THE CO-DIGESTION MANAGEMENT OF TUNA WASTE AND BANANA CROP RESIDUE FOR TUNA FACTORY

UNA TONTAKULCHANCHAI

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by Una Tontakulchanchai

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Oral Defense Committee

....Chair

(Associate Professor Pawinee Chaiprasert, Ph.D.)

....Advisor

(Assistant Professor Sarayooth Vaivudh, Ph.D.)

....Internal Examiner

(Sukruedee Sukchai, Ph.D.)

Approved

....

(Panu Putthawong, Ph.D.)

Associate Dean of the Graduate School

25 Fabruary 2015

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Author	Una Tontakulchanchai
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ABSTRACT

This study aims to investigate anaerobic co-digestion biogas production from tuna waste and banana crop residue to replace diesel consumption for tuna factory. From the experiment, the biogas production was evaluated the potential of co-digestion in tuna solid waste with banana crop residue capacity of 150 liters/reactor in batch study ratio of 1:1, 1.5:1, 2:1, 2.5:1 and 3:1 respectively, operated at condition 30-35% the pH performance range was 6.5 to 6.7, while the COD was 54.46 g/l. Biogas production is started from day 2 in all reactors, total productions of 30 day in each reactor were 2581, 2377, 3403, 2695 and 2638 liters/reactor respectively, the ratio 2:1 provides most optimal result in the biogas production which the methane production was 55.51% equal to 0.55 liter of diesel. Based on the batches study experiments, tuna factory can design its waste management by implementing semi-continuous anaerobic co-digestion system, by utilizing its solid waste and mixed with banana crop residue, to produce biogas to power the factory boiler. The Semi-continuous anaerobic co digestion system will be managed in HRT of 10, 6 and 3 days with 60 kg of waste in the OLR of 2.18, 3.63 and 7.26 g COD/l at ratio 2:1, in which as per analysis of batches experiment was the most optimal for the biogas production. The biogas production result shown 95.25, 127.33 and 127.67 l/d respectively, while the volumetric methane productions were 52.83, 70.67 and 71.07 l/d respectively, the pH during the digestate was 6.1-7.7, the VFA/alkalinity ratio was 0.32-0.37, the COD reduction was 49.85, 55.06 and 58.59% respectively, the HRT of 3 days was the most efficient in the biogas production and methane yield. The result of the economic analysis show the initial investment of the HRT 3 days within the 10 years

period at discount rate of 5%, it found out the payback period of 2 months. Therefore to manage the tuna solid waste that was produce approximately of 1,000 kg/day will use the formula of the calculation based of above information and to provide the semi-continuous digester tank of 15 m^3 to setup the tuna factory waste management biogas production from semi-continuous analysis co-digestion system. Based on this scale, the total investment cost was approximately 3,454,941 baht the operation and maintenance cost 147,296.40 baht, management and wages cost 2,106,000 baht, annual saving and benefits 4,879,038.93 baht, within 10 year period at discount rate of 5%, the payback period was 1 year and 5 month. The co-digestion management of tuna waste and banana crop residue for tuna factory provides the supports to the waste treatment, and to reducing carbon emission as well as to reducing cost as indicated above substantially. The tuna waste management system has benefitted the factory, with this system enable the factory to produce biogas as renewable energy. The waste management provides the economic benefits such as to reduce the consumption of fossil fuel, to increase waste value, to reduce fuel consumption in the transporting the waste to treat, to reduce of carbon emissions. In additional, the environmental benefit such as to reduce the odor from tuna solid waste storage, to reduce health hazards condition within the factory and improve the waste treatment system of the tuna factory.

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CHAPTER I

INTRODUCTION

The industrial world is experiencing a fossil fuel crisis. Fuel prices continue to increase. To minimize their problems, individual manufacturers should start to think about setting up their own energy policies, including energy production to power their factories and that ultimately may reach a sustainable energy factory achievement. Their existing common goals are to reduce fuel demand while seeking to substitute other forms of renewable energy such as biogas to replace the fossil fuels used in manufacturing.

The seafood processing industry is very important to Thai economy and global economy overall. Tuna industry is one of the most important industries for Thailand's economy, as the industry has reach great transformation and growing export activities. In 2009, Thailand exported 534,491 tons of tuna products, with an export value worth USD $1,676.9 million, which represents about 43.2 percent of the world's tuna market. Most tuna caught in Thailand are from coastal waters and of a smaller size. Tuna products provide numerous advantages: It is not only considerably low price compared to other seafood, it is also high in protein and its cholesterol-free seafood. Among the species available in the market, tuna is the most common edible canned seafood products.

Food industry wastes contribute greatly to environmental contamination problems. Research has been carried out in order to develop methods to convert these wastes into useful materials. More than 50% of the unused material from the total fish capture involves almost 32 million tons of waste. The seafood industries produces waste whose characteristics depend upon the raw materials processed, which in turn varies throughout the year. As the total world tuna catch is about 3 Billion metric tons per annum, tuna industry may generates solid wastes that can be as high as 30-40% of the original raw material.

In order to accomplish of law carbon and green growth the tuna waste management to energy through the anaerobic co-digestion process could be considered as an environmental friendly methodology. In addition, there are many aspects of anaerobic digestion system which are quite attractive to the industrialist, that aside from ability to process a low sludge production, with low nutrient requirement and its biogas ability to quick restarted without the need of seeding, capability of being operated on a stop/start basis and no environmental nuisance since the process is totally enclosed. Then the processes are attracting for many industries that looking towards anaerobic biological treatment as an economical method of wastes disposal and energy recovery.

Table 1 Source and approximate yields of by-products from various fish canning operations

By-product	By-product yield from canning operations		
	Tuna (%)	Sardine (%)	Salmon (%)
Pet food	4-6	-	-
Fish meal	30-35	20-30	30-35
Industrial oil	<5	5	-

Source: Duangpaseuth, S., et al. [1]

Since 1985, Thailand has been ranked as the first and second major country in exporting and producing canned tuna, respectively. During the production process the manufacturer generating a lot of waste with high content of organic matter. From the canning process, each ton of raw tuna produces about 8-15 m^3 of wastewater [1]. The anaerobic digestion has the potential to be a financial treatment capability of high organic loading rate and regaining of biogas.

Since there is limited information available on the performance of anaerobic digesters for the biogas production and treatment of tuna-processing wastewater, so this study was undertaken in the conventional anaerobic digester because of its simplicity to install, operate and maintain.

Biogas is much more convenient to use than other fuels. It generates clean energy, does not causing irritation to the eyes as what other fuel does (from smokes generated by the other fuel) and it does not provide foul odor that could attract flies or other bugs. Biogas can power the boilers and electric generators. Biogas production is a microbiological process. The biochemistry of anaerobic fermentation is very complex. While the details are becoming clearer as a result of the effective research, efforts in many countries like USA and China. The design microbiological systems nowadays are created in a better technology that are more effective, user friendly and efficient for the biogas digestion, and it appears to be still good system for future productions.

Anaerobic digestion is a natural process that converts biomass into renewable energy. Biomass is any organic material that comes from plants or garden waste, food processing waste, farm slurry waste, animals or their wastes. Anaerobic digestion has been used for over 100 years to stabilize municipal sewage and a wide variety of industrial wastes. Most municipal wastewater treatment plants use anaerobic digestion to convert solids waste to biogas. The anaerobic process removes a vast majority of the odorous compounds [2]. It also significantly reduces the pathogens present in the slurry. Over the past 25 years, anaerobic digestion processes have been developed and applied to a wide array of industrial and agricultural wastes. It is the preferred waste treatment process since it produces rather than consumes energy, and can be carried out in relatively small enclosed tanks. The by-products of anaerobic digestion have value and can be sold to offset treatment costs.

A great option for improving yields of anaerobic digestion of solid wastes is the co-digestion of multiple substrates. If co-substrates are used in anaerobic digestion system it improves the biogas yields due to positives synergisms established in the digestion medium and the supply of missing nutrients. It is also the simultaneous digestion of two or more organic waste feedstock or food waste. The process can be defined as the simultaneous treatment of two – or more – organic biodegradable waste streams by anaerobic digestion. The co-digestion of organic wastes is a technology that is increasingly being applied for simultaneous treatment of several solid and liquid organic wastes. The main advantages of this technology are improved methane yield because of the supply of additional nutrients from the co-digestion. The most common situation is when a major amount of a main basic substrate (e.g. manure or sewage sludge) is mixed and digested together with minor amounts of a single, or a variety of additional substrate [3]. The use of co-substrates usually improves the biogas yields from anaerobic digester due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates [4].

Anaerobic co-digestion aims at treating different organic residues that can be blended for optimal energy and resources recovery. A primary benefit of co-digestion is that it uses existing infrastructure and expertise to divert food waste and Fats, Oils, and Grease (FOG) for the purpose of biogas production. Production of biogas from organic fraction of municipal solid wastes, different animal manures, fish waste, agricultural waste etc. were reported by different researchers. Not much works of fish waste digestion were reported.

Rationale

Many methods have been developed and used in the treatment and/or disposal of Tuna factory solid waste, but the operation of the treatment or disposal is usually expensive and/or easy to contaminate the environment. In handling and managing its waste, mostly, Tuna industry would deliver its solid waste to the Pet's feed or comfeed (animal feed) manufacture companies. This pattern is still being done by a large number of tuna manufacture companies today. This treatment is not only cost more money for the Tuna industry, as the delivery process and waste transportation require additional cost despite the revenue generated from selling of the waste to the Pet's feed manufacturers, It is due to the long distance transportation to deliver the waste, but it's also required a very careful treatment, from moving the waste sludge to the delivery vehicle's tanks and to unload at destination factory, as well as the fact that the waste's unpleasant odor will create a serious air pollution to the surrounding areas.

Nowadays, most industrial manufacturers are facing industrial waste issues, such as waste disposal, waste treatment, waste management, waste transportation and waste impact to the environment etc. The food industry and tuna factory in particular, was also facing the same serious issue.

As learned that the co-digestion is a good alternative solution for the tuna waste factory, It is good to adopt a co-digestion management of tuna waste theory for tuna factory by using factory's solid waste and banana crop residue as core material, whereas the objective is to produce biogas from the tuna factory waste to power the factory boilers and reduce the consumption of the fossil fuel and ultimately to achieve sustainable green energy tuna factory.

This theory has benefitted the factory on its waste solution in which waste management is becoming easier to do, as the waste doesn't need to be treated it chemically and doesn't need to be transported it to other location and that all can be done within the tuna factory. In addition, with this theory, enable the factory to produce a green energy biogas that reduce the cost of fossil fuel substantially as well as reducing carbon emission of the factory. In the experiments, the theory is proven to be successfully converted tuna factory's waste into a renewable energy that currently powers the factory's boiler.

The tuna factory globally has indicated that the manufacturing cost has increased rapidly overtime. The finding of the status of each relevant factor and determine where the increase is originating. In response to the rising cost of principle raw materials, such as fuel and fish, the factory must find ways to reduce these costs, by increasing production efficiency, reduce wastes and convert their wastes into renewable energy.

One of the facts is that the fuel cost has been increased rapidly for the past decades. Diesel Fuel costs increased early in 2007 from 22.94 baht to 44.24 baht in 2008. Through subsidizes, in 2010 the Thai government stabilized the price at 29.99 baht. Diesel fuel is used in boiler machines to produce steam in the tuna cooking process. Every 1,000 kilograms of tuna uses 40 liters of diesel.

Another facts is that the price of tuna fish, the main raw material of the factory has been increased very rapidly, from its price of 12 baht per kilogram, then 20 baht and then to 28 baht and now at around 38 baht/kilogram respectively within 3 years (year 2007-2010). The Manufacturing process consumes 5,000 kilograms of fresh fish per day. The waste produced is approximately 1,750 kilograms/day, which previously was sold to the pet feed industry for 3.50 baht per kilogram and tuna factory need to delivery these waste to the feed industry that somehow the revenue from the sales was unable to cover the cost of transportation and its handling. However, the tuna solid waste is actually can be used as material to produce the fish oil, soya sauce and other products. In order to be able to sell the tuna waste to the fish oil or soya sauce manufacturers, we have to store our tuna solid waste at a cold storage at below 5° C that may require additional cost. Tuna waste will produce histamine toxin within hours if it's not stored at the storage at below 5C. Tuna factory solid waste such as heads, viscera, fins, bones and skin are good materials for biogas production yielding high levels of methane. Anaerobic digestion of tuna solid wastes can represent a valid alternative to fossil fuels, as this technique produces a biogas whose methane content can be utilized for heating or electricity production.

The concept of replacing fossil fuel by alternative fuels, such as biogas, has encouraged governments in various countries to set up biogas programs. A biogas plant can digest waste materials that are readily available from households and small farms, such as animal dung and crop wastes; and those from industrial by-products and sewage, such as waste water and municipal waste. Biogas digestion not only results in a clean high grade gas, it also produces a good fertilizer. The quality of the fertilizer is often higher than if the same materials were composted by more traditional methods. The tuna solid waste, representing about 35-37% of the tuna's total weight, provides a high organic load. It would be useful to the manufacturer to have a biomass fermentation and treatment method capable of converting these wastes. Due to the tremendous amounts of solid waste in the tuna industry especially solid waste of head, viscera such as spleen, stomach, intestine, bile sac, liver, roe and pancreas, fin, bone, and skin more attention can be focused on this potential renewable energy source. This solid waste was shown to contain a high organic load of COD, BOD5, total solids and total volatile solids. Thus, tuna solid waste can supply the material needed for biogas production. The literature on biogas production from cattle manure, piggery waste waters and the by-products of aquaculture, agro-industries and urban wastes is vast, while literature on anaerobic digestion using solid waste from tuna factory is not extant. This dissertation was performed in order to evaluate the possibility of using tuna factory solid waste to produce biogas as a renewable energy source to sufficiently power the factory's own boilers. Thus, the knowledge gained from this study will help to improve the control and operation of co-digestion process of these types of waste.

Purposes of the Study

1. To produce biogas by co-digestion of tuna solid waste and banana crop residue

2. To analyze economic benefits of biogas steam production from tuna factory waste

3. To create Tuna factory waste management system for biogas production, that support tuna factory waste treatment that resulting a conversion of the factory waste into a useful substance, such as biogas and high quality fertilizer

Scope of study

The scopes of the study are:

1. To conduct multiple experiments of the co-digestion of tuna solid waste and banana crop residue, at laboratory scale

2. To analyze economic and environment benefits of the co-digestion of tuna solid waste and banana crop residue

3. To identify and set the right parameter to achieve actual system for biogas production

Keywords

Co-digestion, anaerobic co-digestion, biogas production, tuna factory waste, and banana crop residue.

