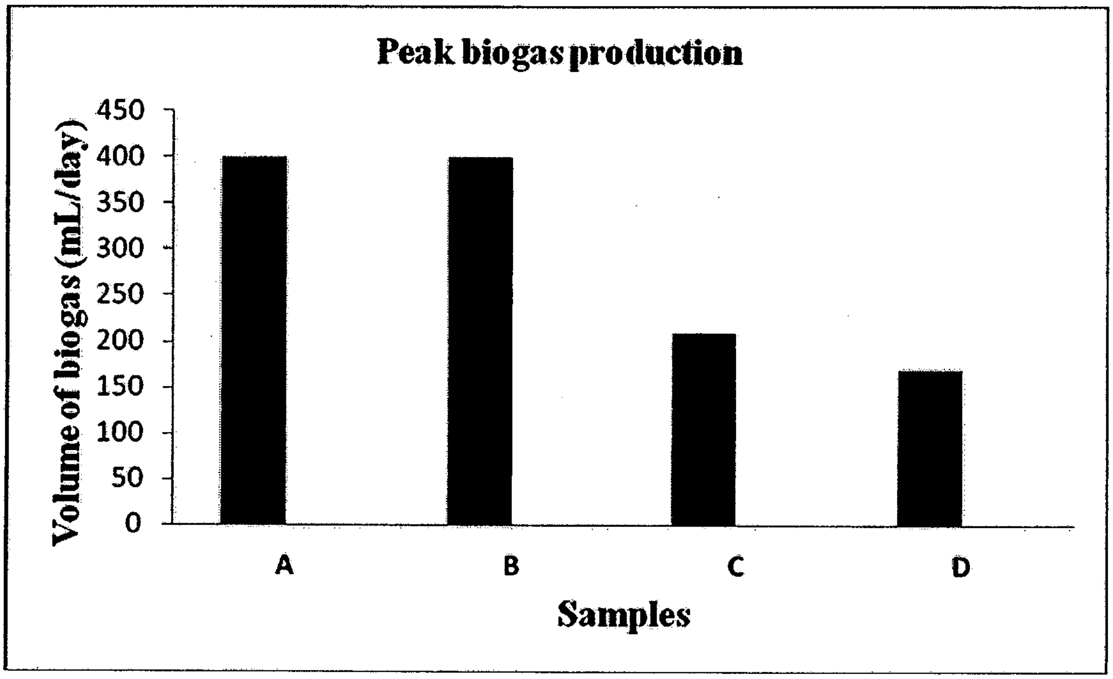

Figure 13 Peak biogas production from different particle size

Based on the table 11, there was no vast difference in methane content for all samples. However, the percentage of methane in all samples was on the lower side. Previous studies have indicated that the methane content of biogas from food waste ranges from 60 to 70% [15]. This might have resulted from the inoculums that were used. There is a strong possibility that the inoculums contained very little microorganisms which might have slowed the growth of the other microorganisms in food waste. It is therefore necessary to grow microorganism by using animal dung as a start up before feeding food waste. This will ensure the smooth process and avoid total failure. The results further indicated higher carbon dioxide concentration in generated biogas, carbon dioxide is usually used as an electron receptor to form methane in the fermentation process, so this high concentration meant that methanogenesis phase of fermentation were just beginning due to slow growth of microorganisms, this means that small carbon dioxide were used to produce methane [26]. Hydrogen is another very important gas that is useful during the fermentation process, because the microorganism uses hydrogen as an electron donor to produce methane. In this study hydrogen concentration was very low. Nevertheless, the effect was clearly noticeable.

Therefore, based on these findings, Naresuan University would produce maximum biogas if the wastes are grounded. A note should be taken that methane yield is not the same as biogas yield. Biogas is the mixture of carbon dioxide, methane and water vapor with few traces of hydrogen sulfide.

Table 11 Methane yield from different particle sizes

Sample	CH_4 (%)	CO_2 (%)
A	3.36	77.78
B	3.07	87.38
C	5.27	55.40
D	2.36	40.36

Influence of Total solids on the volume of biogas

Figure 13 shows the daily yield of biogas from the food waste with different total solids of 5 %, 10 %, 15 % and 20 % operated under the same conditions. The results of the experiment indicated that TS_{15} (360 mL) produced the highest biogas yield. TS_5 (150 mL) produced the least biogas followed by TS_{20} (220 mL). TS_{10} (290 mL) produced second highest biogas yield. This indicates that AD process can increase biogas yield at the TS_{15}, and reduced when the solids were increased to $TS_{20\%}$. As previously discussed in the literature review, high total solids contain low volume of water hence high thickness of the slurry and this might have lead to abrasion. On the other hand, when the solids were reduced from TS_{15}, biogas yield eventually reduced. This is because when the food waste is over diluted, the waste is settled at the bottom of the digester. Therefore, the optimum total solid that yielded maximum biogas yield was TS_{15}.

