CHAPTER II

LITERATURE REVIEWS

Theory Review

Food waste

According to the European Union commission, food waste has been defined as any food substances, raw or cooked, eaten or none eaten, that is thrown away or about to be thrown away [5]. Majority of the organic solids generated in the land fill are mainly from food waste [12]. This is increasingly posing challenges in solid waste management. Thailand has been marked as one of the country with the highest amount of food waste in Asian countries as shown in the figure 1 [12].

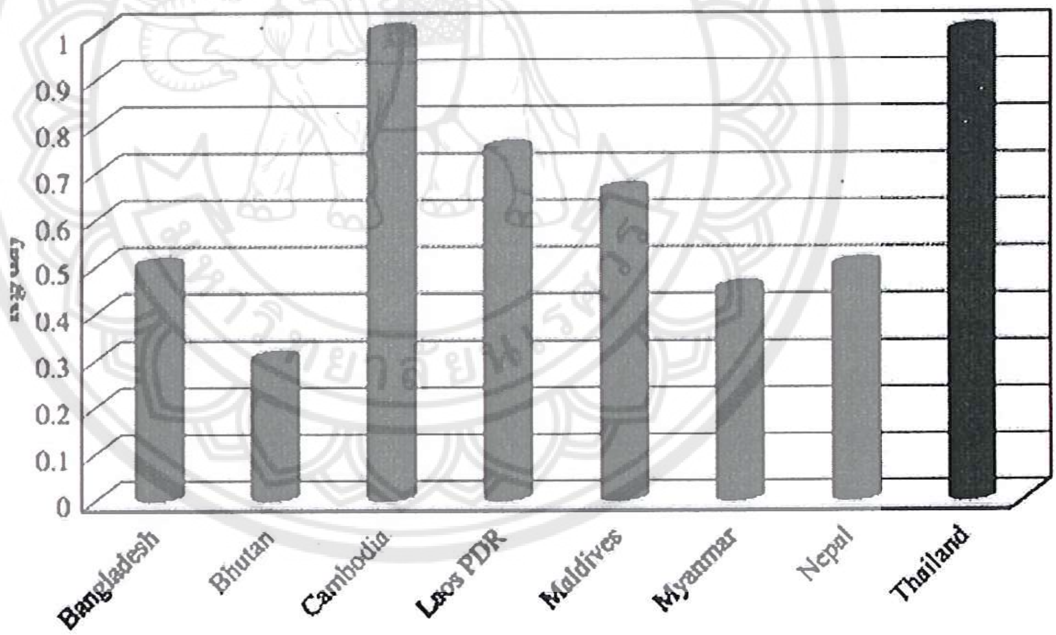

Figure 1 Solid waste generation rate per capita of Asian countries

Source: G. Ali, et al [12]

In order to deal with the increasing challenges of food waste such as poor sanitation and green house gases, EPA has formed the food recovery hierarchy as indicated in figure 2 [7]. The main aim of this hierarchy is to indicate measures that have to be carried out in order to prevent food waste generation. The very first and preferred option is to prevent the wastage of food, however in the case where food has already been wasted, several other options are outlined. Energy generation has been placed as one of the industrial energy recovery process. Energy from food waste is generated through the anaerobic digestion process whereby biogas and organic fertilizer are generated in absence of oxygen.