Benefits of the study

The results of the study will provide

1. Ability to ultimately set the right parameter of biogas production system to achieve the optimal biogas production

2. The tuna factory waste management process to produce biogas that is beneficial to the tuna factory

3. The factory was able to save energy cost and phasing out fossil fuel to reduce carbon emission

4. The application of this research to the general food factory and tuna factory that may improve their sanitary facilities and cleanliness of the factory, as well as reducing the amount of waste that had both odors and germs, thus this application ultimately could reach the green factory

CHAPTER II

THEORY AND LITERATURE REVIEW

Tuna Industrial Waste

Tuna industrial waste is consisting of 2 type of waste:

1. Solid waste
2. Water waste

1. Solid waste

Tuna factory solid wastes are such as heads, viscera, fins, bones and skin. In Factory, wastes are generally produced firstly by improved quality in manufacturing operations, minimizing of rejects and reused and then by using more efficient manufacturing processes and better materials. The application of wastes minimize approaches has led to the development of innovative and commercially successful replacement products. Minimized wastes have proven benefits for factory and the wider environment:

1.1 It reduced raw material costs

1.2 It reduced the cost of transport and processing raw materials and the finished product

1.3 It reduced the wastes disposal cost to other parties (including collection, transport, processing and disposal)

Table 2 Weight percentage of tuna fish components

pecies	*Percentage of raw material and waste in total weight*					
	Flesh	Head	Viscera	Fins	Bones	Skin
Tuna	63	19	10	5	2	1

Source: Halla Food (Thailand) Co., Ltd.

During the processing of tuna a large volume of wastes are generated such as head, viscera, fins, bones, skin and waste water. Tuna wastes are approximate 37% of fish weight.

Figure 1 Tuna wastes from Halla Food (Thailand) Co., Ltd.

Coello, N., et al. [5] Was studied the biodegrade-ability of tuna waste utilizing activated sludge in the Warburg respirometer; a bench model of a batch fed aeration unit and a continuous flow aeration unit. A synthetic tuna waste was prepared in the laboratory to provide continuity of waste characteristics. The parameters used in the biodegradability study were the COD, BOD5, total solids, total volatile solids, organic nitrogen, PH, chlorides, grease, phosphates and the mixed-liquor-suspended solids (MLSS) of the activated sludge. Results showed about 60 percent reduction in BOD and suspended solid could be obtained. Variation in MLSS indicated that a MLSS of 3,500 MG/L was optimum for BOD reduction. Oxygen transfer efficiency was a limitation with greater solids concentrations. Tuna packing waste was shown to be a highly proteinaceous waste. However, the activated sludge units had to be buffered with both phosphates and readily available nitrogen for without these, adverse PH levels were reached rapidly. Studies with variable chloride content indicated that chloride values of up to 9,000 MG/L did not affect oxygen uptake. However, with greater chloride concentrations total oxygen uptake and BOD reductions were inhibited. Complete failure occurred when the units were shock loaded.

An important waste reduction strategy for the industry is the recovery of markeTable by-products from fish waste. Hydrolyzed fish waste can be used for fish or pig meal as well as fertilizer components [6]. The utilization of by-products is an important cleaner production opportunity for the industry, as it can potentially generate additional revenue as well as reduce disposal costs for these materials. The transportation of fish residues and offal without the use of water is an important factor for the effective collection and utilization of these by-products [6]. Fish wastes of the species Sardine pilchards were chopped, mix with 15% molasses, inoculated with 5% starter, and incubated at 22 ± 2 °C for 20 days [6]. The obtained product as broiler feed.

Table 3 Characteristics of pure fractions of fish waste species sardine pilchards (mean values, *n*=3)

Analyses	**Fish waste species sardine pilchards**
Ph	6.90
Partial alk alinity (PA) (mg $CaCO_3$/1)	530
Total alkalinity (TA) (mg $CaCO_3$/1)	2280
Total solid (TS) (% of fish sample)	32.20
Volatile solid (VS) (% of TS)	55.30
Organic carbon (OC) % (dry wt)	510
Total rilrogen (TN) % (dry wt)	5.85
C:N	9

Source: Laufenberg, G., et al. [6]

2. Waste water

Waste water generated from smoke dry tuna processing contain high loads of organic matter due to the presence of oil, proteins and suspended solids. They can also contain high levels of phosphates and nitrates. In operations, waste water is also discharged from thawing, eviscerate, washing, precooking (boiled), spray cooling. Below Table show tuna waste water characteristics.

Tuna water waste generally are tuna blood, production cleaning water, steaming fish water, tuna boiled water, processing water, etc.

Table 4 Wastewater characteristics in canned tuna (pet food) process

Parameters	Storage	Precooking	Spray cooling	Can washing	Storage (cleaned tuna)	Combined wastewater
pH	7.4	6.4	7.4	8.4	8.8	7.3
COD (mg/L)	4364	66.222	7911	45	16	3248
O&G (mg/L)	25	1727	164	20	0	216
TS (mg/L)	4688	59.192	6750	308	302	3799
SS (mg/L)	752	7000	599	34	16	742

Source: Mulika U., et al. [7]

Nowadays, most industrial manufacturers are facing industrial waste issues, such as waste disposal, waste treatment, waste management, waste transportation and waste impact to the environment etc. There are a number of waste management strategies and principal that offer positive benefits to businesses, communities, industrial sectors, schools and homes. Many methods have been developed and used in the treatment and/or disposal of sewage sludge, but the operation of the treatment or disposal is usually expensive and/or easy to contaminate the environment. The anaerobic digestion processes have been used for treating the industrial wastes for over a century. The process relatively simple that many food industries have adopted the anaerobic digestion system as part of their energy production that convert their wastes into useful substance. Anaerobic co-digestion offers great potential for the proper disposal of the organic fraction of solid waste coming from source or separate collection systems

Anaerobic digestion

The Anaerobic digestion is a biological process in which organic matter is degraded to methane under anaerobic condition. Methane can be produce from biomass by either thermal gasification or biological gasification. Methane can then be used for energy to replace fossil fuel and thereby to reduce carbon dioxide emissions. Anaerobic digestion reduces pathogens and odors, requires little land space for treatment and may treat wet and pasty wastes [8]. Anaerobic digestion occurs in three stages, hydrolysis/liquefaction, acidogenesis and methanogenesis [9].

1. Anaerobic digestion oxidation process

1.1 Hydrolysis/liquefaction

In the first stage of hydrolysis, or liquefaction, fermentative bacteria convert the insoluble complex organic matter, such as cellulose, into soluble molecules such as sugar, amino acids and fatty acids. The complex polymeric matter is hydrolyzed to monomer, e.g., cellulose to sugars or alcohols and proteins to peptides or amino acids, by hydrolytic enzymes, (lipases, proteases, celluloses, amylases, etc.) secreted by microbes. The hydrolytic activity is of significant importance in high organic waste and may become rate limiting. Some industrial operations overcome this limitation by the use of chemical reagents to enhance hydrolysis. The application of chemicals to enhance the first step has been found to result in a shorter digestion time and provide a higher methane yield [10].

Hydrolysis/liquefaction reactions

Lipids $\longrightarrow$ Fatty Acids

Polysaccharides $\longrightarrow$ Monosaccharides

Protein $\longrightarrow$ Amino Acids

Nucleic Acids $\longrightarrow$ Purines & Pyrimidines

1.2 Acetogenesis

In the second stage, Acetogenic bacteria, also known as acid formers, convert the products of the first phase to simple organic acids, carbon dioxide and hydrogen. The principal acids produced are acetic acid (CH_3COOH), propionic acid (CH_3CH_2COOH), butyric acid ($CH_3CH_2CH_2COOH$) and ethanol (C_2H_5OH). The products formed during Acetogenesis are due to a number of different microbes, e.g., *syntrophobacter wolinii,* a propionate decomposer and *sytrophomonos wolfei,* a butyrate decomposer. Other acid formers are *clostridium spp., peptococcus anerobus, lactobacillus,* and *atinomyces* [9]. An Acetogenesis reaction is show below:

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

1.3 Methanogenesis

Finally, in the third stage methane is produce by bacteria called methane formers (also known as Methanogens) in two ways: either by means of cleavage of acetic acid molecules to generate carbon dioxide and methane, or by reduction of carbon dioxide with hydrogen. Methane production is higher from reduction of carbon dioxide but limited hydrogen concentration in digesters results in that the acetate reaction is the primary producer of methane [11]. The Methanogenic bacterial include *methanobacterium, methanobacillus, methanococus and methanosarcina.* Methanogens can also be divided into two groups: acetate and H_2/CO_2 consumers. Methanosarcina spp. And methanothrix spp. (also, methanosaeta) are considered to be important in AD both as acetate and H_2/CO_2 consumers. The Methanogenesis reactions can be expressed as follows:

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

(acetic acid) (methane) (carbon dioxide)

$$2C_2H_5OH + CO_2 \longrightarrow CH_4 + CH_3COOH$$

(ethanol)

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O$$

(hydrogen) (water)

Generally the overall anaerobic digestion process can be divided into four stages: pretreatment, waste digestion, gas recovery and residue treatment. Most digestion systems require pre-treatment of waste to obtain homogeneous feedstock. The preprocessing involves separation of non-digestible materials and shredding. The waste received by anaerobic digestion, digester is usually source separated or mechanically sorted. The separation ensures removal of undesirable or recyclable materials such as glass, metals, stones etc. In source separation, recyclables are removed from the organic wastes at the source. Mechanical separation can be employed if source separation is not available. However, the resultant fraction is then more contaminated leading to lower compost quality [10]. The waste is shredded before it is fed into the digester. Inside the digester, the feed is diluted to achieve desired solids content and remains in the digester for a designated retention time. For dilution, a varying range of water sources can be used such as clean water, sewage sludge, or re-circulated liquid from the digester effluent. A heat exchanger is usually required to maintain temperature in the digesting vessel. The biogas obtained in anaerobic digestion is scrubbed to contain pipeline quality gas. In case of residue treatment, the effluent from the digester is dewatered, and the liquid recycled for use in the dilution of incoming feed. The bio solids are aerobically cured to obtain a compost product.

Anaerobic digestion processes can be classified according to the total solids (TS) content of the slurry in the digester reactor. Low solids systems (LS) contain less than 10%TS, medium solid (MS) contain about 15-20% and high solids (HS) processes range from 22%-40% [12]. Anaerobic digestion process can be categorized further on the basis of number of reactors used, into single-stage and multi-stage. In single stage processes, the tree stages of anaerobic process occur in one reactor and are separated in time (i.e., one stage after the other) while multi-stage processes make use of two or more reactors that separate the Acetogenesis and Methanogenesis stages in space. Batch reactors are used where the reactor is loaded with feedstock at the beginning of the reaction and products are discharged at the end of a cycle. The other type of reactor used, mostly for low solids slurries, is continuous flow where the feedstock is continuously changed and discharged.

The rate at which the microorganisms grow is of paramount importance in the anaerobic digestion process. The operating parameters of the digester must be controlled so as to enhance the microbial activity and thus increase the anaerobic degradation efficiency of the system. Some of these parameters are discussed in the following section.

Anaerobic co-digestion

The Anaerobic co-digestion aims at treating different organic residues that can be blended for optimal energy and resources recovery

Co-digestion is a process whereby energy-rich organic waste materials (e.g. Fats, Oils and Grease (FOG) and/or food scraps) are added to dairy or wastewater digesters with excess capacity. In addition to diverting food waste and FOG from landfills and the public sewer lines, these high-energy materials have at least three times the methane production potential (e.g. biogas) of bio solids and manure.

Co-substrates are used in anaerobic digestion system it improves the biogas yields due to positives synergisms established in the digestion medium and the supply of missing nutrients. A great option for improving yields of anaerobic digestion of solid wastes is the co-digestion of multiple substrates.

Traditionally, anaerobic digestion was a single substrate, single purpose treatment. Recently, it has been realized that AD as such became more stable when the variety of substrates applied at the same time is increased. The most common situation is when a major amount of a main basic substrate (e.g. manure or sewage sludge) is mixed and digested together with minor amounts of a single, or a variety of additional substrate. The use of co-substrates usually improves the biogas yields from anaerobic digester due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co-substrates [13].

Advantages and disadvantages of anaerobic Co-digestion:

Advantages:

1. Improved nutrient balance and digestion.
2. Additional biogas collection.
3. Possible gate fees for waste treatment.
4. Additional fertilizer such as soil conditioner

5. Renewable biomass disposable for digestion in agriculture.

Disadvantages:

1. Increased digester effluent COD.
2. Additional pre-treatment requirements.
3. Increased mixing requirements.
4. Wastewater treatment requirement
5. Hygiene requirements.
6. Restrictions of land use for digestate.
7. Economically critical dependent on crop.

Digestion operating Parameters

There are many parameters that influence the performance of AD, such as volatile solid (VS), pH, temperature, carbon to nitrogen ratio (C:N), total solid content (TS), organic loading rate (OLR), retention time, mixing conditions, compost, nutrient, toxic materials, and moisture content [14].

1. Waste composition/Volatile Solids (VS)

The waste treated by AD may comprise a biodegradable organic fraction, a combustible and an inert fraction. The biodegradable organic fraction includes kitchen scraps, food residue and grass and tree cuttings. The combustible fraction includes slowly degrading lignocellulosic organic matter containing coarser wood, paper and cardboard. As these lignocellulosic organic materials do not readily degrade under anaerobic conditions, they are better suited for waste to energy plants. Finally, the inert fraction contains stones, glass, sand, metal and etc. This fraction ideally should be removed, recycled or used as land fill. The removal of inert fraction prior to digestion is important as otherwise it increases digester volume and wear of equipment. In waste streams high in sewage and manure, the microbes thrive and hydrolysis the substrate rapidly whereas for the more resistant waste materials, such as wood, digestion is limited. The volatile solids (VS) in organic wastes are measured as total solids minus the ash content, as obtained by complete combustion of the feed wastes. The volatile solids comprise the biodegradable volatile solids (BVS) fraction and the refractory volatile solids (RVS). [15] Showed that knowledge of the BVS fraction of MSW help in better estimation of the biodegradability of waste, of biogas generation, organic loading rate and C:N ratio. Lignin is a complex organic material that is no easily degraded by anaerobic bacteria and constitutes the refractory volatile solids (RVS) in organic MSW. Waste characterized by high VS and low non-biodegradable matter, or RVS, is best suited to AD treatment. The composition of waste affects the yield and biogas quality as well as the compost quality.

2. pH Level

Anaerobic bacteria, specially the Methanogens, are sensitive to the acid concentration within the digester and their growth can be inhibited by acidic conditions. The acid concentration in aqueous systems is expressed by the pH value, i.e. the concentration of hydrogen ions. At neutral conditions, water contains a concentration of 10^{-7} hydrogen ions and has a pH of 7. Acid solutions have a pH less than 7 while alkaline solutions are at a pH higher than 7. [10] It has been determined that an optimum pH value for AD lies between 5.5 and 8.5. During digestion, the two processes of acidification and Methanogenesis require different pH levels for optimal process control. The retention time of digestate affects the pH value and in a batch reactor Acetogenesis occurs at a rapid pace. Acetogenesis can lead to accumulation of large amounts of organic acids resulting in pH below 5. Excessive generation of acid can inhibit Methanogens, due to their sensitivity to acid conditions. Reduction in pH can be controlled by the addition of lime or recycled filtrate obtained during residue treatment. In fact, the use of recycled filtrate can even eliminate the lime requirement. As digestion reaches the Methanogenesis stage, the concentration of ammonia increases and the pH value can increase to above 8. Once methane production was stabilized, the pH level stays between 7.2 to 8.2 levels.