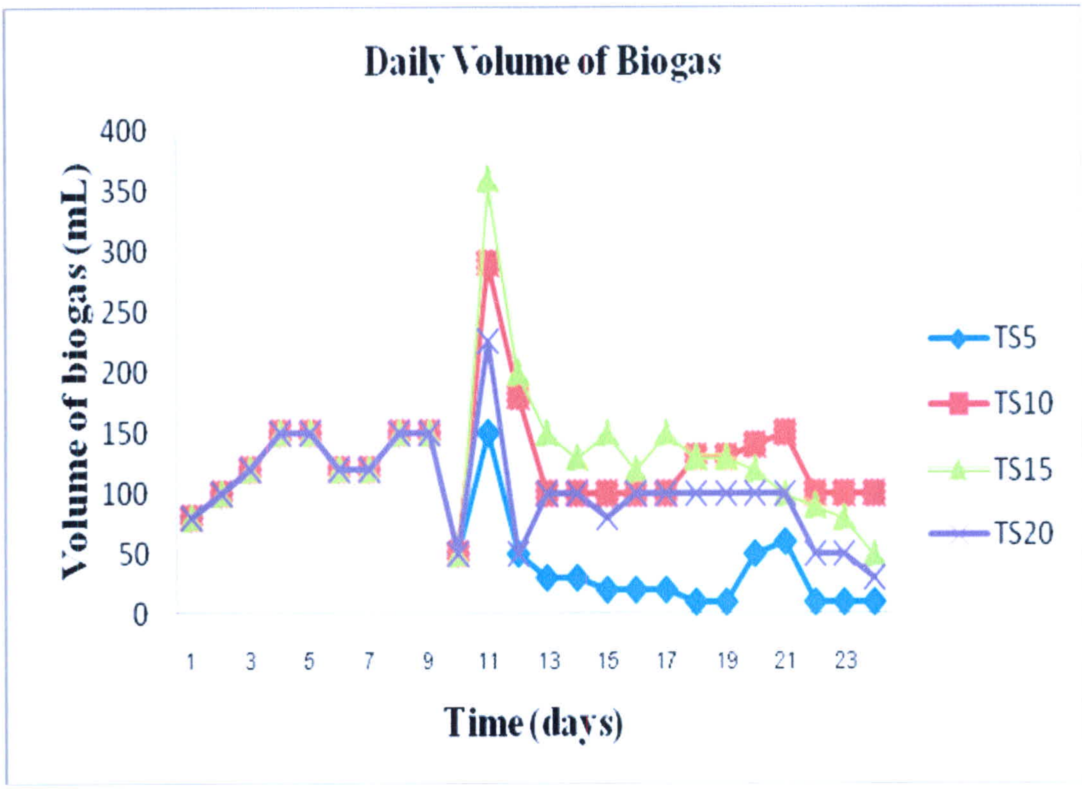

Figure 14 Daily biogas production from different total solids

Economic Evaluations

The economic evaluation for this study involved the steps:

1. Estimation of the capacity of the digester
2. Estimation of the power and dimension of the engine
3. Estimation of the costs
4. Benefits of the systems
5. Economic evaluation results

Three biogas production scenerios were evealuated and these were

1. Producing biogas from the food waste ground by an electric grinder (Project A).
2. Producing biogas from the food waste ground by a hand mixer (Project B).
3. Producing biogas from non ground food waste (Project C)

Capacity of the digesters

Secondary data were used to determine the amount of food waste generated at the campus. According to Sasithorn Jitpranee and Sahataya Ladpala, the university generates about 879 kg/day of organic waste of which 333 kg are food waste [35]. To estimate the capacity of the required digester size, the following formula was used [36].

$$Vd = Sd \times RT$$

Whereby:

V_d =Biodigester size (m^3)

S_d =Daily substrate input quantity (m^3)

S_d= Biomass + water

RT = Retention time (days), for food waste the rention time is 28 days [37]. And the appropriate suitable mixing for food waste and water is 1:1 [37].