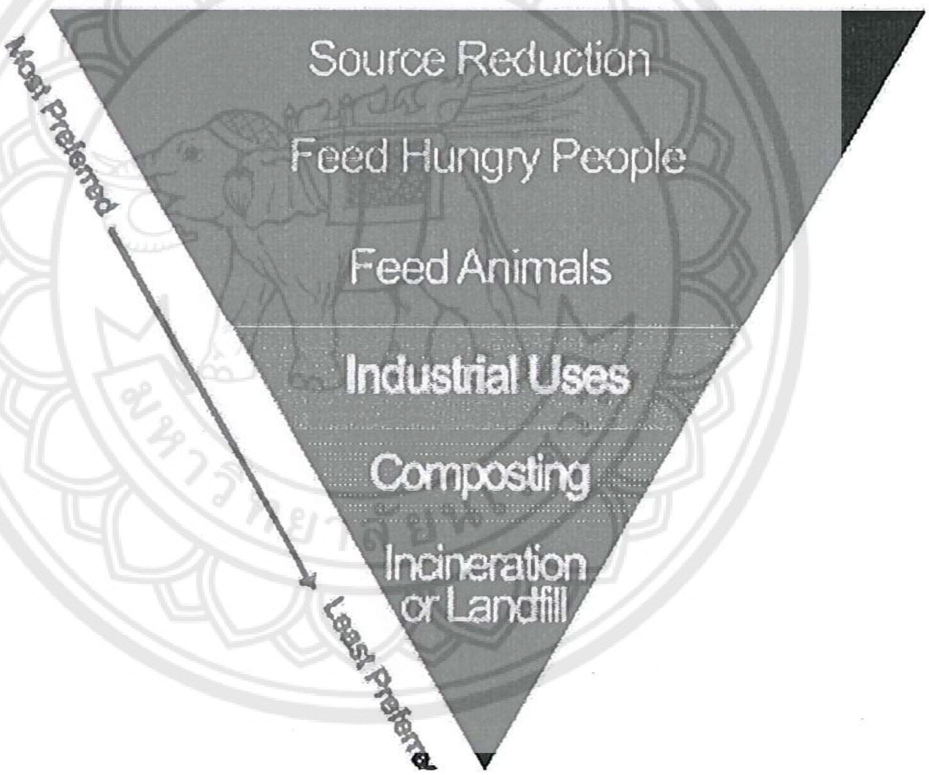

Figure 2 EPA Food waste recovery hierarchy

Source: K. Moriaty [7]

Biogas is an odorless and colorless gas which has a blue flame similar to LPG [13]. It is 20 % lighter than air with an ignition temperature range of 650-750 °C. It's calorific value is 21.1 MJ/m^3 and usually burns with 60 % efficiency in conventional biogas stove [13]. Methane which is the main and useful component in biogas has low solubility in water. Only three units of methane (volume) at 20 °C and 1atm atmosphere pressure dissolve in 100 units of water. It has a chemical formula of CH_4 and molecular weight of 16.04 [14]. Composition and physical properties of biogas are compared to other fuels, as shown in the tables 1 and 2 respectively.

Table 1 Composition of biogas [15]

Substances	Symbol	Percentage
Methane	CH_4	50 - 70
Carbon dioxide	CO_2	30 - 40
Hydrogen	H_2	5 - 10
Nitrogen	N_2	1 - 2
Water vapor	H_2O	0.3
Hydrogen sulfide	H_2S	Traces

Source: S. Pumpuang, 2008

Table 2 Properties of various fuels[15]

Fuel	Density	Calorific value (kJ/kg)	Ignition temp in the air (°C)	Ignitability (% Vol gas in air)
LPG	0.54 kg/l	46,000	400	2.0-9.0
Petrol	0.75 kg/l	43,000	220	0.6-8.0
Diesel	0.85 kg/l	42,000	220	0.6-0.85
Natural Gas	0.83 kg/m^3	57,000	600	5.0-17.0
Biogas (60 % CH_4)	1.2 kg/m^3	18,000	600	5.0-15.0

Source: S. Pumpung, 2008

The Anaerobic Digestion (AD)

Biogas is the product of anaerobic digestion in which organic matter is decomposed by various groups of microorganisms in the absence of oxygen. It occurs in three stages: hydrolysis/liquefaction, acid genesis and methanogenesis as shown in the figure 3 [5].