3. Temperature

There are two main temperature's ranges that provide optimum digestion conditions for the production of methane – the mesophilic and Thermophilic ranges. The mesophilic range is between 20°C-40°C and the optimum temperature is considered to be 30°C-35°C. The Thermophilic temperature range is between 50°C-65°C [10]. It has been observed that the higher temperatures in the thermophilic range, it reduced the required retention time [16].

4. Carbon to Nitrogen Ratio (C:N)

The relationship between the amount of carbon and nitrogen present in organic materials is represented by the C:N ratio. Optimum C:N ratios of anaerobic digesters are in between 20-30. A high C:N ratio is an indication of rapid consumption of nitrogen by Methanogens that will result of lower gas production. On the other hand, a lower C:N ratio causes ammonia accumulation and pH values exceeding 8.5, which is toxic to Methanogenic bacteria. Optimum C:N rations of the digester materials can be achieved by mixing materials of high and low C:N ratios, such as organic solid waste mixed with sewage or animal manure. Kayhanian [17] concluded that maintaining the right C:N ratio would increase biogas production and stability of the process. This report was recommended a C:N ratio between 25 and 30 as optimal, based on the level of biodegradable carbon, rather than total carbon. However, some investigations reported that an approximate C:N ration of 16 to 19 [18] and 16.8 to 18 [19] are optimal for methanogenic performance, if poorly degradable compounds such as lignin are used.

5. Total Solid Content (TS)/ Organic Loading Rate (OLR)

As discussed earlier, low solids (LS) anaerobic digestion systems contain less than 10% TS, medium solids (MS) about 15-20% and high solids (HS) processes range from 22% to 40% [12]. An increase in TS in the reactor will results a corresponding decrease in reactor volume. Organic Loading Rate (OLR) is a measurement of the biological conversion capacity of the anaerobic digestion system. Feeding the system above is sustainable OLR will results in low biogas yield due to accumulation of inhibiting substances such as fatty acids in the digester slurry. At such, the feeding rate to the system shall be reduced. OLR is one of important control parameters in continuous systems [20]. Many plants have reported system failures due to the over-loading [20]. Reports OLR is twice in HS in comparison to LS [9].

6. Retention (or residence) Time

The required retention time for completion of the anaerobic digestion reactions varies with differing technologies, process temperature and waste composition. The retention time for wastes treated in mesophilic digester range from 10 to 40 days. Lower retention times are required in digesters operated in the thermophilic range. A high solids reactor operating in the thermophilic range has a retention time of 14 days [9]. The retention time of solid waste digestion process, most dry processes ranges between 30 days to 50 days and for wet process can be low as 3 days. The optimal value was varies according to some specific technology used, as the process temperature or the waste composition [21].

7. Mixing

The purpose of mixing in a digester is to blend the fresh material with digestate containing microbes. Furthermore, mixing prevents scum formation and avoids temperature gradients within the digester. However excessive mixing can disrupt the microbes so slow mixing is preferred. The kind of mixing equipment and amount of mixing varies with the type of reactor and the solids content in the digester.

8. Compost

When the digestion is complete, the residue slurry, also known as digestate, is removed, the water content is filtered out and re-circulated to the digester and the filter cake is cured aerobically, usually in compost piles, to form compost. The compost product is screened for any undesirable materials, (such as glass shards, plastic pieces etc) and sold as soil amendment or fertilizer. The quality of the compost is depending on the waste composition [9].

9. Nutrients

The most important nutrients for anaerobic digestion are nitrogen and phosphorus. The amount of these elements needed for microbial growth can be estimated from biomass yield coefficients, which may vary with the energy source. The estimated optimum COD/N/P rations are related to the amount of COD consumed. It may be concluded that the requirements of nitrogen in relation to influent COD will be lower, especially for waste containing high COD/BOD ratio [22]

Nitrogen present in the feedstock provides an essential element for microbial synthesis of amino-acids, proteins and nucleic acids. In addition, it is converted to ammonia which meutralizes the bolatile acids and thus helps maintain neutral pH conditions essential for microbial growth. On the other hand, an excess of nitrogen in the substrate can lead to excessive ammonia formation, resulting in toxic effects. Thus, it is important that the proper amount of nitrogen be in the feedstock, to avoid either nutrient limitation or ammonia toxicity. As well as nitrogen and phosphorus, a large number of the other elements have been shown to be necessary for optimum anaerobic treatment. The growth of many acetogenic and methanogenic bacterial is stimulated by various elements like Fe, Se, Ca, Na, Co and Mo, when they are presented as free ionic species [23]. An insufficiency of these trace elements limits the synthesis of enzymes, catabolic and metabolic activities, particularly of acetogenic and methanogenic bacteria.

10. Toxic materials

Toxic compounds affect digestion at two levels, by slowing down the rate of metabolism in low concentrations, of by poisoning or killing the micro-organisms in high concentrations. Although all bacterial groups involved in anaerobic digestion can be affected, the methanogenic bacteria are generally the most sensitive. Due to their slow growth, inhibition of the methanogens can lead to process failure in completely mixed systems, and cause the washout of the bacterial mass.

In organic captions, such as Ca^{++}, Mg^{++}, Na^{+}, K^{+}, or Fe^{++}, show stimulatory effects at low or normal concentrations but exhibit inhibitory effects at higher concentrations. Inorganic ions, such as $So_4^{=}$,NO_3^{-}, are reported potential inhibitors of methanogenesis as are alternative electron acceptors. Sulfide (S), which is essential for most methanogens, is toxic above 200mg l^{-1} and is insoluble when heavy metals are present [24]. Certain heavy metals are toxic to anaerobic organisms, even at low concentrations. Heavy metal ions inhibit metabolism and kill organisms. Since these reactions involve metal ions, which is toxic in the soluble form, toxic effects are dependent on the solubility of heavy metals, under various digesting conditions.

11. Moisture content

Lay, et al. [25] reported that the methanogenic activity of the digester, treating organic fraction of municipal solid waste (OFMSW), decreased with the decrease in moisture content. Wujcik and Jewell [26] studied the effect of moisture content on methane yield, in the batch fermentation of wheat straw and dairy manure. Methane yields decreased when moisture content was lower than 70%. The yield at 30% moisture was only 22% that at 70% moisture. The moisture content and moisture flow could promoted the contact between micro-organisms, their substrates and other necessary growth factors, as well as dilute and remove inhibitory fermentative products.

Biogas system

1. Biogas Production

The design according to gas storage of biogas digester may vary as per requirement of the owner. This can be divided into three sections, such as: fixed-dome, floating gas holder and bag digester.

1.1 Fixed Dome Digester

Fixed-dome digester (Figure 2) is the most common type of design that widely used. The four major components of the digester which are gas storage, fermentation chambers, hydraulic tank and inlet tanks are integrated into on structure. Their distinct advantages over the other designs are:

1.1.1 All concrete construction, hence, durable and lifelong investment. Simple structure. Least cost

1.1.2 No moving parts and metal components, thus easy to maintain

1.1.3 Capable of generation higher gas pressure (on the average 10 times higher than floating gas holder type) and does not use floating tank

1.1.4 Completely constructed underground, thus it save a land space

1.1.5 Input materials easy flow into the digester by gravity, hence simplifying operation

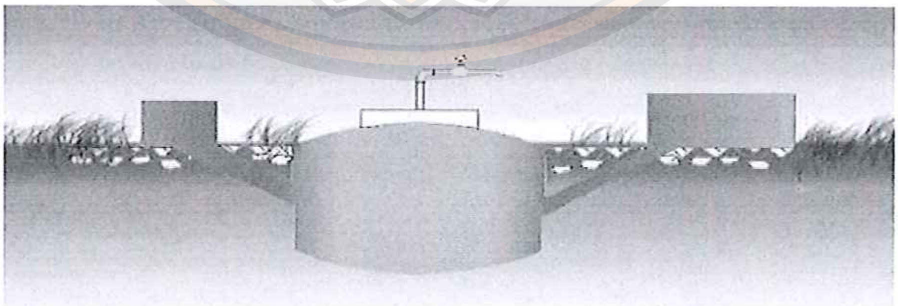


Figure 2 Fixed-Dome Digester type

Source: Khoiyangbam, et al. [20]

1.2 Floating Gas Holder Digester

The floating gas holder digester makes use of the floating tank for gas storage. This can be further subdivided into:

1.2.1 Top Floating Gas Holder Digester

1.2.2 The floating tank (Figure 3) for gas storage is directly installed on top of the digester. This is usually employed for small size digester

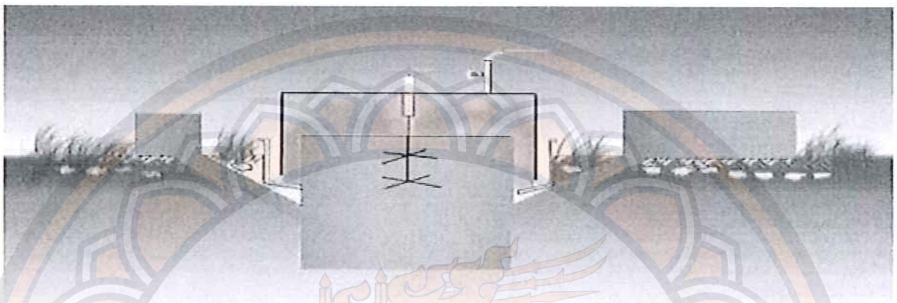


Figure 3 Floating Gas Holder Type

Source: Khoiyangbam, et al. [20]

1.2.3 Separator Floating Gas Holder Digester The application of this style is for medium to large size digester. There are two tanks involved: one is the fermentation tank and the other is the storage tanks

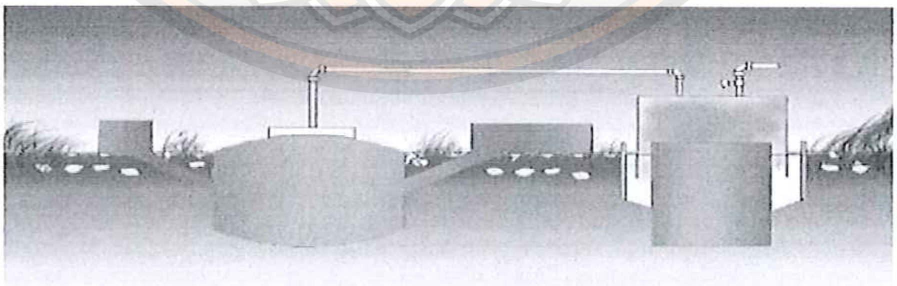


Figure 4 Separate Floating Gas Holder Type

Source: Khoiyangbam, et al. [20]

1.3 Bag Digester

The bag digester (Figure 5) is a type of digester with a separate bag for bag storage

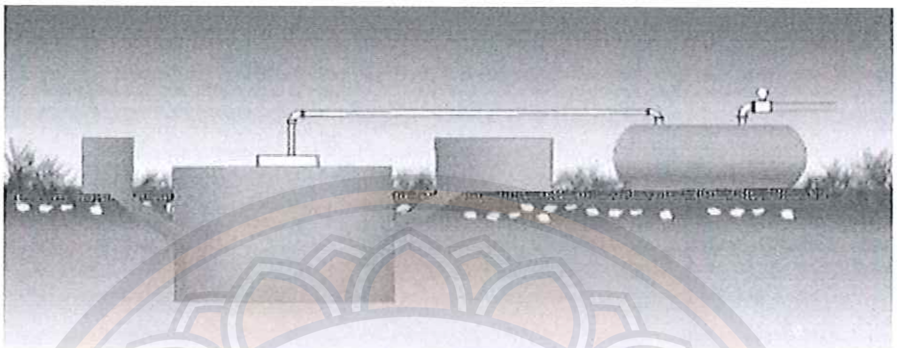
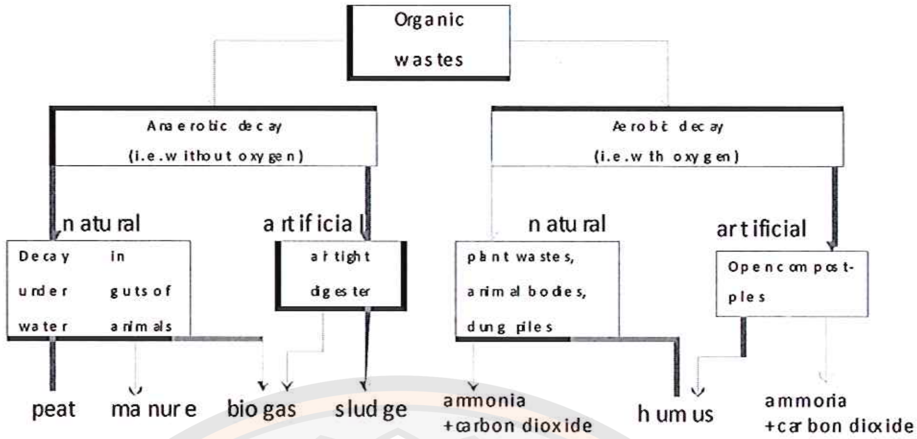


Figure 5 Bag Type Gas Holder

Source: Khoiyangbam, et al. [20]

When organic refuse decays, it does so in the presence or absence of air (and hence oxygen) and its referred as aerobic or anaerobic decomposition respectively. This decomposition could be naturally occurring or may be artificially induced, under the controlled conditions, in either case of several byproducts, as per shown on Figure 6



Organic-decay processes.

Figure 6 Organic – decay process

Source: General Environmental Multilingual Thesaurus [27]

The end-products of anaerobic decay are biogas, which is produced naturally from decay under water or in the guts of animals and artificially in airtight digesters. Itodo and Phillips [28], described biogas as "a methane-rich gas that is produced from the anaerobic digestion of organic materials in a biological engineering structure called the digester. This definition suggests that biogas is only produced artificially, but this is not the case. It is believed that the scope of their definition may perhaps have been limited by their comparison of artificial production-processes, thus ignoring the natural occurrence of biogas. However, they are not alone in this way of defining biogas.

2. **Composition of Biogas**

The minute anaerobic digestion start and biogas production begin on a technical scale, the chemical proposition of the substrates are involved, and these are the starting point for the later biogas composition. Hobson [29] stated that the decomposition of organic matter in the absence of air could be elicited by the use of physical or chemical processes at high temperature and/or pressure, or the use of microorganisms at near ambient temperature and atmospheric pressure; the preferred method being dependent on the relative polluting impacts to the environment.

However, irrespective of the method used, gas is produced; it is referred to as biogas if generated as a result of the action of microorganisms on the organic wastes. This is way biogas – see Table 5 – is now defined as "a by-product of the biological breakdown, under oxygen-free conditions of organic wastes such as plants, crop residues, wood and bark residues and human and animal manure and it's also known as swamp gas, marsh gas, will the wisp or gobar gas" [30], digestion gas [31], natural gas [32], landfill gas (LFG) and sewage gas [33]. The gas is colorless, relatively odorless and flammable. In addition, it is also relatively sTable and non-toxic. It burns with a blue flame and has a calorific value of 4500-5000 k cal/m3 when its methane content ranges from 60% to 70%.

