CHAPTER III

RESEARCH METHODOLOGY

The methodology was divided into two parts. Part 1 involved the anaerobic digestion tests on the influence of particle size and total solids of food waste on biogas production. Part 2 involved the economical evaluation of biogas production from food waste using different particle size and different uses of biogas. The whole process that was followed in this study is outlined in the flow chart:

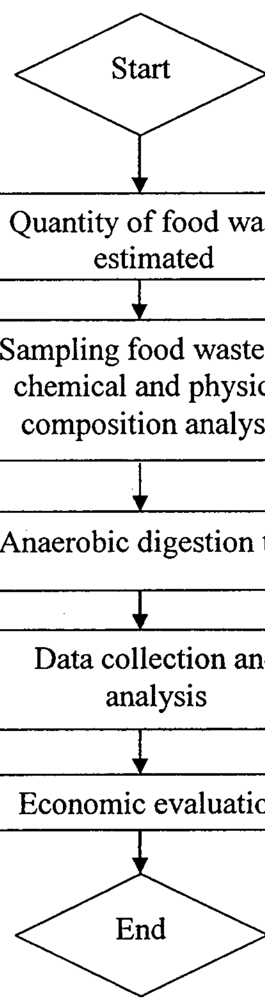

Figure 4 Flow chart of the methodology

Part 1 : Anaerobic digestion tests on the influence of particle sizes and total solids on biogas production

The following activities were carried out:

1. Physical and chemical composition analysis
2. Anaerobic digestion test on influence of particle sizes on biogas production
3. Anaerobic digestion test on influence of total solids on biogas production
4. Data collection and analysis

Physical composion

Food waste samples were collected to anayse it's physical composition such as rice, noodles, meat and vegetables.

Chemical composition

Samples of food waste were collected to determine its physical and chemical characteristics to assess its suitability for biogas production. The analyzed chemical parameters were moisture content (MC), total solids (TS), volatile solids (VS), pH levels, carbon/nitrogen (C/N) ratio, chemical oxygen demand and biological oxygen demand. These parameters were measured using the standard methods for the examination of water and waste water recommended by the American Public Health Association (APHA) as indicated in the table 5 [5].

Table 5 Chemical composition analytical methods

Parameter	Method	Procedure
Moisture content	Evaporation method	[5]
Total solids	100-moisture content	[5]
Volatile solids	Igniting solids at 600-650 °C for 2 hrs	[5]
Biological oxygen demand	5-day BOD test	Food waste was diluted with distilled water and incubated at 20 °C for 5 days. Bod was determined by measuring the oxygen consumed per litre within the incubation days [5]
Chemical oxygen demand	Open reflux	Food waste was mixed with the potassium hydrogen phthalate and the mixture was put in a heating block at 600-650 °C for 2 hours. After 2 hours, the mixture was removed from the heating block to the cooling rack to cool and let the solids settle at the bottom. Finally the mixture was put in a calorimeter to measure COD [5]

Influence of particle size on biogas production and methane content

As previously discussed in the literature review, some researchers have established that the particle size of the biogas subtracts has a great influence on the biogas production and methane yield [23, 28]. This is because smaller particle size enhance anaerobic digestion due to an increase in surface area hence rendering them more accessible to microbial attacks. This research study evaluated this claim by comparing four samples of food waste containing different particle size in anaerobic digestion test. Previous studies have recommended that the addition of the inoculums to food waste to reduce digestion time and improve the digester efficiency [23]. Therefore, this study used the active inoculums source which was obtained from already existing biogas digester treating waste water generated from the pig slaughter house. The samples were as follows; sample A contained food waste that was ground by an electric grinder for 5 minutes (smallest particle size), sample B had food waste that was ground by the manual grinder and finally sample C contained food waste that was not ground (biggest size). Sample D was a blank. All samples were filled with 200 mL of food waste which was mixed with 100 mL of inoculums except for the blank sample which contained only food waste and water. After food waste was well mixed with the inoculums, tap water was added to fill a volume up to 500 mL using 1:1 mixing ratio. The samples used in this study are outlined in the table 6.

Table 6 Samples used for the experiment on the influence of particle sizes

Particle sizes	Sample	Food waste (mL)	Water (mL)	Inoculum (mL)	Total (mL)
Electric ground (smallest size)	A	200	200	100	500
Manually ground (medium size)	B	200	200	100	500
Non ground (biggest size)	C	200	200	100	500
Blank	D	200	200	No inoculum	400

The pH of the mixtures was measured by a pH meter prior to the anaerobic digestion as shown in the figure 5 and was adjusted by the sodium dicarbonate to the suitable range of 6.5-7.