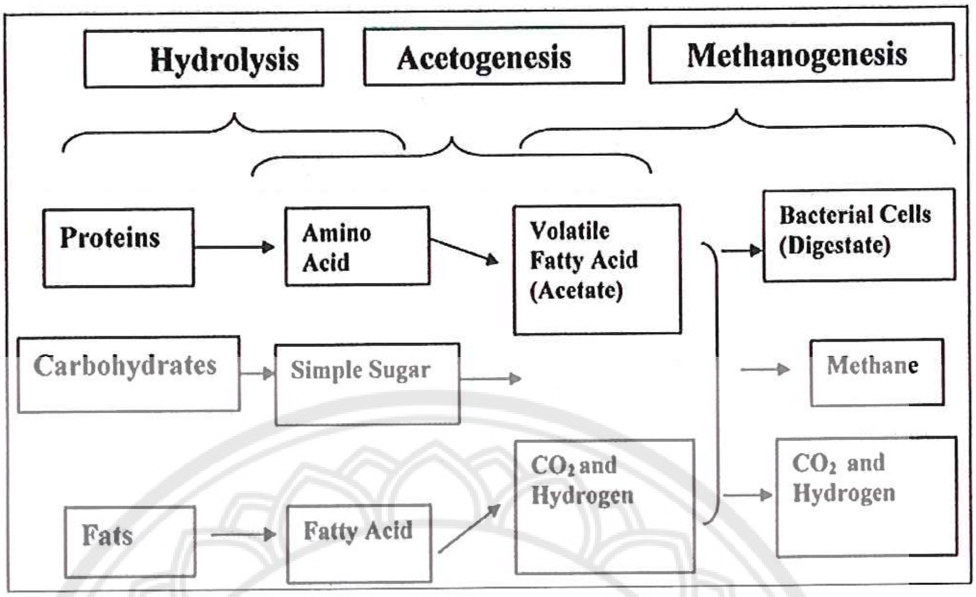

Figure 3 Biological process of anaerobic digestion

Source: D. Das [5]

1. Anaerobic digestion processes

1.1 Hydrolysis/liquefaction

Hydrolysis is the first stage of the process. In this stage, insoluble organic matters are converted by fermentative bacteria into soluble molecules such as sugars and amino acids. In this process, solid biomass is broken into liquid for each digestion.

1.2 Acetogenesis

The second stage is acetogenesis in which the products of Hydrolysis are further transformed by the microorganism known as acid formers into simple organic acids as well as ethanol, carbon dioxide and hydrogen. This reaction is shown in this chemical equation:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad \text{[Eq.1]}$$

1.3 Methanogenesis

Methanogenesis is the third stage of anaerobic digestion whereby methane is produced by bacteria known as methane formers. These bacteria include methanobacterium, methanobacillus, methanococcus and methanosarcina. The methanogenesis reactions can be expressed in form of this chemical equation 2 [16].

$$CH_3COOH \rightarrow CH_4 + CO_2 \quad [Eq.2]$$

Benefits of the anaerobic digestion.

Anaerobic digestion has a number of benefits and these include:

1. It transforms organic waste into useful energy,
2. It provides economical benefits of energy and fertilizer
3. Can be used in decentralized energy
4. It helps in solving environmental problems such as air pollution, water pollution and killing pathogens that are responsible for certain diseases.
5. It saves time and labor for collection and disposal of waste

Types of digesters used for anaerobic digestion

Biogas digesters are classified as continuous and batch system or single and two stage systems. For batch system, feedstock is added into the digester once, when biogas is fully used and the digester cannot produce any gas, the organic waste in the form of digestate are removed from the digester and the process starts all over again while for continuous digesters, waste is added continuously into the digester. In single stage digester, AD process is done in one tank while in two /multi stage digester, the digestion process is separated into two different tanks.