Table 5 Composition of biogas

Constituent	Composition
Methane (CH_4)	55–75%
Carbon dioxide (CO_2)	30–45%
Hydrogen sulphide (H_2S)	1–2%
Nitrogen (N_2)	0–1%
Hydrogen (H_2)	0–1%
Carbon monoxide (CO)	Traces
Oxygen (O_2)	Traces

Source: Madu, C. and Sodeinede, O.A. [34]

3. Material

The generation of biogas has traditionally been from feedstock such as "livestock farm-waste (e.g. various manures, slurries and waste waters) and agro-industrial waste (from abattoirs, wineries, vegeTable processing plants, etc.)" [35].

This is why biogas is also described as the fuel produced through anaerobic fermentation of manure and vegeTable matter in digesters, or the fermentation of animal dung, human sewage or crop residues in an airtight container. Hence, the general belief is that liquid-manure systems work best for anaerobic digestion in the production of biogas. However, this is not the case, except that the generation of biogas was indeed first associated with liquid wastes and sludge. So Kiely, G. [36] explained that anaerobic digestion is used worldwide for the treatment of industrial, agricultural and municipal waste-water and sludge: he also noted that, in recent years, it has also been applied for the treatment of municipal solid wastes. Hence Vassiliou [35] after successfully generating biogas from wastes of raw manure plus wash water from large livestock-farms and the wastes from food and drink industries, explained that the second stage of any project should be the biogas generated from the organic components of source-separated municipal solid-wastes (MSWs).

Loading rate of organic materials into the digester, this specification greatly affects the anaerobic-digester's design, particularly the volume of the digester, and indeed the overall process-performance. The loading rate is an important parameter because it indicates the amount of volatile solids to be fed into the digester each day [10]. Volatile solids represent that portion of the organic-material solids that can be digested, while the remainder of the solids is fixed. The 'fixed' solids and a portion of the volatile solids are non-biodegradable. The actual loading rate depends on the types of wastes fed into the digester, because the types of waste determine the level of biochemical activity that will occur in the digester.

Anaerobic Digestion is a process which breaks down organic matter in simpler chemicals components without oxygen. This process can be very useful to treat arising organic waste such as:

1. Waste water
2. Organic farm wastes
3. Municipal wastes
4. Organic industrial and commercial wastes

Before being digested, the feed stock has to undergo pre-treatment. There are various types of pre-treatment depending on the feedstock. The purpose of such treatment is to mix different feedstock, to add water or to remove undesirable materials such as large items and inert materials (e.g. plastic, glass) to allow a better digestate quality, a more efficient digestion and it will avoid failure in the process.

The digestion process itself takes place in a digester, which can be classified in relation to the temperature, the water content of the feedstock and the number of stage (single or multi-stage). Each digester has it characteristics and properties and thus can be more suiTable for a specific feedstock. There are at the present more mesophilic (35°C) than thermophilic digester (55°C) but the difference tends to decrease. There used to be more wet digesters than dry digesters but there is no clear trend anymore. Multi-stage processes aim at optimizing digestion and improving control of the process by separating stages of digestion. Only a few of these digesters are used at the present time. Finally, the batch processes are less expensive and less complex but there are also less efficient.

The by-products of anaerobic digestion, biogas and digestate, can be used in order to create a source of incomes. Biogas can be upgraded, most of the time by removing the carbon dioxide and the water vapour and then, used in a CHP unit to produce electricity and heat. The digestate can be used as a fertilizer or further processed into compost to increase its quality. The financial aspect of anaerobic digestion including the capital and the operating costs are quite high, but the source of incomes coming from the sale of electric, heat and digestate allows important benefits [37].

4. Gas Scrubbing

Biogas consists of methane (CH_4) and carbon-dioxide (CO_2) along with some trace gases such as water vapour, hydrogen sulphide (H_2S), nitrogen, hydrogen and oxygen. Before used biogas, first need to be purified by removing the CO_2, H_2S and water vapour because the H_2S gas is corrosive, water vapour may cause corrosion when combined with H_2S on metal surface and reduce the heating value. Once the CO_2, H_2S and water vapour is efficiently and economically removed, the methane can then be reused for power generation without harm to engine. The biogas scrubbing system can improve the economic feasibility of energy recovery by reducing maintenance and operating cost biogas handling. Biogas is mostly used as fuel in power generators and boilers. For these use, the H_2S content in biogas should be less than 200 parts per million (ppm) to ensure a long life for the power and heat generators.

A variety process are being used for removing CO_2 from biogas as physical absorption, chemical absorption, adsorption on a solid surface, membrane separation, cryogenic separation and chemical conversion method. The most commonly used H_2S removal process can be classified into two general categories namely (1) Dry oxidation process and (2) liquid phase oxidation process.

5. Implementation

Biogas is increasingly becoming an attractive source of energy in many nations of the world. For example, in the UK, Xuereb, P. [33] reported that, although the use of biogas for electricity generation was still at an experimental stage, it already accounts for about 0.5% of the total electricity output and biogas fuels account for about 1% of US electricity generation, while achieving a climate-change benefit equivalent to reducing CO_2 emissions in the electricity sector by more than 10%. Biogas is also presently used in India, China, Taiwan, Brazil, Singapore, etc. Tchobanoglous and Burton stated that, in large plants, digester gas may be used as a fuel for the boiler and internal combustion engines, which are in turn used for pumping waste water, operating blowers and generating electricity. Despite the heating-and-electricity generation uses of biogas, in addition, the residues of such biogas production can be used as low-grade fertilizers.

Xuereb, P. [33] enumerated the characteristics of biogas:

5.1 It is flammable, potentially explosive and a readily controllable source of energy

5.2 Its use helps to reduce the amount that would otherwise be released naturally into the atmosphere, and so reduces the excessive greenhouse-effect

5.3 Although on burning biogas, carbon dioxide is released, it is not considered as a net contributor to the global carbon-dioxide level because it originated from plants, which have absorbed it from the atmosphere. Hence this carbon dioxide does not make a net contribution to the 'greenhouse effect'

5.4 The harnessing of biogas also helps to minimize the unpleasant decomposition smells produced in landfill sites because, otherwise, these gases would be released directly into the atmosphere. Hence, especially where landfills are situated close to inhabited areas, the harnessing of LFG makes landfills slightly more socially accepTable.

6. Biogas compression and storage system developments

Biogas, contain mainly methane, could not be stored easily, as it does not liquefy under pressure at ambient temperature (critical temperature and pressure required are -82.5°C and 47.5 bar, respectively).

Compressing the biogas reduces the storage requirements, concentrates the energy content and increases the pressure to a level required overcoming resistance to gas flow [38]. Compression is better in the scrubbed biogas. Most commonly used biogas storage systems are given in Table 6.

Table 6 The most commonly used biogas storage options

Pressure	*Storage device*	*Material*
Low (0.14–0.41 bar)	Water sealed gas holder	Steel
Low	Gas bag	Rubber, plastic, vinyl
Medium (1.05–1.97 bar)	Propane or butane tank	Steel
High (200 bar)	Commercial gas cylinders	Alloy

Source: J.L Walls, et al. [39]

Integrated units with facilities for scrubbing, compressing and storing have been developed in certain developed countries. For instance a water scrubber coupled with a gas compressor is being promoted for uniform use in New Zealand. Similarly, the biogas produced from poultry manure is being dried, scrubbed, compressed and stored at a pressure of 4 bars in 0.2 m 3 still tanks in Belgium [40]. Khapre [38] conducted a study on scrubbing and compression of biogas and subsequently used it for domestic cooking. He found reduced requirement of scrubbed and compressed biogas (0.353 m^3) than raw biogas (0.591 m^3) for cooking a day's meal of a six member family. He stored the scrubbed and compressed biogas at a pressure of 7 bars in cylinder of 0.1m^3 capacity.

By purifying the biogas produced from the distillery wastes, scientists of jadhavpur University, Kolkatta, India [41] claimed to have generated huge quantities of compressed methane, a gas with an immense potential and an alternative source of vehicle fuel. Experimenting with bulk distillery wastes, from alcohol manufacturing breweries, researchers produced the gas yield bio-methanation of the effluents. Similar results have also been reported from Netherlands, UK, Australia, New Zealand and USA. All these results indicate that biogas is one of the potential substitutes for present day fuels including CNG, petrol, diesel and LPG. Nema and Bhuchner [42] stressed on value addition to biogas by scrubbing and compressing, making it as good as the compressed natural gas (CNG). They reported the economic feasibility of producing energy from solid wastes of Delhi city. From 5000 tonnes wastes generated per day in Delhi, 100,000 Nm^3/day biogas can be produced which is equivalent to 309.5 m^3 CNG worth US $ 70,000 per day. Beside this, by adopting this technology 117 tonnes/day CO_2 gas can be prevented from entering into the atmosphere.

The biogas compression system is developed based on the principle of an air compressor design. The composition and properties of biogas are different than air, thus auxiliary equipment is added for a suiTable system. The components could be separated in to 3 parts, as follows; [43]

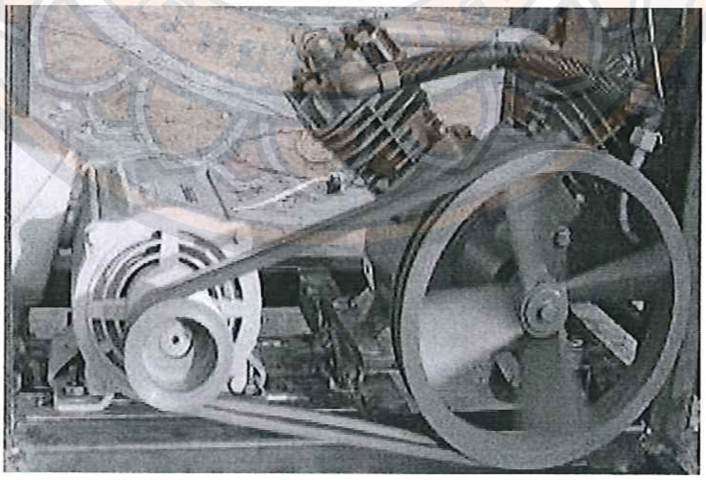


Figure 7 Biogas compressor and motor

Source: Singbua, P. and Suntivarakorn, R. [43]

7. Biogas equipments

7.1 Biogas compressor

The advantages of this piston compressor were durability and standard size for 15 bar of compression. The disadvantage was longer time-consumption when compared to other compressor.

7.2 Biogas upgrading equipment

A biogas upgrading system was developed which ran the biogas through sodium hydroxide solution 2 times, then a run through iron fiber and then sent to decrease moisture by entrapment and finally sent into the biogas compressor. Figure 8 shows the system using, 4 inch diameter and 80 centimeters long PVC tube and ¾ inch diameter copper tube which conducted the biogas into the sodium hydroxide solution.

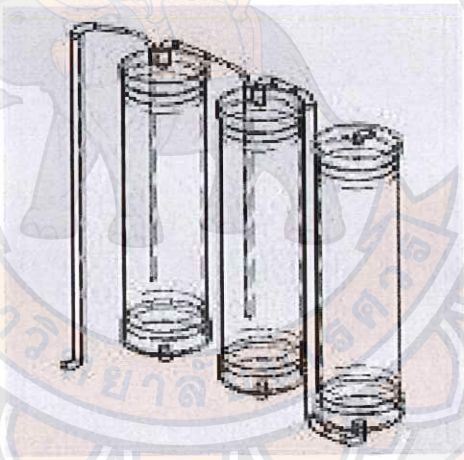


Figure 8 Biogas Scrubbing System

Source: Singbua, P. and Suntivarakorn, R. [43]

7.3 Biogas cooling system

The initial temperature of the biogas before compressing was 30°C, and the final temperature would be increased to 172.84°C after compression. Because of higher pressure, a cooling system was necessary for decreasing its temperature before compressing the biogas into a container. Figure 10 shows the cooling system next to a 150 watt electric fan, which blows air up to the biogas in the copper tube.

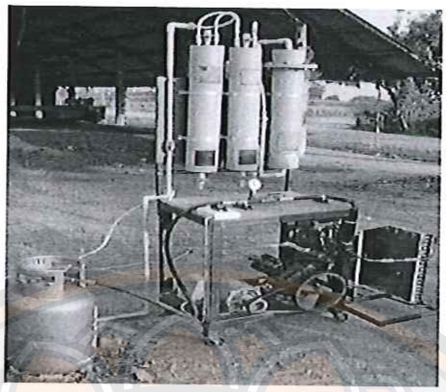


Figure 9 Biogas compression Systems

Source: Singbua, P. and Suntivarakorn, R. [43]

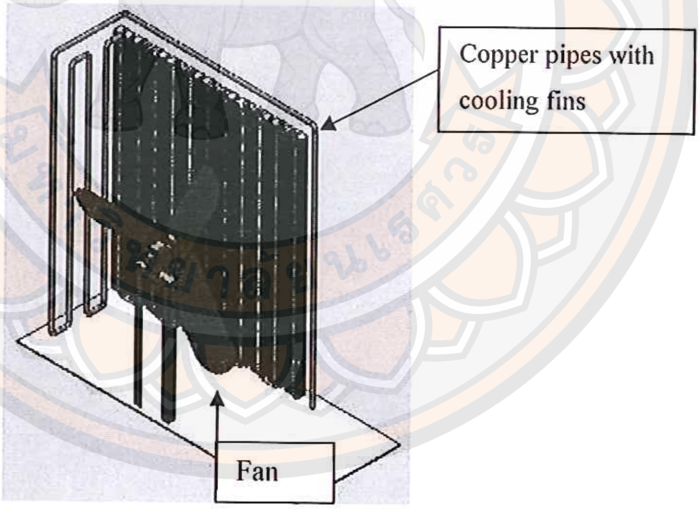


Figure 10 Biogas cooling System

Source: Singbua, P. and Suntivarakorn, R. [43]

8. Type of anaerobic treatment systems for solid waste

The anaerobic digesters for solid waste are classified in a single stage, multi stage and batch systems.

8.1 Single-stage process

A single stage process has been widely applied, due to its simple configuration and operation. In a single stage digester, all of the bacteria exist in the same environmental conditions, which kept the intermediaries of each stage of anaerobic digestion process at equilibrium. The most crucial parameter is the pH, which must be kept close to neutral, in order to ensure the strong activity of the methanogenesis. In order to maintain a favorable environment for the mixed culture of micro-organism in such reactors, volatile fatty acids (VFA) production and utilization must be balanced. If the VFA production exceeded the utilization, the reactor may fail, because of pH drops and a consequent inhibition of methanogens. The reactor mainly used is the continuously stirred tank reactor (CSTR), which is generally operated at solid content less than 15%. The reactor is commonly operated at retention time in the range of 14-28 days, depending on the type of feedstock and operating temperature.