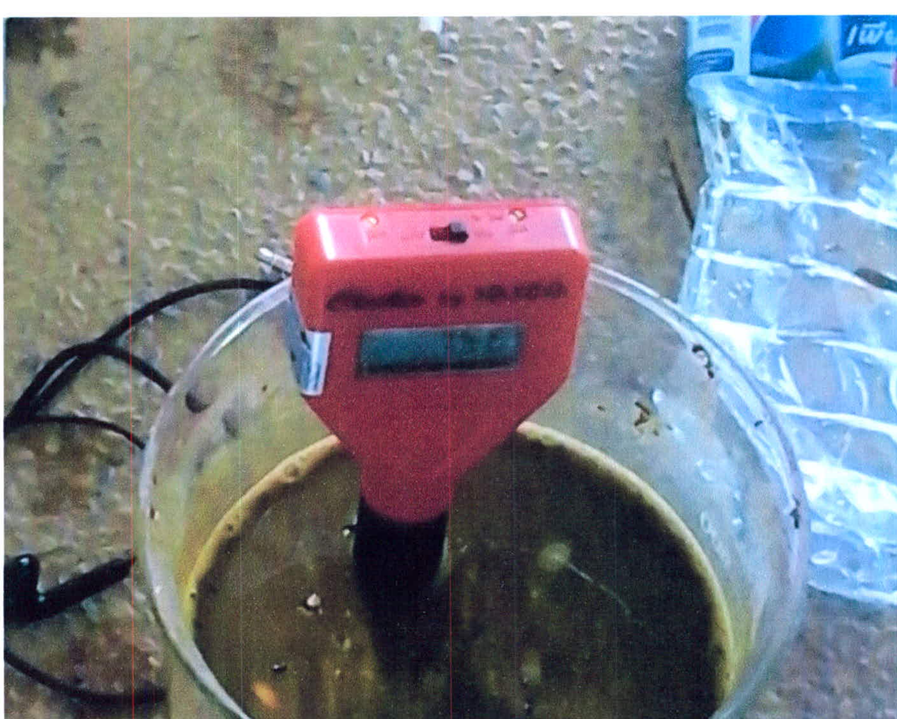

Figure 5 pH measurement

The whole anaerobic digestion process took place within 23 days. The main aim of conducting this experiment was to assess if it was necessary to grind for waste prior to anaerobic digestion. The experimental set up of this digestion test is shown in figure 6.

Figure 6 Experiment on the influence of particle size on biogas production set up

Influence of total solids on biogas production and methane content

The aim of this part was to determine the optimum total solid that was suitable for maximizing biogas production from food waste. The influence of total solid on biogas production from food waste was measured by performing a series of laboratory digesters in different total solid level of food waste. The study laboratory used 900 mL digesters made from the glass bottle which were operated in a batch system. Food waste was diluted with tap water to come up with three different total solid content of 5 % (Low solid) 10 % (medium solid), 15 % and 20 % (high solid) as indicated in the table 7 [11]. The setting of the total solids was based on the chemical composition analysis results which stated that the food waste at Naresuan University contains 22.83 % of total solids. The size of the digesters were 500 mL. Therefore to come up with the amount of the food waste and water, the following calculations were done.

TS 5 % means that

100 mL of food waste has TS of 5 g

In this case 500 mL:

100mL = 5 g

500mL= ??

$$\frac{(500\,\text{mL} \times 5\,\text{g})}{100\,\text{mL}} = 25g$$

Therefore, 500 mL digester will need 25g of food waste

However,

Food waste contains total solid of 23 %

Therefore

If 23 TS = 100 g

What about 25 g

$$\frac{(25\,\text{g} \times 100\,\text{g})}{23} = 108\,\text{g}$$

This means that at total solids of 5% , food waste needed was 108 g and the remaining 392 mL was water. This process was done for all the percentages and the amount of food waste and water are outlined in the table 7:

Table 7 Samples used for the experiment on the total solids

TS %	Sample	Food waste (mL)	Water (mL)	Total (mL)
5%	A	108	392	500
10%	B	284	284	500
15%	C	324	176	500
20%	D	432	68	500

Initially, the digesters were filled with 100 mL of cow dung (inoculums) and 200 mL of water as a start up as shown in the figure 7 . The main reason for using cow dung as a start up in this experiment was to grow microorganisms suitable for biogas production. It has been previously stated that microorganisms suitable for producing biogas are naturally available in the wetlands, lake sediments, rice paddies and in the stomach of the ruminants such as cow dung [28] .The digesters were made airtight to prevent any access of air into the digesters hence promoting anaerobic environment. All digesters were shaked manually for 1 minute once a day to provide proper mixing of the digester [29]. The experiment setup for this paart is illustrated in the figure 8.