Optimum conditions for anaerobic digestion

There are several factors that affect the production of biogas and need to be controlled. These factors include temperature, pH, Carbon/Nitrogen ratio, organic loading, particle size, and total solid. The bacteria responsible for anaerobic digestion grow and survive in two optimum temperature ranges: in the mesophilic temperature range of 35-40 $^{\circ}C$ and thermophilic temperature range of 50-60 $^{\circ}C$. Temperature has also effect on the retention time. This is a required time for microorganism to work on organic substrates fed in digester to produce biogas. In lower temperatures of mesophilic, it takes 15-30 days for biogas to be produced, however it takes shorter time (12-14 days) in the higher temperatures of thermophilic [5]. The most appropriate pH range of methane producing bacteria is within in the range of 7-7.2. Bacteria suitable for anaerobic digestion require a neutral or mildly alkaline condition. Too acidic or too alkaline is dangerous and could inhibit the activities of methanorgenic bacteria [14]. Mixing of the substrates is another factor that affects production of biogas in the anaerobic digestion process. Hence, there is need to mix the organic substrates fed into the biogas digester to avoid sedimentation of digested solid at the bottom of the digester and at the same time to enhance the production of biogas [17]. Another factor is the carbon/nitrogen ratio in organic substances which affects production of biogas. Organic substances such as food waste exist as living being or dead organism. They are made up of Carbon (C), Hydrogen (H), Oxygen (H) and Nitrogen (N) to produce various organic compounds such as carbohydrates, protein and lipids [18]. C/N ratio is the relationship between available carbon and nitrogen in organic material. For anaerobic digestion, optimum C/N ratio ranges from 20 to 30. If the organic waste contains a high C/N ratio, then biogas production will be reduced because the nitrogen will be depleted more rapidly than carbon by methanogens bacteria as its protein requirement. On the other hand, if the C/N ratio is low, nitrogen available in the organic waste will accumulate in the form of ammonia thereby increasing pH in the digester subsequently reducing biogas production [15].

Total solid content of the organic waste/substrate is made up of total dissolved solids (TDS) and total suspended solid (TSS) [15]. Typically, biogas substrates are classified into three total solid content and these are: High solid (dry-stackable substrate) which ranges from 22 % to 40 %. Medium (wet-pumpable substrates) solid ranging from 15-20 % and finally low solids (wet-pumpable substrate) with less than 10% solids [19]. High solid anaerobic digestion systems are designed to digest solid feedstock without addition of water. These systems need high energy requirement to process. High total solid content means low volume of water hence high thickness of slurry which might lead to abrasion [19].

Volatile solid is the amount of solids in a biogas feedstock that is burned off when exposed to temperature around 538 °C [15]. Volatile solid is composed of biodegradable fraction (BVS) and fractory VS (RVS) [17]. BVS is that part which is digested under anaerobic digestion while RVS is the complex part mostly lignin that is not digestible. It has been observed and recommended by several studies that feedstock with high BVS and lower RVS is favored [15].

Product of Anaerobic digestion

The anaerobic digestion has two products namely biogas and digestate. Biogas is composed of methane, carbon dioxide and other gases. Another product of AD is digestate. Digestate has 70 % liquid and 30 % biosolid [20]. The liquid part of digestate is rich in nutrients as shown in table 3 and mostly used as fertilizer. The solid part is mostly used as bedding for animals.

Table 3 Digestate Characteristics [7]

Parameter	Digestate content
Total solids	6 %
Volatile Solids	69 %
pH	7.6-8.8
Carbon to Nitrogen Ratio	1.5:1
Nitrogen	15 %
Potassium	4.70 %
Phosphorous	0.70 %
Calcium	0.34 %
Surfer	0.30 %
Magnesium	0.19 %

Source: K. Moriarty, 2013

Advantages of producing biogas from food waste

Though there are many feedstocks that are currently used for biogas production, food waste has many potential and is readily available. It has high organic matter and moisture content [5]. It also has high energy content, hence rendering them potential for biogas production as shown in the table 4.

Table 4 Food waste characteristics [7]

Food waste Characteristics	
Moisture content	70 %
Energy Content	1500-3000 Btu/ib
Density	200 pounds per cubic yard

Source: K. Moriarty, 2013

Methods used to increase the yield of biogas production from food waste

There are several methods that are currently in use to enhance and improve the efficiency of the biogas production. These methods range from the use of addictives, pretreatment of the feedstock before anaerobic digestion, mixture of the feedstock with the recycled slurry and finally the optimization of the parameters that have effect on the rate and volume of biogas production.