8.2 Multi stage process

The introduction of multi stage process was intended to improve digestion by separating reactors for the different stages of anaerobic digestions. Typically, two reactors are used, the first for hydrolysis/acetogenesis and the second for methanogenesis. The concept to design a two phase system came from the fact that anaerobic digestion involves two phases of activities. The design takes advantage of phase separation, using separate units for acidogenesis and methanogenesis, to reduce treatment cost and improve efficiency. Two stage digesters can be more efficient because the micro-organism have separate nutrient needs, growth capacities and ability to cope with environmental stress [44, 45]. Two-stage anaerobic digestion systems have several advantages over conventional single-stage system, such as the higher loading rate, organic degradation rate, methane production rate and process stability, as well as reducing significantly any risk of digester overloading, by optimizing environmental conditions for each phase [46, 47, 48, 49].

8.3 Batch process

Batch digesters are simplest to construct and operate. The operation of a batch reactor consists of loading the digester with organic materials, with or without the addition of inoculum and allowing it to digest in dry mode, i.e. at 30-40% total solid. The retention time depends on temperature and other factors. Once the digestion is complete, the effluent is removed and the process is repeated. The batch systems have been developed to achieve much higher reaction rates and higher biogas yields, by recirculation of leachate [50]. There are three basic batch designs, which differ in the perspective locations of the acidification and methanogenic phases. In the single stage batch design, the leachate is recirculated to the top of the same reactor. In the sequential batch design, the process comprises two or more reactors. The leachate of a freshly filled reactor, containing high levels of organic acids, is recirculated to another more mature reactor, where methanogenesis takes place. The leachate of the latter reactor containing low concentration, but is high in buffering bicarbonate, is returned to the new reactor. This configuration also ensures cross-inoculum between new and mature reactors which eliminates the need to mix the fresh with seed material [51]. Finally, in the hybrid batch design, the mature reactor where the methanogenesis takes place, is replaced by a high rate reactor, such as an upflow anaerobic sludge blanket (UASB) reactor and anaerobic hybrid reactor.

Leticia Regueiro, et al. [52] was study on the anaerobic digestion of pig manure with fish and biodiesel waste was evaluated and compared with sole pig manure digestion. Results indicated that co-digestion of pig manure with fish and/or biodiesel waste is possible as long as ammonium and volatile fatty acids remained under inhibitory levels by adjusting the operating conditions, such as feed composition, organic loading rate (OLR) and hydraulic retention time (HRT). PM and FW co-digestion (90:10 and 95:5, w/w[4]) was possible at OLR of 1-1.5 g COD/L d, resulting in biogas production rate of 0.4-0.6 L/L d and COD removal efficiencies of 65-70%. Regarding biodiesel waste, good results (biogas production of 0.9 L/L d and COD elimination of 85%) were achieved with less than 5% feeding rate. Overall, operating at the same OLR, the biogas production and methane content in the co-digester was higher than in the only pig manure digester.

Linn Solli, et al. [53] study examined the effects of an increased load of nitrogen-rich organic material on anaerobic digestion and methane production. Co-digestion of fish waste silage (FWS) and cow manure (CM) was studied in two parallel laboratory-scale (8 L effective volume) semi-continuous stirred tank reactors (designed R1 and R2). A reactor fed with CM only (R0) was used as control. The reactors were operated in the mesophilic range (37 °C) with a hydraulic retention time of 30 days and the entire experiment lasted for 450 days. The rate of organic loading was raised by increasing the content of FWS in the feed stock. During the experiment, the amount (volume %) of FWS was increased stepwise in the following order: 3% - 6% - 13% - 16% and 19%. Measurements of methane production and analysis of volatile fatty acids, ammonium and pH in the effluents were carried out. The highest methane production from co-digestion of FWS and CM was 0.400 L CH_4 gVS^{-1}, obtained during the period with loading of 16% FWS in R2. Compared to anaerobic digestion of CM only, the methane production was increased by 100% at most, when FWS was added to the feed stock. The biogas processes failed in R1 and R2 during the periods, with loading of 16% and 19% FWS, respectively. In both reactors, the biogas processes failed due to overloading and accumulation of ammonia and volatile fatty acids.

S.S. Kapdi, V.K. Vijay, S.K. Rajesh and Rajendra Prasad [54] study on biogas scrubbing and compression at high pressure for storage in cylinder are essential. Different methods of scrubbing are reviewed and found that water scrubbing is simple, continuous and less expensive method for CO_2 removal from biogas for Indian conditions. It simultaneously also removes H_2S. After removal of CO_2, biogas is enriched in methane and become equivalent to natural gas. It can be used for all such applications for which natural gas is being used viz. as a fuel for vehicles, CHP, electricity generation, etc.

Lanari, D. and Franci, C. [55] Study on an experimental small scale partial recirculation system for rainbow trout assembled. The system components were two 1.3-m^3 fish tanks with sloping bottoms, each connected to a sedimentation column and containing 50 kg rainbow trout biomass, an anaerobic up-flow digester connected to the funnel shaped bottom of the sedimentation column by means of a peristaltic pump, an aerobic submerged plug-glow filter and a submerged pump. Aeration was provided through porous stones. The anaerobic digester was kept at a temperature of 24-25°C using an electric heater. The gas chamber at the top of the anaerobic digester was connected to a gas meter and to an infrared continuous gas analyses. Measures on system performance with a recirculation rate of 60% were done following three feeding levels (1, 1.5 and 2% live weight). At the highest feeding rate, 2.8L of fecal sludge collected from the trout tanks were pumped every four hours in the anaerobic digester. Biogas production was 144L-d^{-1} (mean value) with a methane content higher than 80% Methane volumetric production was $0.3m^{3}\cdot m^{-3}\cdot d^{-1}$ and methane daily yield was 0.4 and 0.32 m^{-3}-kg^{-1} VS and SS respectively. The anaerobic digester was able to significantly reduce VS and SS content of wastewater and the zeolite ion-exchange column significantly improved water quality of effluent produced by the digester. The aerobic bio-filter significantly reduced the ammonia content of the water leaving the fish tanks. The produced biogas can be used directly in a burner to produce thermal energy or, following depuration, can be employed as fuel in a cogeneration plant to produce thermal and electrical or mechanical energy.

Anaerobic batch digestion of sisal pulp and fish waste separately, as well as co-digestion of both substrates was investigated by Anthony, M., et al. [56]. Sisal pulp and fish waste (offal, scales, gills) and washing water, were digested separately at 5-60% wet biomass (v/v) in 30 batch bioreactors for 25 and 29 days, respectively. In the co-digestion experiment, mixtures of fish waste and sisal pulp of different proportions wer 3e digested in 15 bioreactors for 24 days at 27 ± 1°C. The highest methane yield of 0.32 m^3 CH_4/kg volatile solids (VS) for sisal pulp and $0.39m^3$ CH_4/kg VS for fish waste at 5% TS was reported after 25 and 29 days, respectively. Co-digestion with 33% fish waste and 67% sisal pulp, at 16.6% TS and C:N ratio 16, resulted in the highest methane yield of $0.62m^3$ Ch_4/kg VS, an increase of 59-94% in the methane yield compared to that obtained during the digestion of sisal pulp and fish wastes at 5%TS. Biogas recovery with 60-65% methane content was recorded in the case of anaerobic co-digestion of fish waste and sisal pulp [56].

Table 7 Effect of trout daily feeding allowance (1%, 1.5%, 2% of live weight) on operational data and biogas production from up-flow anaerobic digester and ion-exchange column filled with zeolite

Parameters	Feeding Allowance 1%	1.5%	2%
Upflow anaerobic digester			
Biogas production (L day^{-1})	49.8	78.8	144.2
CH_4 content in biogas (%)	>80	>80	>80
CH_4 production (L day-^{1})	39.84	63.04	115.36
pH reduction (units)	-	0.1	0.1
Total nitrogen increase (%)	157.4	26.1	23.4
TAN increase (%)	1751.4	1093.5	1533.1
Total solid decrease (%)	92	92.7	91.2
Soluble solids decrease (%)	45.5	42.6	44.7
Suspended solid decrease (%)	99.5	98.6	96.4
Volatile solids decrease (%)	97.4	96.1	93.7
Ion-exchange column filled with zeolites			
pH increase (units)	0.5	0.5	0.7
Total nitrogen decrease (%)	87.3	89.6	89.7
Tan decreases (%)	99.4	97.7	97.3
COD reduction (%)	15	35.5	44.6

Source: Lanari, D. and Franci, C. [55]

Tuna factory energy consumption

The factory energy consumption is a significant part of the total cost of processing foods, especially at the unit operations level, such as cooling, heating, sterilizing, pasteurizing of foods, where various forms of energy may be used. The cooling and heating process are two unit operations where energy consumption is critical. Heating process is particularly import due to the requirements of having steam at different temperatures to achieve accepTable food safety levels. For example, in tuna smoking, an adequate supply of energy by steam is necessary to obtain the right temperature during the process time in order to achieve commercial sterility. Several factors make energy assessment difficult. For Example, a canned product requires unit operations such as heating, cooling, mixing, pumping, and packaging. In addition, various forms of energy in tuna factory may be used, including boiling, electricity, firewood and fossil fuels. The energy usage areas in the factory are largely divided into two categories: the production process, where the actual production takes place using production equipment and the non-processing equipment, where the equipment or utility system that functions as a part of factory's management process. The tuna factory energy consumption is shown in Table 8 are processing of cooling, cutting, boiling, smoking, packing and management, which used of 34, 15, 18, 47.61, 7 and 12 kW per ton production respectively. All consumption shown electric, diesel and firewood, only boiling process used 40 liters per ton production of diesel for boiler machine and only smoking process used 320 kilograms per ton production of firewood as consumption for dried tuna.

Table 8 Halla food energy consumption

Production Process	Energy Consumption			(per ton production)		
	Cooling	Cutting	Boiling Tuna	smoking	Packing	Management
Electric (kW)	34	15	18	47.61	7	12
Diesel (liter)			40			
Firewood (kg)				320		

Waste Management System

Waste management is the collection, transport, processing recycling or disposal and monitoring of waste materials. A typical waste management system comprises of collection, transportation, pre-treatment, processing and final abatement of residues. The purpose of waste management is to provide sanitary living conditions to reduce the amount of matter that enters or leaves the society and encourage the reuse of matter within the society [57].

A waste management concept including the following goals [58]:

1. Reduction of total amount of waste by reduction and recycling of refuse
2. Recycling and re-introduction of suiTable groups of substances into production cycles as secondary raw material or energy carrier
3. Re-introduction of biological waste into the natural cycle

4. Best-possible reduction of residual waste quantities, which are to be disposed on “suiTable” landfills

5. Flexible concept concerning fluctuations in waste quantities and the composition of domestic waste. New developments in the field of waste management must be included into the system

The initial situation of the developing country in the field of waste management differs compared to industrialized countries. [57] The transfer of proven technology from one country to another can be quite inappropriate although technically viable or affordable [58]. Very important is the need to understand the local factors such as waste characteristics and seasonal variations in climate, the social aspects, cultural attitudes towards solid waste and political institutions as well as having an awareness of the more obvious resource limitation which often exist.

The waste management system consists of the whole set of activities related to handling, treating, disposing or recycling the waste materials. The purpose of waste management system is to make sure that the waste materials are removal from the source or location where they are generated and traded, disposed of or recycled in a safe and proper manner. Campbell DJV [59] state that the system consists of several steps as tabulated in Table 9.

Modern waste management systems, which many developing countries aspired to, are all characterized by high recycling rates of clean, source separated materials. The system consists of four main parts: (a) generation e.g., waste-production, (b) collection e.g., collection systems and transport of waste materials, (c) treatment e.g., transformation of the waste materials into useful products and (d) final disposing e.g., the use of recyclable products or the placement of on-recyclable materials in landfills. Each of these steps is again comprised of several subparts.

Table 9 Components of waste management system

Main components	Subparts
Production of materials	Waste sources Source separation Internal collection Production rates Waste types
Collection and transport	Collection Transport Transfer
Treatment or reprocessing	Physical reprocessing: Shredding, sorting, compacting Thermal reprocessing: Incineration, gasification, Biological reprocessing: Anaerobic digestion, aerobic composting
Final disposition	Recycling Land filling

Source: Campbell, D.J.V. [59]

Advanced waste management systems include prioritized management strategies to minimize environmental problems and preserve resources. Waste management strategies are categorized into four areas with respect to their final disposition of the waste:

1. Minimization or prevention of waste generation,
2. Recycling of waste,
3. Thermal treatment with energy recovery,
4. Land filling.

Minimization of waste has the top priority is generally the responsibility of the waste producer.

Recycling has second priority as it results in the recovery of materials that can be used as raw materials for other purposes than the one where it was generated. When recycling began to be recognized as essential for both environmental and resource management reasons, recycling rates for household wastes in most developed countries in the 1980s were in the low single figures by percent. Modern western waste management systems have re-built recycling rates over the last 20 years [60].

Disposal options can be categorized environmental impacts into six levels, from low to high; namely, reduce, reuse, recycle compost, incinerate and landfill [61].

Collection is not an ordinary job. Waste collection methods vary widely amongst countries and regions. Domestic waste collection services are often provided by local government authorities, or by private industry. Some areas, especially those in less developed countries, do not have a formal waste- collection system [58].

Pedro, S., Moura and Anibal, T., De Almeida [62] they paper proposed a novel multi-objective method to optimize the mix of the renewable system maximizing its contribution to the peak load, while minimizing the combined intermittence, at a minimum cost. In such model the contribution of the large-scale demand-side management and demand response technologies are also considered. Demand-side management DSM and demand response DR can also have a major role, either by reduction the needs of new intermittent capacity or by adjusting the consumption in real time, to face production variations. Thus the demand consumption reduction due to the application of those technologies should be incorporated in the analysis.

Zeng Jun, Liu Janfeng, Wu Jie and H.W. Ngan [63] their paper was presents a development of the proposed a multi-agent solution MAS for the reorganization and optimization of the energy management. In this paper, four parts of the system are presented. Firstly, the Energy management system EMS in a typical Renewable Energy RE generation system is introduced and analyzed. Basic characteristics of the system components are analyzed respectively. To simplify the behaviors and situation recognition, four kinds of state are defined, which form the basis of the optimization and reorganization of the EMS. Secondly, the MAS are envisaged as the feasible solution to satisfy all the requirements of the system. The concept of the main facilitator is introduced as the executor to carry out the overall optimization. Thirdly, a framework based on JADE (Java Agent Development) is proposed in detail, including the discussion about agents, and their behaviors. Finally, a scenario case study is demonstrated and indicates that the MAS are a sui Table solution for the energy management of the distributed hybrid renewable energy generation system. From the experiment it was found that the developed system could compress biogas into a 15 kg container with 15 bar of pressure, resulting in 0.50 kg of biogas. From the further study, increasing the biogas volume by decreasing the temperature before compressing, the result showed that the tree cooling system methods could lower the temperature at 9.87, 32.07 and 30.07°C, respectively. When the biogas was compressed by 15 bars, the quantitative outcomes of each cooling system were 0.56, 0.55 and 0.54 kg, respectively. The most effective method was the cooling system using ice, which increase the biogas 12% more than the conventional method (without cooling system).

In addition to the cost of an anaerobic digester for processing of solid waste for harnessing energy, there will be the costs of (i) constructing and maintaining the plant, (ii) obtaining the feedstock and (iii) preparing the solid waste for digestion. The Process costs (i.e. capital, operating and maintenance) are extremely important in selecting the type and size of reactor [64]. The bio-kinetic and design models for the reactor will directly affect the digester's cost, particularly in terms of the digester and feedstock volumes required to yield the desired quantity of gas via batch digestion.