Thus,

Daily substrate	=	Biomass + Water
	=	333 kg + 333 kg
	=	666 kg/day
	=	0.6 m^3

So the digester needs to be

$Vd = Sd \times RT$

$Vd = 0.6 \times 28$

$Vd = 16.8\,m^3$

Assuming the plant will operate at 80 % capacity factor:

$\text{Plant capacity} = 0.8 \times 16.8\,m^3$

$\text{Plantcapacity} = 13.44\ m^3$

Therefore 13.44 m^3 digester will be required. This information was used in the economic evaluation.

3.2. Power production and dimension of the engine

Biogas can be used in several ways such as cooking, heating and electricity generation. This part of the thesis will discuss how to use biogas for electricity generation by using the internal combustion engine. The potential power and engine dimension were calculated by the following steps provided in the study done by the royal engineering veterinary and agricultural university [36].

For the calculation of the power, the following parameters were used:

1. Methane heating value =36 MJ/m^3 [36]
2. % of TS on the food waste = 98.47 % (Laboratory results on chemical composition anaysis)
3. Methane content = 65% [36]
4. Mean gas yield in food waste = 0.6 (m^3/kgVS) [38]
5. Food waste production per month = 333 kg/day which is 9,990 kg per month
6. Power engine yield = efficiency
7. Conversion factor: 1 kWh = 3.6 MJ [36]

The potential power production (without considering the engine yield) (PPP)

1. Total volatile solids = 9,990 kg/month x 98.47 % = 9,837.15 kgVS/month
2. Gas yielded 0.6 m^3/kg x 9,837.15 Kg/ month = 5,994 m^3/month
3. Methane content: 65% x 5,994 m^3/month = 3,836.49 m^3/month
4. PPP = 3,836.49 m^3/month x 36 MJ/m^3 = 138,113.63 MJ/month
5. 1 kWh = 3.6 MJ [36].
6. PPP = 38,364.90 kWh/month

Assuming that the plant is going to work 22 hrs per day, 292 days per year the potential power is (38,364 kWh/month) x (1 month/24 days) x (1 day/22 hours) = 72.66 kW

Assuming the yield of 29% in the engine [36], the power production will be around: 72.66 kW x 29 % = 21.07 kW. The energy production: 38,364.90 kWh/month x 29 % = 11,125.82 (kWh/month)

According to the catalogue by john Deere in 2005, the size for this power are 20 and 15 kW and this study choose 15 kW engine because the quantinty of food wastes varies each day and season therefore there is need to ensure continuous production of the electricity [36].

Energy production = 11,125.82 (kWh/month) x 12 months =133,509.84 kWh
Power of the plant = 15 kW

Cost estimation of the projects

1. Investment cost (Fixed costs)

1.1 Project A (ground food waste with an electric hammer mill grinder)

The initial cost was the summation of the digester cost, generator engine set and biogas purification unit. Digester cost was estimated using the assumption that one cubic meter of concrete fixed dome digester cost at about 1,303 Baht/m^3 [39]. Based on the calculations of the digester size done previously, 333 kg/day will require a digester with the volume of 11 m^3. The cost of the fixed dome for this size was estimated at 18,000 baht. Generator set cost was calculated based on the estimated energy production. With the proposed system, the energy production was calculated at 135,384 kWh. According to Bareli et al, the suitable generator engine for this energy production costs about $10,000 [36] and this is equivalent to 300,000 Baht. To avoid destruction of the system due to the presence of hydrogen sulfide in biogas, the project calculations included the biogas purification unit using chemical absorption. This unit has been estimated based on assumptions made by Renac that a 50 m^3 biogas system will need $24,953 as an initial cost [40]. All these projections were based on 80 % capacity factor of the digester, considering that at times the system will require maintenance hence would not operate at the full capacity. The projections on the project A were based on the assumptions that food waste will be grinded by using an electric blender. Therefore the cost of the blender was included in the investment cost. The total investment cost for this project was estimated at 1,005,819.00 Baht.

1.2 Project B (ground food waste with a hand crank manual grinder)

The projections on the project B were based on the assumptions that food waste will be grinded by using hand mixer therefore the cost of a hand mixer was included in the investment cost. All the other costs such as a generator set, upgrading system and the digester cost were similar to the project A. Therefore the total investment cost for this project was estimated at 989,679.70 Baht.