Figure 7 Cow dung used as start up

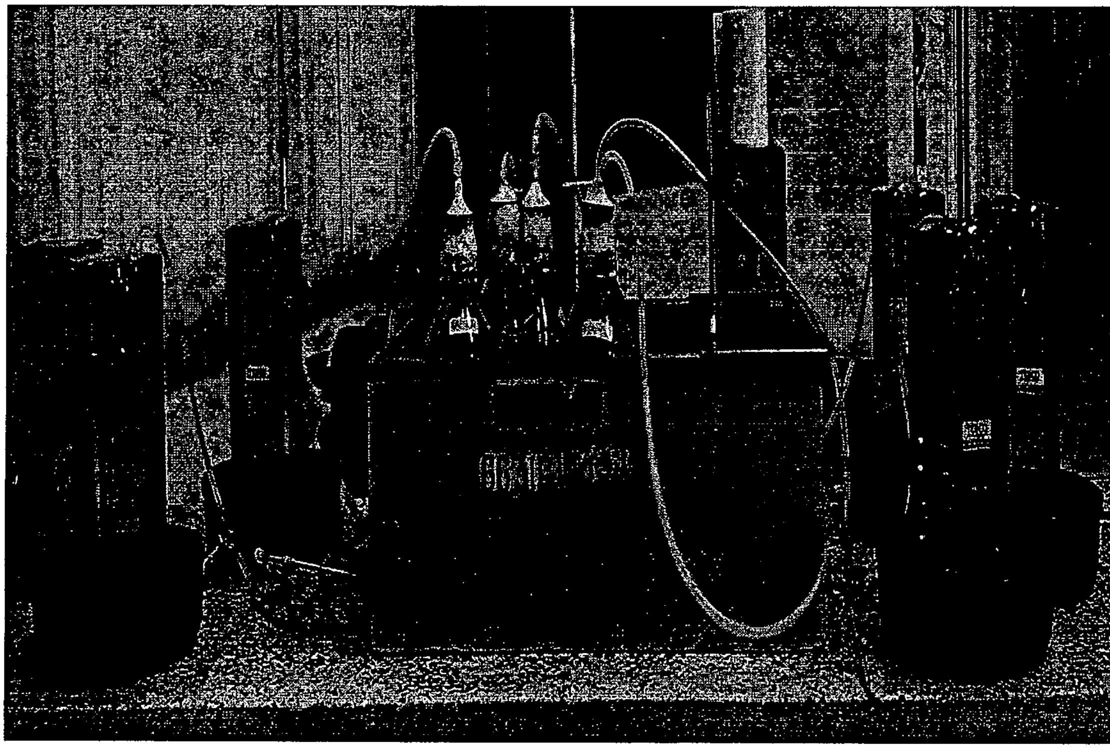

Figure 8 Setup of the experiment on the influence of total solid on biogas production

Constant and variable parameters

For both experiments, particle size and total solids were two parameters that were varied and other parameters that have similar effects on biogas production such as pH and temperature were maintained constant throughout the experiment.

Data collection and analysis

For both experiments, the daily volume of biogas was measured using the downwards displacement method shown in the figure 9 [30]. In this method, volume of biogas is measured by observing the height of water in the bottle connected to the digester. The amount of water that was replaced was equal to the biogas produced.