1. Pretreatment of biogas feedstock

   1.1 Chemical pretreatment

These are methods that depend on the oxidation reaction and are classified into the use of ozone and addition of chemicals. Ozation is the one of the most interesting method to many researchers because of its capacity to increase the degradation of the waste biodegradability. Ozone reacts with polysaccharides proteins and lipids making them into smaller particles. Cesaro and Belgirno observed that ozone dose of 0.16 g_{03}/grs provided up to 55 % soluble COD increase which resulted into 37 % biogas improvement [21]. Chemicals such as acids and alkalis are added into the anaerobic digestion digesters to improve biogas digestion. The use of alkalis is more convenient in the anaerobic digestion than addition of acids. The alkali is used to adjust and increase the pH of the system. Some studies that observed that addition of

62.0 mEq Ca $(OH)_2$ increased the solubility of COD [21]. Some chemicals employed are diluted acid, pH controlled hot water, cellulose solvents such as alkaline H_2O_2, glycerol, dioxane, phenol and ethylene, concentrated mineral such as H_2SO_4 and HCl [22]. Though these methods are very effectives and suitable option to solve problems of inhibitory conditions, but they are too expensive to use in practical and large scale systems [21, 22].

1.2 Physical pretreatment

Physical pretreatment can be grouped into mechanical, thermal, micro wave irradiation and ultra sound. Physical and chemical pretreatment are those that are currently in use whilst others are at research level. Mechanical pretreatment methods involve the reduction of the particle size to increase the surface area. This is achieved by grinding, chipping or milling. Previous studies have established that smaller particle size increase the surface area available to the microorganism resulting in increased accessibility of food to microorganism [23]. The drawback of this method is the high cost associated with reduction of substrate particle size. Thermal pretreatment is the method which uses heat to alter the structure of the insoluble fraction to make it more accessible to microbial attack [21]. This method is grouped into low temperature (less than 100 °C) and high temperature (more than 100 °C). The high temperature uses steam injection or steam explosion [24]. The advantage of this process is that it provides stable operation, however the major drawback of this method is that it needs high pressure and temperature hence making it very expensive [22].

1.3 Biological pretreatment

Biological methods use the microorganisms and enzymes that have high ability in degrading on substrate. Sometimes the pre-composition of the substrate, white fungi and micro aeration (introduction of small amount of oxygen into an AD process) are also used [21]. The main advantages of these methods are that they don't need chemicals hence no waste stream generation, no pressure requirement and reduced energy input. The disadvantages of these methods are lower efficiency and increased time for higher degree of degradation achievement.

Use of the addictives

Some addictives such as zeolites are put in the anaerobic digestion to absorb ammonia thereby improving their performance [21].

Optimization of the various parameters

Another method to enhance the production from biogas is to optimize certain parameters that have effect on biogas production. This method involves varying certain parameters whilst maintaining other parameters constant. As discussed above, there are several parameters that have effect on biogas production such as temperature, pH, C/N ratio, total solids and organic loading. Some of these parameters such as temperature, pH and C/N ratio are well researched and does not depend much on the feedstock, however some parameters such as total solids and volatile solids vary from one feedstock to another. Optimizing such parameters will increase biogas production hence profiting more from the biogas feedstock. This method is easier compared to other methods of enhancing biogas production which have more cost and labor implications.

Review of the related studies

Budiyoni et al. [11] conducted a research study with the aim of analyzing the influence of total solid on biogas production from cattle manure using rumen fluid as inoculums. The study used a series of laboratory experiments using 400 mL bio-digester which were performed in batch operation mode. 100 g of fresh cattle manure was fed to each bio-digester and mixed with 50 mL of rumen fluid and different volumes of tap water resulting six different Total Solid (TS) percentages of 2.6, 4.6, 6.2, 7.4, 9.2, 12.3 and 18.4 %. The results of the experiment showed that the best performance for biogas production was the digester with 7.4 and 9.2 % of total solid which gave biogas yield of 184.09 and 186.28 mL gVS^{-1}, respectively after 90 days observation. While the other TS content of 2.6, 4.6, 6.2, 12.3 and 18.4 % gave the biogas yield 115.78, 122.33, 172.34, 137.99 and54.87 mL gVS^{-1}, respectively.