Steadman [65] stated that the simplest type of methane digester is just a closed container such as a drum, tank or pit in the ground into which the digestible material is loaded, that is, a batch digester. The simplicity of the batch-digester design clearly should also influence the process cost. The Oregon State Department of Energy [31], after describing three types of digesters, namely a covered-lagoon digester (i.e. a batch digester), a complete-mix digester and a plug-flow digester, stated that the batch digester was the least expensive of the three.

Biswanath Mahanty, etc [66] studied shows a scientific approach to find a practical solution to utilize diverse industrial sludge in both treatment and biogas production perspectives. The optimal biogas production and sludge treatment were studied by co-digestion experiments and modeling using five different wastewater sludge generated from paper, chemical, petrochemical, automobile and food processing industries situated in Ulsan Industrial Complex, Ulsan, South Korea. The co-digestion model incorporating main and interaction effects among sludge were utilized to predict the maximum possible methane yield. The optimization routine for methane production with different industrial sludge in batches were repeated with the left-over sludge of earlier cycle, till all sludge have been completely treated. Among the possible scenarios, a maximum methane yield of 1161.53 m^3 is anticipated in three batches followed by 1130.33 m^3 and 1045.65 m^3 in five and two batches, respectively.

Joonas Hokkanen and Pekka Salminen [67] were report on an actual application of the ELECTRE III decision-aid in the context of choosing a solid waste management system in the Oulu region, Finland, in 1993. The Electre III method proved useful, especially when dealing with environmental problems involving many decision-makers and in cases where the outcomes of the various alternatives remain to some degree uncertain. One of the main conclusions of our study is that all the proper landfill capacity available in the planning region should be used up. In addition, the energy potential of waste should be utilized within the region. Therefore, the solution recommended for a solid waste management system was intermediate landfill, composting and RFD-combustion. The decision-makers commented positively on the method used and were satisfied with the options recommended. The scheme will be implemented for use from the beginning of the year 1995.

Economic Analysis

Economic evaluation of the actual biogas plant depends on the purpose of the analysis, in what concerns the viability of biogas-to-energy project, figures like the projects capital cost, the projected energy (electricity and thermal energy) output and annual revenues from sales of the fiber fraction (compost) will be considered, while the expenses (operating costs) usually comprise of net operating cost (including feedstock costs) and financing cost. A pro-forma earnings statement, debt redemption schedule and statement of a after-tax, cash flows will typically also be prepared. Annual after-tax cash flows are then compared to initial equity investment, to determine an available return. For another perspective, before-tax, and no-debit cash flows may also be calculated and compared to the project’s total cost. The primary figures of merit are:

In economics and cost accounting, total cost describes the total economic cost of production and in made up of variable costs, which vary according to the quantity of a good produced and include inputs such as labor and raw materials, plus fixed costs, which are independent of the quantity of a good produced and inputs that cannot be varied in the short term, such as buildings and machinery [68].

Life Cycle Cost (LCC) is the total discounted (present worth) cash for an investment with future costs during its economic life.

$$LCC=CC+\sum C_n/(1+i)^n - SV/(1+i)^t \quad (3)$$

Where as;

CC	=	initial capital cost (capital, labor, overhead)
C_n	=	operating cost (O&M, fuel, tax and interest) in year n
SV	=	Salvage Value (in year t)
i	=	interest rate or discount rate (percent)
n	=	project period (in year)
t	=	year at the end of the project (year of salvage value)

Cost – Effectiveness Analysis and Cost – Benefit Analysis

Cost – Effectiveness Analysis

1. The cost-effectiveness analysis is a tool to compare the projects that have similar or equal amount of project's benefit or project's goal
2. It is a simple analysis too when it is difficult to appraise the benefit of the project
3. The goal is to find the project which presents an expected benefit at the lowest cost and the maximize benefit at the limited cost (budget)

There are two factors present as criteria for Cost-Effectiveness Analysis;

1. Present Value Cost (PVC)
2. Levelized Cost (Cost per unit)

The Present Value Cost (PVC) method of evaluating the desirability of investments can be defined as follows:

$$PVC = TIC + \sum_{n=1}^{N}\left[\frac{C_n}{(1+i)^n}\right] \qquad (4)$$

Whereas;

PVC	=	Present Value Cost
TIC	=	Total Initial Cost or Fixed cost
C	=	Variable cost
n	=	Year
N	=	Project period

Noted: The most beneficial project is the project presents less Present Value Cost (PVC)

The levelized cost presents the cost per unit of energy or power.

Cost – Benefit Analysis (CBA)

1. CBA is a tool for resource distribution / policy determination / criteria of the government for the most efficient resource use
2. Government evaluates the cost and benefit of the project from the standpoint of social welfare
3. The project evaluation for cost and benefit is done for public resources without reference of market price

There are three factors present as criteria for Cost-Benefit Analysis:

1. Net Present Value (NPV)
2. Benefit to Cost Ratio (BCR)
3. Internal Rate of Return (IRR)

Net Present Value (NPV)

Net present value (NPV) is a financial measure that ascertains the time value of money invested in a business. R.W. Grubbström [69] has show that where the economic consequences of production planning decisions need to be known then the NPV may be applied. The net present value (NPV) method for evaluating the desirability of investments can be defined as follows:

$$NPV = \frac{B_1}{(1+i)} + \frac{B_2}{(1+i)_2} + \text{———} + \frac{B_n}{(1+i)^n} - TIC = \sum_{n=1}^{N} \frac{B_n}{(1+i)^n} - TIC \qquad (5)$$

$$\text{Or, } NPV = \sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = PVB - PVC \qquad (6)$$

Where as,

B_n = Expected benefit at the end of year n

TIC = Total initial cost (investment)

C_n = Expected cost at the end of year n

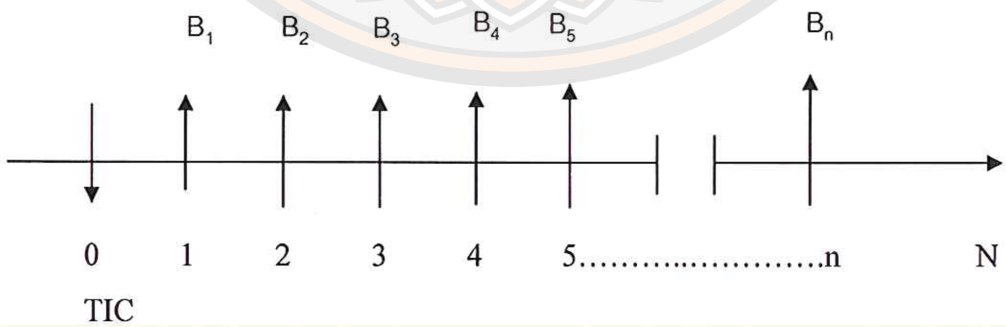
i = Discount rate, i.e., the required minimum annual rate on new investment

n = Project's duration in years

N = Project's period

PVB = Present Value Benefit

PVC = Present Value Cost



Noted: When NPV is below zero, the project is regarded as less profitable

Benefit to Cost Ratio (BCR)

This criterion, sometimes, is used in large power and water project by the ratios of the present worth values of revenues to the present worth values of costs.

This formulation gives a measure of the discounted benefits per dollar of discounted costs.

Objections of BCR are occurring for the reasons that presenting the size of competing projects (in terms of costs and benefits) are not revealed in the resultant ratios.

$$BCR = \frac{PVB}{PVC} \qquad (7)$$

Where,

PVB = Present Value Benefit and

PVC = Present Value Cost

Note: When BCR is below one, the project is considered to be in loss.

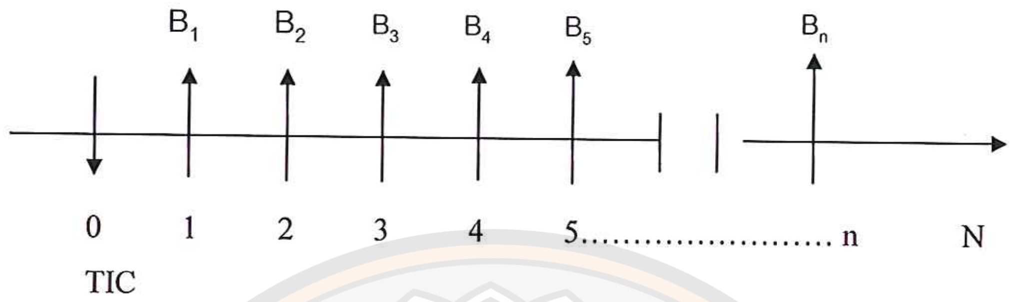
Internal Rate of Return (IRR)

The internal rate of return (IRR) is another time-discounted measure of investment worth. The IRR is defined as that rate of discount which equates the present value of the stream of net receipt with the initial investment outlay:

$$NPV = \sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = PVB - PVC \qquad (8)$$

Where, "r" denotes the internal rate of return (IRR). An alternative and equivalent definition of the IRR is the rate of discount which equates the NPV of the cash flow to zero:

$$\text{NPV} = \sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = 0 \qquad (9)$$



There are two type of Internal Rate of Return (IRR):

1. Financial Internal Rate of Return (FIRR)
2. Economic Internal Rate of Return (EIRR)

Both IRR have similar calculation methods, but have different scope for the determination of project's benefit and cost.

$$\text{Financial analysis} = \text{Profit} - \text{Loss analysis} \qquad (10)$$

The financial analysis does not consider the impact of cost. The analysis is focused on financial value such as value of money, profit and loss.

$$\text{Economic analysis} = \text{Cost} - \text{Benefit analysis} \qquad (11)$$

The economic analysis takes into consideration of the value which is not present in term of money, called "Total Economic Value (TEV)" or externality cost. The analysis is focused on social impact or any issues that relate to social and environmental impacts.

Criteria based on payback time have often been applied for selection of projects both in planned economics and in private enterprise.

In general, the payback time N is defined by equation:

$$\text{Payback period} = \sum_{n=1}^{N}(B_n - C_n) = 0 \qquad (12)$$

Note: Shorter payback period is preferable over longer payback period

Michael, A. [70] Studies the NPV method can be used for many types of decisions, especially those with revenue and expense streams over several years. Becoming familiar with the process, including the use of spreadsheet software to lay out your estimates and variables, can be an important tool in making decisions with a high dollar impact. As our industry continues to be pressured by outside influences that will decrease our profitability, the ability to make sound financial decisions on capital equipment and high-dollar programs becomes even more crucial.

Shawn, M. and Alfons, W. [71] reported on determining the appropriate criterion for assessing the financial feasibility of an anaerobic digestion investment by reviewing capital budgeting on the feasibility of anaerobic digestion. This report also show the assess breakeven point and sensitivity of the net benefits from an anaerobic digestion in the changing in electricity price, electricity yield, capital costs, annual cost, real discount rate, investment period and Ontario' standard offer electricity prices.

Thomas, P. and Maria, L. [72] Present financial analysis is one part of evaluating the feasibility of an energy consumption plan. As outlined in this chapter, beyond consideration of NPV, IRR and payback period analysis both qualitative and quantitative externalities resulting from the installation of PV systems must be considered to complete the financial analysis includes all factors present during the life-cycle of a PV system. These factors include, but are not limited to, the financing structure terms, investment costs, available incentives, utility energy costs and externalities. Proper application of financial analysis to determine the financial feasibility of a PV system provides a critical portion of the overall due diligence procedures in implementing a PV system.

T. Dolan, M.B. Cook and A.J. Angus [73] This paper, through the use of cash flow modeling, investigated whether financial viability was the limiting factor to adoption of AD in the UK. The criterion of choice to indicate financial viability was an IRR of 15%, which was agreed in consultation with waste management experts: those who decide whether or not to invest in AD technology. The results showed that AD derived biogas together with economic incentive payments can produce financially viable IRRs. However, the IRR achieved is significantly influenced by available economic incentive payments.

CHAPTER III

RESEARCH METHODOLOGY

Biogas Production setup and measurement

Anaerobic reactor setup and feeding strategy

At laboratory, batches of experiments were conducted with anaerobic digestion system that designed to support experimentation system for tuna factory as presented in the following Figure:

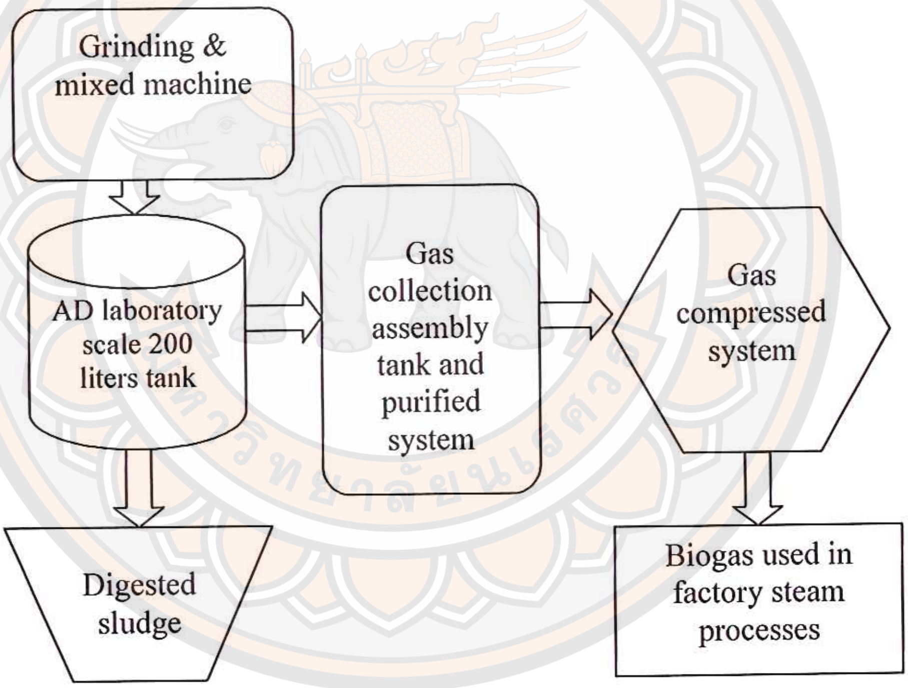


Figure 11 Anaerobic digestion experimentation system capacity 150 litters for tuna factory waste

1. Grinding and mixing machine

Wastes grinding and mixing is a process in which stringy and large material contained in tuna factory solid waste is cut and mashed into small particles to prevent clogging or wrapping around horizontal rotation equipment in the AD tank. The stainless steel grinding and mixing uses motor 1 Hp 220 V, capacity volume of 40 liters with 4 cutters. The wastes grinding and mixing machine is as shown on Figure 12.