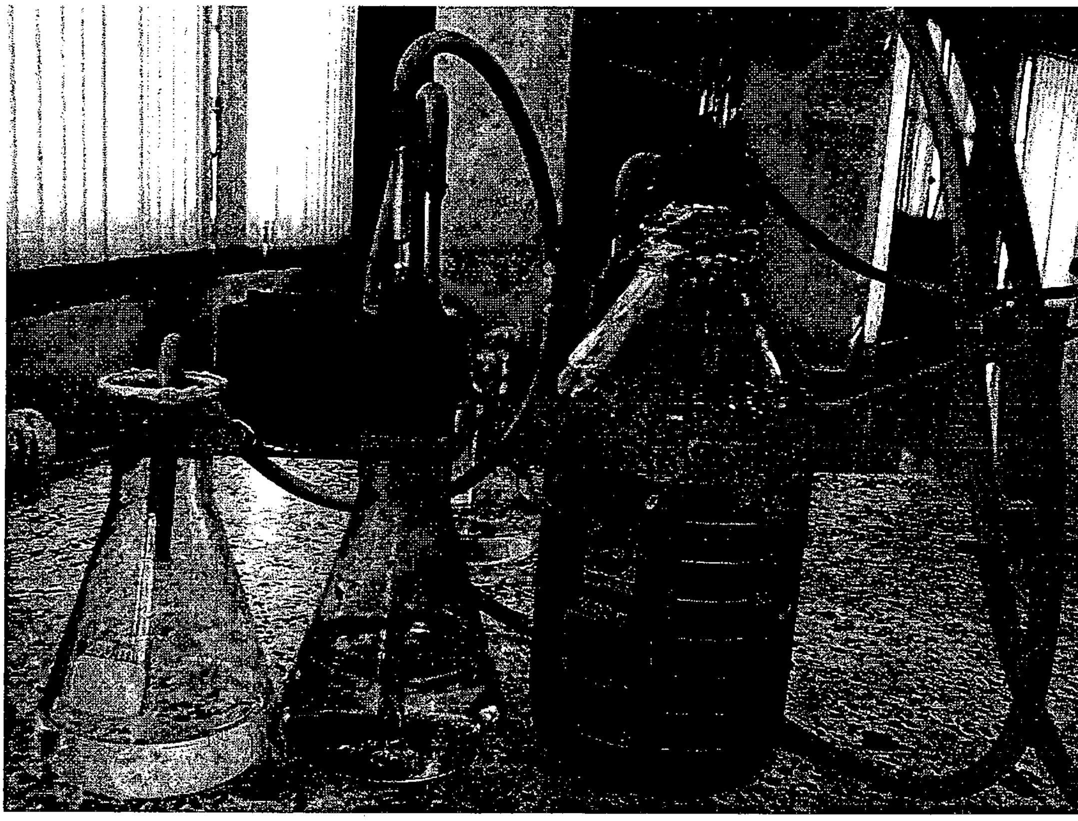

Figure 9 Water displacement method for measuring biogas

The temperature was controlled in the range of 40 to 45 °C by a water bath [10]. Samples of biogas were collected using a syringe to compare the composition of biogas (CO_2 and CH_4,) concentration by the use of the gas chromatography (Shimadzu Gas Chromatography, series GC-2014, WG100) as indicated in the figure 10. This gas analyzer was able to detect the percentage of carbon dioxide, hydrogen sulfide, methane and moisture content in biogas produced [31]. The temperature of the GC column was controlled at 50 °C and helium was used as a carrier gas. The column flow rate was at 60.0 mL/min.

Figure 10 Gas chromatography

Part 2 Economic evaluation of biogas production using different particle sizes of food waste

Part 2 of this methodology involved the economic evaluation of biogas production from using different particle size of food waste and this was based on the results from the experiment. The results indicated that the variation in biogas production from biggest size particle (non ground) and smallest particle size (ground food waste) was about 2:1 ratio. Therefore, it was necessary to conduct an economic evaluation to determine if it was necessarily important to grind the waste and what were the economic implications, at the same time evaluating if it was economic to invest in anaerobic digestion to produce biogas from the food waste generated at the Naresuan University. The fixed dome digester was selected for this study because it is easy to design and install by local communities. Further, it has low cost of construction and maintenance because it contains few moving parts [32]. The net present value was calculated for 15 years which is normal case for biogas power plants [33]. The currency in all economic calculations was in Thai Baht at a conversion rate of 30 Baht/USD$. The discount rate was fixed at 7 %. Tables 8 and 9 illustrate all the economic and technical parameters that were used in this study.

Table 8 Technical assumptions

Item	Value
Digester type	Fixed Dome
Digester capacity factor (%)	80
Retention period (days)	23
Operation time (hours)	22
Operating time (days)	292

Table 9 Economic assumptions

Parameter	Assumption	Source
Project life time (yrs)	15	[7]
Discount rate (%)	7	Thailand discount rate
Cost of concrete fixed dome (Baht/kWh)	1303	[8]
Generator cost (Baht/15 kW)	300,000	[9]
Labor cost skilled (Baht)	15,000	
Labor cost unskilled (Baht)	4,000	
Capital cost of upgrading (Baht/50 m^3)	1,707,720	[10]
Carbon credit (Baht/1 $kgCO_2$/kWh)	30	
Cost of organic fertilizer (Baht/Metric tons)	757.8	[9]
Dollar to Thai Baht	30	

To appreciate the practical procedure of this system, three scenarios were used to compare NPV, BCR and PBP for each three production conditions. These production conditions (sensitivity) were as follows: grinding of food waste by an electric grinder (smallest size), grinding of food waste by a hand mixer (medium particle size) and food waste without being grinded (biggest particle size). NPV, BCR and PBP were evaluated by using the equations presented in equation 3, equation 4 and equation 5.

Where;

C_n	=	Expected cost
i	=	Discounted rate
n	=	Project's duration in years
N	=	Project's period
PVB	=	Present Value Benefit
PVC	=	Present Value Cost

Cost-Benefit ratio (BCR)

$$BCR = \frac{PVB}{PVC} \quad [Eq.3]$$

Net Present Value (NPV)

$$NPV = \sum_{n=0}^{N} \frac{Bn}{(1+i)n} - \sum_{n=0}^{N} \frac{Cn}{(1+i)n} = PVB - PVC \quad [Eq.4]$$

Payback period (PBP)

$$PBP = \frac{Investmentcost}{PVB - PVC} \quad [Eq.5]$$