1.3 Project C (Non ground food waste)

The projections on the project C were based on the assumptions that food waste will not be ground. In this case, the total investment cost for this project was estimated at 1,005,819.00 Baht.

2. Operational cost for the project (variable costs)

The Operational cost of all projects were similar (water cost and operation cost of the upgrading system) except for the labor cost. For the project A, only one officer responsible for the operation of the system was included because the system used an electric blender hence less labor requirement, this was the same case with the project C which used non ground food waste, two full time workers were estimated for the project B which required hand mixer grinder. For the water cost, it was previously estimated that 1 m^3 of water will cost about 5 Thai Baht. For 333 kg/day of food waste, all digesters will require 3.3 m^3 per day of water using 1:1 ratio. For all the projects, the study assumed that 50% of water will be purchased and the other half will use recycled water from the system hence reducing the cost of water by half [33].

Another operational cost that was included in all three projects was the operating cost of the purification system. Renac reported that a 50 m^3 of biogas system will require $24,924 per year. Therefore the cost of the 13.9 cubic meter system was estimated at 208,108.02 Baht per year [40]. The maintenance cost for all projects only included the repairing cost of the generator set which was estimated at 2 % of the initial cost [41].

4. Estimated benefits of the projects

All the three projects had electricity generation, carbon credit and organic manure as their benefits. The nominal price of the electricity in Thailand is 4 Baht per kWh. The estimated energy production and money gained for each project are compared in the table 11. For the organic manure, it has been estimated that any biogas substrate will produce about 70 % as digestate (organic manure) and 80 % of that digestate is mainly water [33]. Based on this assumption, with 333 kg of food waste, the digester will produce about 0.18648 ton of solid organic manure per day. Furthermore, this study assumed that 90 % of organic manure will be sold and only 10 % will be used in the university. The price of the organic fertilizer was estimated at 25.04 \$/ton [33]. The total benefits of these projects also included carbon credit at 1 \$/kgCO_2 and are compared in the table 12 [33]. Furthermore, these projects had several other benefits which could not be calculated in this evaluation such as reduction in air, land and water pollution, saving on the costs associated with collection and handling of food waste from the university to the land fill and the improved sanitation.

This economic evaluation of all projects did not include the cost of land because the university has already vacant land which can be used for biogas production. In addition to this, transportation cost was also excluded because the waste is generated inside the campus hence little cost for transportation.

Table 12 Cost and benefit analysis for 15 yrs fixed dome digester

Benefits	**Project A**	**Project B**	**Project C**
Generated electricity (Baht)	9,089,420	9,089,420	4,354,708
CO_2 credit (Baht)	46,200	46,200	22,350
Organic fertilizer (Baht)	428,269	428,269	628,269
Total benefits at 7 % discount rate (Baht)	**9,763,889**	**9,763,889**	**4,983,243**
Cost	**Project A**	**Project B**	**Project C**
Digester cost (Baht)	18,111.70	18,111.70	18,111.70
Purification system (Baht)	669,708.58	669,708.58	669,708.58
Generator set (Baht)	300,000.00	300,000.00	300,000.00
Hand mixer (Baht)	NA	1,860	NA
Electric mixer (Baht)	18,000	NA	NA
Total cost at 7 % discount rate (Baht)	**1,005,819.00**	**989,679.70**	**987,820.28**

5. Economic evaluation results

Table 13 shows the economic results when biogas was produced under different conditions. Comparison of the three production conditions shows that project A that included production of biogas using ground food waste by an electric blender had the highest NPV, BCR and shortest PBP of 9,351,503 Baht, 2.09 and 8.00 yrs respectively. Project B had the second highest NPV, BCR and shorter PBP of 6,796,643 Baht, 1.61 and 10.18 yrs respectively. Project C had less NPV, BCR and high PBP of 601,069 Baht, 1.07 and 15.60 yrs respectively. This project is not economically viable because the PBP exceeded the lifetime of the project.This is due to the higher production costs involved and less benefits generated, therefore this study recommends producing biogas using ground food waste by using either a manual hand mixer or an electrical blender however economically, using an electric blender is more desirable.

Table 13 Results of economic comparison and sensitivity analysis of biogas power plant from the food waste

Economic Evaluation	NPV (Baht)	BCR	PBP (Yrs)	LCOE (Baht/kWh)
Electrical grinder (Project A)	9,351,503	2.09	8.00	4.34
Hand mixer (Project B)	6,796,643	1.61	10.18	5.64
Non grinded (Project C)	601,069	1.07	15.60	9.07