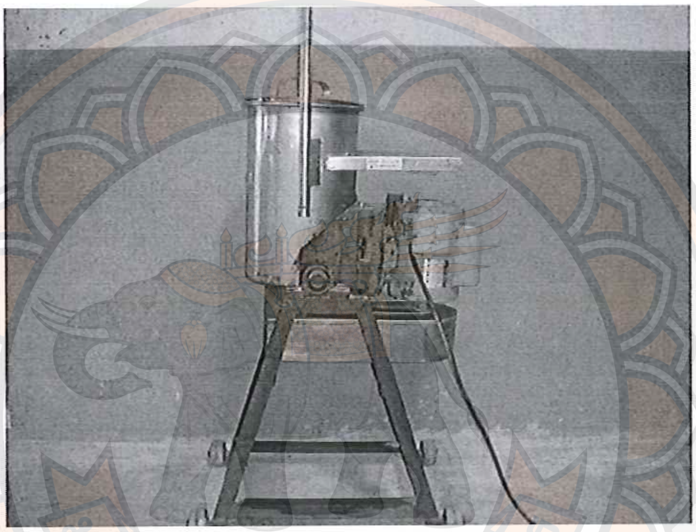


Figure 12 Grinding and mixing machine

2. Anaerobic digester laboratory scale tank

The anaerobic digestion laboratory scale tank was made of modified polyethylene buckets. The total volume capacity of the tank was 200 liters while the effective volume of the digester was 150 liters. At the top of the bucket was sealed with a gasket and covered by bucket cover. The covered was installed a waste feeding pipe and a sleeve pipe for a mixing shaft insertion. The mixing shaft was designed by using 95 cm. length of PVC pipe (1 inch in diameter) joined with bucket cover as a horizontal, circular mixing paddle. The waste feeding pipe was made of 2 inch in diameter of PVC pipe with the length of 65 cm from the cover of digester tank. Gas outlet was installed at the approximately 15 cm. length from the cover, located at the side of the digester tank. The Reactor had two outlets that located at the bottom of tank for effluent waste removal and the other one was installed at 20 cm. below the tank cover for effluent over flow out. The Anaerobic digestion lab scale tank was shown on Figure 13.

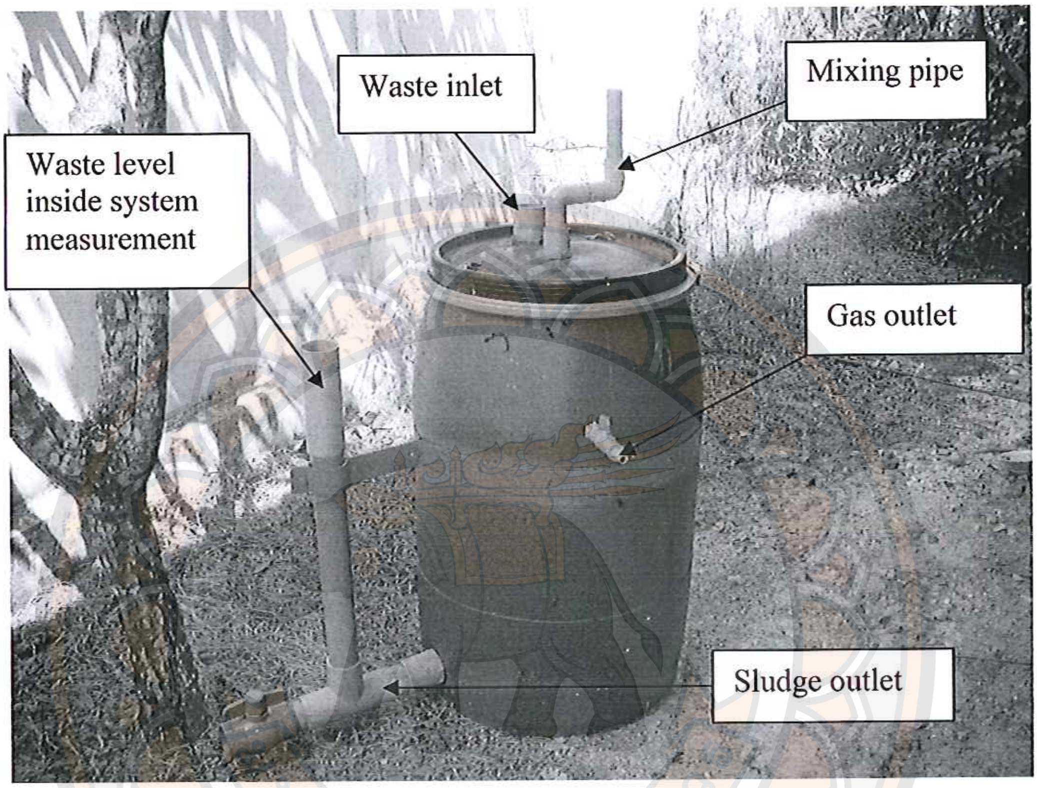


Figure 13 Anaerobic digestion laboratory scale tank (capacity 150 liter)

3. Gas collection assembly and purified system

All cumulative biogas productions were measured using the liquid displacement method. A set of 3 collections assembly tank of 200 liters capacity were created to support the experiments as shown in the Figure 14. The gas from digestion tank was vented to a pipe line and the system was designed to run under a vacuum. This assembly tank made of polyethylene bucket of 200 liters capacity and combined with 150 liters polyethylene bucket that placed upside down in the 200 liters bucket, and installed 3 pipes connectors for each set of assembly tank.

A tank of 150 liters full of water will be floating when the gas is being produced and overflowing the tank space and pressuring the water that causing the tank to float. This sensation can be used as an indicator of gas production that enables to be recorded.

In addition, the iron fibers were used as an oxidizing agent that produced ferrous sulfide precipitates in proper climate conditions in which iron sulfide could be oxidized by air as reusable iron oxide. The hydrogen sulfide gas was removal by iron fibers purifier system was show on Figure 15. The biogas upgrading system was developed which run the biogas through an iron fibers, used 4 inch diameter 6 inch long PVC tube and finally sent into the biogas compressor in Figure 16.

Figure 14 The 3 Collection assembly tank

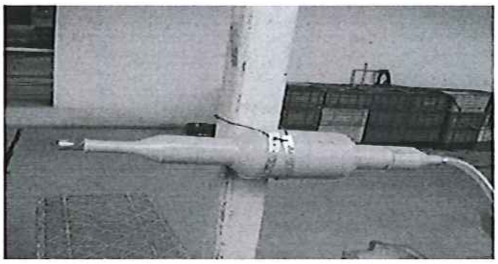


Figure 15 Iron fibers purifier system

4. Gas compressed system

The gas compress system is using of electric power to run the motor. The concept of this research aims to compress of the excess biogas produced from tuna factory waste into a container (15kg LPG container tank) as shown on Figure 17, for easy storage and movable container for factory use to replace diesel used in the steam production process.

Figure 16 Gas compressed system

Figure 17 Bio gas storage tank

Wastes and inoculum

1. Tuna factory waste in this study consist of head, viscera, fin, bone and skin collected from Halla Food (Thailand) Co., Ltd in Rayong province Thailand. The factory produce tuna waste between 1,000 kg to 2,000 kg per day depending on their production process and requirements. Tuna waste samples were homogenized by grinded and stored for biogas process.

2. Banana tree crop residue used in co-digestion experiment was from tuna factory's farm and nearby farm. The banana tree crop residue was homogenized by grinded, stored and mixed with grinded tuna waste for biogas process.

3. The Inoculum using native banana roots microorganism (NBRM), the microbial community was found in the native banana roots were bacillus sp., lactic acid bacteria, acetic acid bacteria and fungi such as yeasts and molds [74].

Experimental set-up for biogas studies

Experiments were carried out with mixture of five set of different ratios of tuna waste and banana crop residue ratios (TW: BCR ratios) namely 1:1, 1.5:1, 2:1, 2.5:1 and 3:1 respectively. The proportion ratio of fish waste and banana tree crop residue co-digestion as shown on Table 10. The total of material in the digestion system was 60 liters. And these batch experiments reactors were operated under mesophilic conditions of temperature between 29°C to 35°C. The experiments were conducted by adding in proportions of 90 liters inoculum, and 60 liters substrate. The inoculum was kept inside the digester for 7 days, at temperature 35°C, until the microorganisms attained a high growth rate of biogas, as indicated on the gas production, then the 5 substrate ratios of co-digestion (the grinded material) were added in the chamber and stirred.

The influences of waste ratios were interpreted from the 30 days-cumulative methane production data. After the process completed, the slurry is drained and analyzed for its quality fertilizer.

Table 10 Mixture of waste proportion ratio of fish waste and banana tree

(weight/kgs)

Waste proportion	Co- digestion				
	1:1	1.5:1	2:1	2.5:1	3:1
Tuna solid waste	30.00	36.00	40.00	42.86	45.00
Banana tree crop residue	30.00	24.00	20.00	17.14	15.00
Total waste	60.00	60.00	60.00	60.00	60.00

Measuring equipment

The measuring tools are thermometer, pH meter, gas sampling bag and pressure gauge.

1. Two thermometers were installed in each anaerobic digester tank, located in the bottom and in the middle of the tank for data recording.

2. The pH meter is used for checking pH value of the digested sludge.

3. The pressure gauge was installed at the gas compressed system to measure the gas pressure in the gas storage tank.

4. Gas sampling bags were used to collect the biogas sample from the reactor to be analyzed at the laboratory.

Chemical analytical of feedstock and effluents

1. Characteristics of co-digestion of tuna factory waste and banana crop residue The tuna waste and banana crop residue were collected as samples for further analysis of its physical and chemical characteristics. These characteristics were pH, COD, TKN, TS, VS, Ammonia nitrogen content, Total Alkalinity, VFA, and C:N by according to standard methods. The methods of analyzing of each parameter were summarized in the Table 11.

Table 11 Tuna waste characteristics analytical parameters and methods

Parameters	Methods/Equipment	Unit
1. pH	AWWA 2012 Part 4500-H^+ B.	-
2. COD	AWWA 2012 Part 5220 C.	g/l
3. Total Kjeldahl Nitrogen (TKN)	AWWA 2012 Part 4500-N_{org} B	g/l
4. Total Solids (TS)	AWWA 2012 Part 2540 B.	g/l
5. Total Volatile Solid (TVS)	AWWA 2012 Part 2540 G	g/l
6. Total Alkalinity	AWWA 2012 Part 2320B	g/l
7. VFA	Titrimetric method	g/l
8. Ammonium-N	Titrimetric method	g/l
9. C:N	Manual on Organic Fertilizer Analysis, APSRDO,DOA:4/2551	-

2. Characteristics of slurry in the digester

In each day of biogas production process, the slurry from each digester was analyzed for pH and temperature records, while other physical and chemical parameters (COD, TKN, TS, TVS, Total Alkalinity, VFA, and Ammonium-N) were measured on every 3 days.

3. Gas measurements

Biogas production was measured by the volume displacement method. The percentages of methane (CH_4), carbon dioxide (CO_2) and other gas were determined by gas chromatography (GC). Gas chromatography is the most popular instrument to be used for such process that has several advantages such as high resolution, high speed, high sensitivity and good quantitative results.

4. Characteristics of biogas by-product

After 30 days of anaerobic co-digestion process, the sludge of each ratios was taken to be analyzed for its characteristics, as organic fertilizer, APSRDO, DOA: 4/2008 method.

Table 12 Analysis of biogas by-product

Component	Unit
Total Phosphate (P_2O_5)	g/100g
Total Nitrogen (N)	g/100g
Potassium (K_2O)	g/100g
Calcium (Ca)	g/100g
Magnesium (Mg)	g/100g
Iron (Fe)	g/100g
Manganese (Mn)	g/100g

Economic analysis

The economic analysis of this project is one of the most important elements for tuna industry to analyze its benefits to the factory and to the environment as well as to decide on the investment for biogas production plant. The methods used to measure the economic benefits are as follows:

Cost-Benefit analysis (CBA) estimates and totals up the equivalent money of the benefit and cost to the project to establish whether they are worthwhile. If the discounted present value of the benefit exceeds the discounted present value of the cost then the project is worthwhile. This was equivalent to the condition that the net benefit must be positive. Another equivalent condition is that the ratio of the present value of the benefits to the present value of the cost must be greater than one.

1. Net Present Value (NPV) in equation (5) or (6)

NPV of project was calculated from the present value of costs and benefits over the project life. The project having NPV more than zero (0) that project were economics.

2. Benefit to Cost Ratio (BCR) in equation (7)

BCR was an indicator that attempts to summarize the overall value of money of the project. All benefits and cost should be expressed in discounted present values.

3. Internal Rate of Return (IRR)

Internal Rate of Return was used to provide calculator on cash flows. IRR formula is “if NPV=0 then IRR=Discount Rate” mean NPV was equaled to zero, then the IRR was equaled to the discount rate.

4. Payback Period (PB) in equation (12)

Payback period was presented the length of time that required recovering capital cost of investment to recover its initial cost.

Assumption of the biogas financial feasibility analysis of the laboratory scale project data was constant throughout the project show in Table 13. The assumption of the biogas financial feasibility analysis consists of project life 10 years with the discount rate of 5% was reference from minimum loan rate (MLR) for corporate clients were entrepreneurs, the interest rate of Bank for agriculture and agricultural co-operatives (BAAC). The interest rate was effective from 20 April 2011 onward. Employee was constant 1 people working as one month wage. The management including of electricity, water supply and management salary cost constant throughout the project. Maintenance cost at 5% of initial investment cost constant throughout the project. Repair cost at 1% of initial investment cost constant throughout the project. The cost ratio was constant throughout the project and rate of return constant throughout the project.

Table 13 Assumption of the biogas financial feasibility analysis

	Assumption of the biogas financial feasibility analysis	Reference
1.	10 years project life time	
2.	5% discount for interest rate constant throughout the project	MLR of BAAC (effective on 20 April 2011 onward)
3.	Employee is constant 1 people	Government announced the minimum wage at 300 baht start from 1 January 2013
4.	Management included electricity and water supply cost constant throughout the project	
5.	Maintenance cost 5% of initial investment cost constant throughout the project	
6.	Repair cost 1% of initial investment cost constant throughout the project	
7.	Cost ratio constant throughout the project	
8.	Rate of return constant throughout the project	

The cost of 200 liters biogas equipment is shown on Table 13 above. The biogas 200 liters laboratory scale digester tank of 150 liters capacity as shown on Figure 13 is cost 1,645 baht, while the 3 collection assembly tank as shown on the Figure 14 is cost 3,050 baht, the biogas compression system for compress in to the storage LPG gas tank is cost 6,485 baht, the storage system used LPG gas tank of 15 kg. is cost 900 baht/tank, the grinding machine is cost 5,000 baht, and the biogas burner system to boiled water for tuna factory boiling production process is cost 1,200 baht.

The assumptions for financial and economic assessment including: Benefit and Cost Ratio (BCR), Net Present Value (NPV) and Internal Return Rate (IRR).