Y.Li, C.Wan and S.Y Park [23] conducted the research study with the objectives of evaluating the effects of temperature, feedstocks /inoculums ratio and total solid on biogas production from corn Stover. The biogas production from f/I ratios of 2.43, 3.44, 4.55 and 7.41 were compared at the temperature of 37 and 55 °C. Total solids of 22 and 27 % were also compared at 37 and 55 °C. Further the study compared the biogas production from particle sizes of 5, 10 and 15 mm. The results showed an increase in biogas production from TS of 22 % at 55 °C, F/I of 4.58 and particle size of 5 mm.

Brown, Dan and Li, Jebo [25] conducted a research study on solid state anaerobic co-digestion of yard waste and food waste for biogas production. The aim of the study was to determine the optimal feedstock/effluent (F/E) and food waste/yard waste mixing ratios for optimal biogas production. To achieve the objective, the study compared the co-digestion of food waste and yard waste at different F/E ratios 1, 2 and 3. In addition, the study evaluated the dry volatile waste with 0 %, 10 % and 20 %. The result of the study showed that biogas production was increased by 10 % and 20 % of the substrate of F/E ratios of 2 and 1 respectively. The study recommended that co-digestion of food waste with yard waste at a specified ratio can improve digester operating characteristics and end performance metric over SS-AD of yard waste alone.

Tubagus et al [26] conducted in a study in which they investigated the effect of C/N ratio of a mixture of beef cattle feaces and water hyacinth on the quality of biogas. Three C/N ratios of 20, 25 and 30 were assessed. The results showed that C/N ratio has significantly increased the methane yield and that C/N ratio at 30 provided the highest methane content while having no effect on carbon dioxide.

Kometo et al [10] conducted a study with the objective of examining the effect of temperature on solubilization and acedogenesis methane concentration. The study used the food waste with the solubilization rate of 47.5 %, 62.2 %, 70.0 %, 72.7 %, 56.1 % and 45.9 % at the temperature ranges of 35 °C, 25 °C, 35 °C, 45 °C, 55 °C and 65 °C respectively. The production of biogas was higher under mesophilic conditions at 35 °C and 45 °C at 64.7 and 62.7 mL/g-VS respectively while it was lower at thermophilic conditions.

Kup and Cheng [27] conducted a study on thermal pretreatment of the kitchen waste under different temperature of 37, 50 and 60 °C. The objective of the study was to increase the effect of hydrolysis. The results of the study observed that at 60 °C was the suitable temperature with the hydrolysis efficiency of 273 % and had the oil and grease removal of 37.7 %.

Summary of literature review

Anaerobic digestion (AD) is the process whereby organic wastes are decomposed in the absence of oxygen to produce biogas (CH_4, H_2S, CO_2 etc.) and digestate. There are three stages of AD namely hydrolysis, acedogenesis and methanogenesis. The AD process is affected by pH level, temperature, total solid and C/N ratio. There are two types of digesters that are used for anaerobic digestion and these are batch and continuous system. These two are further categorized into single and multi stage systems. The AD process uses different types of waste such as municipal waste, industrial waste, agricultural waste, food waste, animal waste and hospital waste. Food waste has higher potential for biogas production in public and commercial places such as hospitals and universities. To improve the rate and volume of biogas production, there are several methods that are currently used such as addition of chemicals, mechanical reduction of particle sizes, and addition of addictives and optimization of the parameters that have effect on biogas production. Most of these methods are very expensive and time consuming. Optimizing parameters and grinding of food waste are the easiest and cheapest methods of improving biogas production. Therefore, this study observed the influence particle size and total solid on biogas production from food waste in order to improve biogas production from the food waste. The research further analyzed the economic evaluation of biogas production from food waste using different food waste particle size.