Table 14 Cost of 200 L Biogas Equipment

Description	Price (Baht.)
Digester tank	1,645.00
Gas holder tank (3 tanks)	3,050.00
Biogas compression system	6,485.00
Storage system (LPG gas tank of 15Kg)	900.00
Grinding machine	5,000.00
Biogas burner system	1,200.00
Total 200 L biogas equipment price	18,280.00

Tuna factory waste management

According to the average of data collection of 2 years from Halla food factory tuna solid waste was average of 13,451 kgs/month in year 2010 and 16,466 kgs/month in the year of 2011. During the year of 2010 and 2011 the average of tuna solid waste disposal were 672kgs/day and 823kgs/day respectively. The record has shown that the tuna solid waste volume is inconsistent. The tuna solid waste in the usual management was delivery to the animal food factory and fertilizer factory, the distant to deliver the tuna solid waste was 100 km far from the tuna factory. To deliver the tuna solid waste the factory need to transport by truck with was consume diesel as transport energy to deliver to dispose. The tuna factory production process and waste management in business as usual (BAU) scenario was shown below in Figure 18.

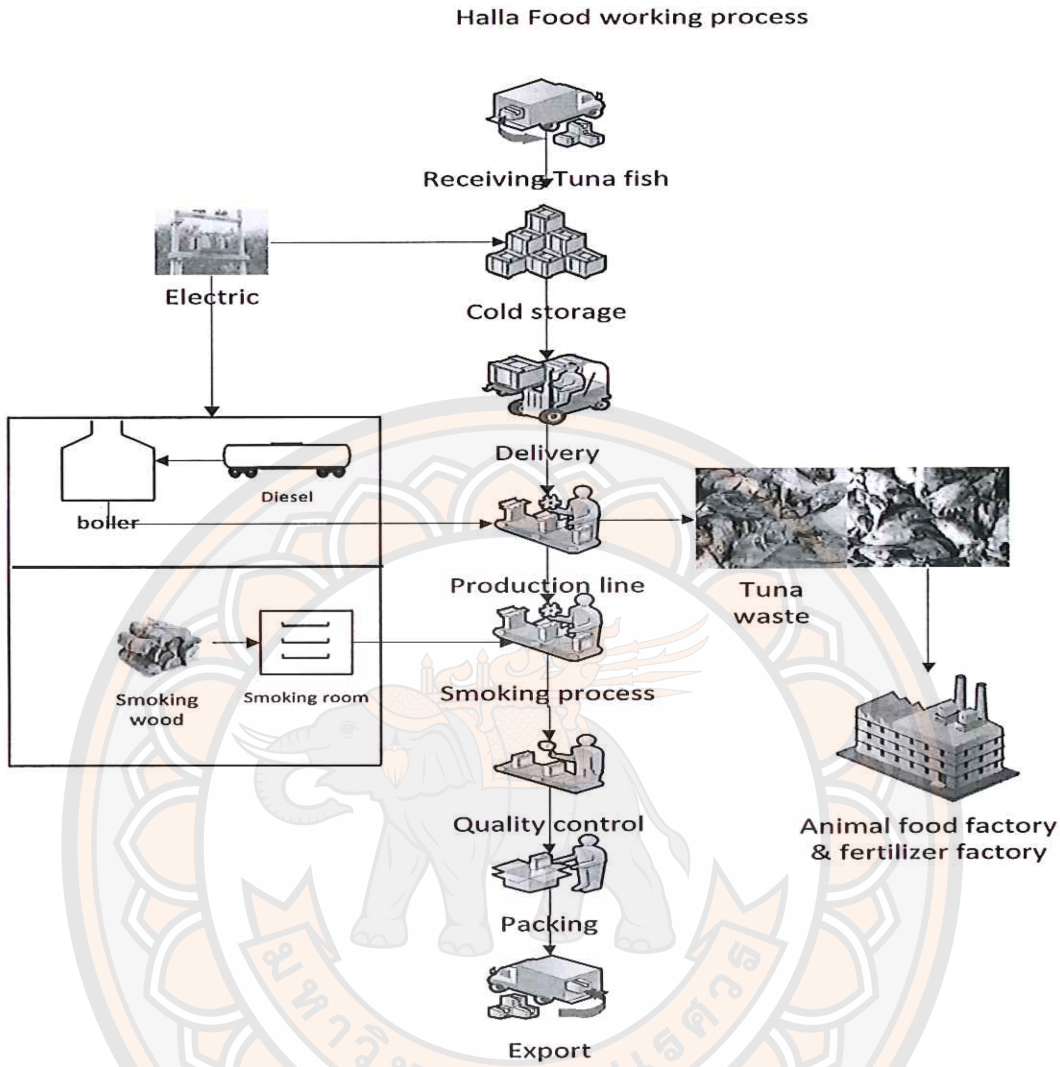


Figure 18 Tuna factory production process and waste management in business as usual (BAU) scenario

The anaerobic co-digestion of tuna solid waste of Halla food factory should adopt 4M the management theory (Man, Management, Money and Material) in managing the semi-continue biogas production system.

Man or man power is required to manage day to day operation of the waste management and biogas production.

Management in this theory is to manage the waste and to convert it into useful substance like biogas and fertilizer. Management is a core element in the whole process of waste management and biogas production management, from waste collection, biogas production, gas storages and use of biogas as renewable energy to power the factory and ultimately achieve the sustainable energy for the factory.

Money in this process is required to pay for the man power and other cost for biogas production and waste management. However, money also generated from the biogas production as a result of selling the by products like high quality fertilizer. Money is also saved as the biogas is produced, as biogas is used to power the factory to replace the fossil fuel.

Material in the biogas production is collected from the waste generated from the factory production. Thus it's available within the factory. The co-digestion material, banana crop residue is bought from the tuna factory farm or nearby farm, and it's easily to be found and available within short distance. The factory waste data that collected from Halla Tuna factory is shown on Table 26 and Table 27.

The management is designed to use waste from production process of tuna factory. In implementing the pilot scale, the management designed biogas production system from tuna factory waste based on the above data collection to install the semi-continue anaerobic co-digestion system for biogas production.

The laboratory scale of semi continue anaerobic co-digestion at working capacity of 150 liters was installed with 2:1 ratio as it's the most optimal ratio based on the previous experiments. The result of the experiments of semi continue anaerobic co-digestion at the laboratory scale will determine the pilot scale production system that will formulate the calculation of OLR (Organic Loading Rate) at 2.18 g COD/l d with HRT (Hydroulic Retention Time) of 10 days, OLR at 3.63 g COD/l d with HRT of 6 days and OLR at 7.26 g COD/l d with HRT of 3 days for the waste management and biogas production system. Based on each condition mentioned above, the test has been carried out and operated 2 times of the duration of the HRT to ensure that steady state conditions were reached. The reactor was operated with a withdraw/feed method. The optimum result of semi-continue will be proven as tuna factory waste management systems for biogas production, which support tuna factory wastes treatment conversion to renewable energy.

The management in this research is aimed to efficiently use biogas as renewable energy that generated from tuna waste in tuna factory production process, and to improve the biogas production process by converting the waste into valuable energy and byproducts that may lead to zero solid waste of the tuna factory, that it's not only improving the factory's hygiene standard, but also to increase the factory waste's value.

The management design specifically links and relates biogas usage in production output, aimed at achieving the required level of output with the minimum consumption of diesel fossil energy and maximizing the consumption of biogas as renewable energy. The essence of management design is to measure regularly the consumption of fossil energy and relate them to production renewable energy output. Production process present a demand side of factory's energy system therefore, production processes set the requirement for energy quantity and quality. Energy performance must be evaluated and improved on:

Biogas energy production ==> how efficiently the raw material is processed into energy product.

Energy used in production ==> how efficiently input energy was used in the tuna fish factory process and how optimal the production and the use of biogas produced by tuna factory to replace the fossil fuel.

CHAPTER IV

RESULTS AND DISCUSSION

In this chapter, based on the purpose of the study, the main objective is consist of 3 main parts, such as to produce biogas by co-digestion of tuna solid waste and banana crop residue, to analyze economic benefits of biogas steam production from tuna factory waste and to create Tuna factory waste management system for biogas production, that support tuna factory waste treatment that resulting a conversion of the factory waste into a useful substance, such as biogas and high quality fertilizer.

Biogas daily production and consumption

According to the experiments of biogas production on the co-digestion of tuna solid waste and banana tree crop residue for a period of 30 days process, at the ratios of 1:1, 1.5:1, 2:1, 2.5:1 and 3:1 respectively, and operated in between 30-35°C around mesophilic condition (25-40°C), the results from 150 liters biogas laboratory scale are as follows:

1. Feedstock characteristics

The analyzed compositions of tuna solid waste and banana crop residue are shown in Table 15. Tuna solid waste contained 97.13 g/l TS with 88.43 g/l VS. The TKN concentration and ammonium-N content in tuna solid waste were 17.80 g/l and 9.24 g/l respectively. The COD content of tuna solid waste was 70.85 g/l, pH was 6.2, total alkalinity was 33.21 g $CaCo_3$/l, VFA was 25.08 g COD and C:N ratio was 2.95. The banana crop residue contain 28.74 g/l TS with 11.47 g/l VS. While COD content was 18.89 g/l, pH was 5.2, total alkalinity was 0.48 g $CaCo_3$/l, VFA was 2.70, C:N ratio was 53. The TKN concentration and ammonium-N content in banana crop residue were only 2.78 g/l and 0.09 g/l respectively.

Table 15 Chemical compositions of tuna solid waste and banana crop residue

	Tuna solid waste	Banana crop residue
pH	6.2	5.2
COD (g/l^{-1})	70.85	18.89
TKN (g/l^{-1})	17.80	2.78
TS (g/l^{-1})	97.13	28.74
VS(g/l^{-1})	88.43	11.47
Ammonium-N (g/l^{-1})	9.24	0.09
Total Alkalinity (g $CaCO_3$ l^{-1})	33.21	0.48
VFA (g COD^{-1})	25.08	2.70
C:N	1:2.95	1:53

2. The relationship of the pH and the process time

The pH was a control parameter during the anaerobic digestion of biogas production. The finding in 5 reactors that run without adjustment of pH inside the reactors, were some increase of pH value during the process, as per recorded was in the range of 5.7 to 8.4. The pH profiles at various digestions on Figure 19 showed that the pH value during the 30 days of operation were on average of 7.51, 7.51, 7.50, 7.60 and 7.56 respectively, while according to Barnes and Bliss [75] the performance of co-digestion process in pH range between 6.5 to 7.5 is found to be the best and the most optimum. The value indicated that the digester is working at optimum rate for methane formation when it was not under inhibitory conditions. Methane production usually terminates with the digester pH drops below 6.0.

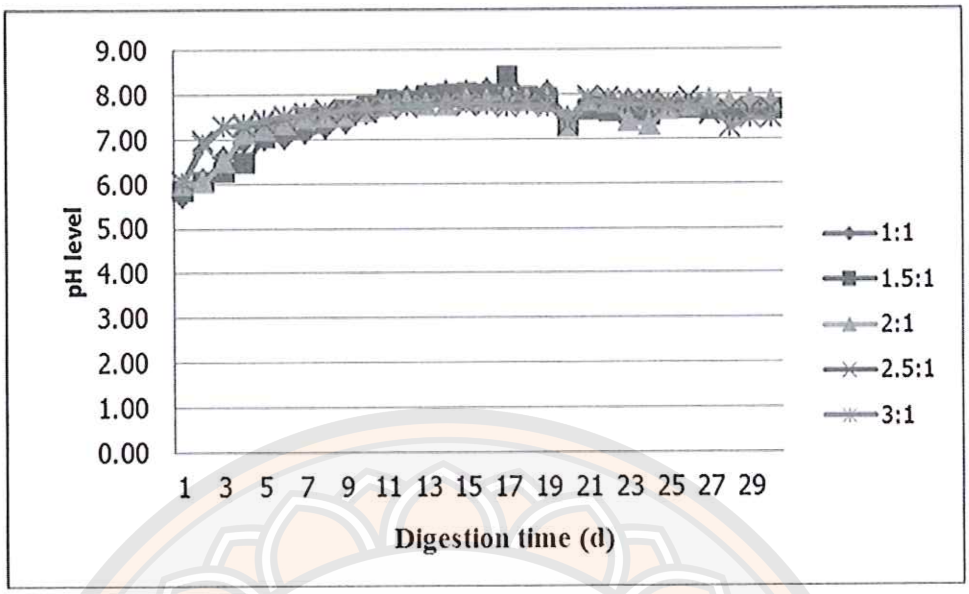


Figure 19 pH profiles at various digestions

3. Chemical Oxygen Demand (COD)

The Figure 20 showed the COD evolution in meshopholic digestion of different ratios at the start up process it showed 45.2, 49.19, 64.64, 58.24 and 60.14 g/l respectively. During the 30 days process, the effluent of COD removal efficiency of 5 ratios were 41.39%, 45.77%, 56.72%, 50.82% and 34.30%respectively. The most efficient ratio was 2:1 in which the COD at start up process was 54.46 g/l that after 30 days process was reduced to 23.57g/l.

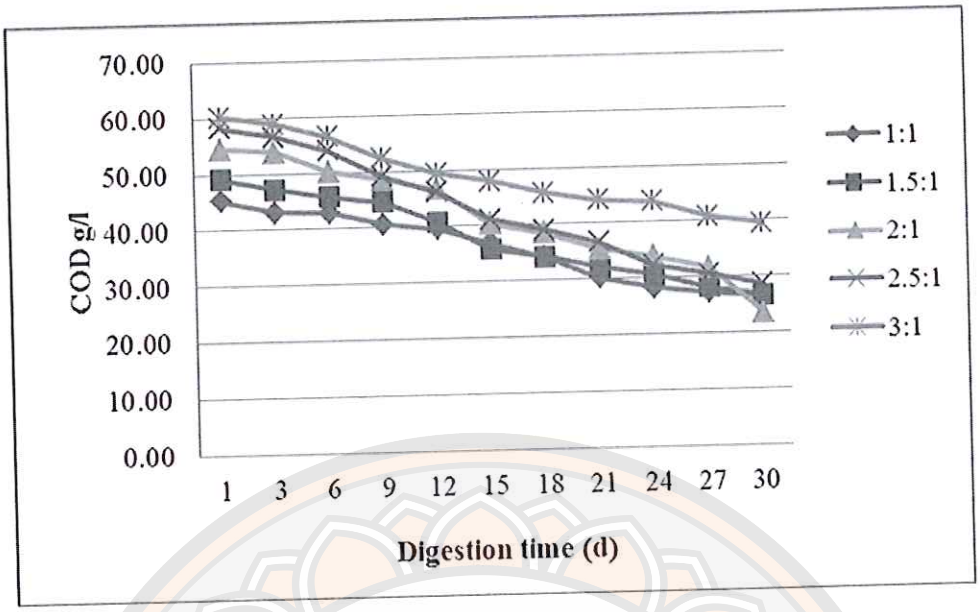


Figure 20 COD profiles at various digestions

4. Total Solid (TS)

The total solid was important parameter as it is able to help to determine the characteristics of co-digestion's sludge. The TS were used to determine the loading rate of the anaerobic digestion and give clues as to when the maintenance is needed. The TS content found was in the range of 66.43, 68.65, 73.86, 75.27 and 81.61 g/l respectively. As comparison to this study, Chen, et al. [76] reported his fish waste had a lower TS content (55.8%) and VS/TS ratio (0.982) in his experiments. In addition, in this study the TS content of the fish waste silage decreased when the banana crop residue was mixed. The TS content result of 30 days process is as per shown on Figure 21.

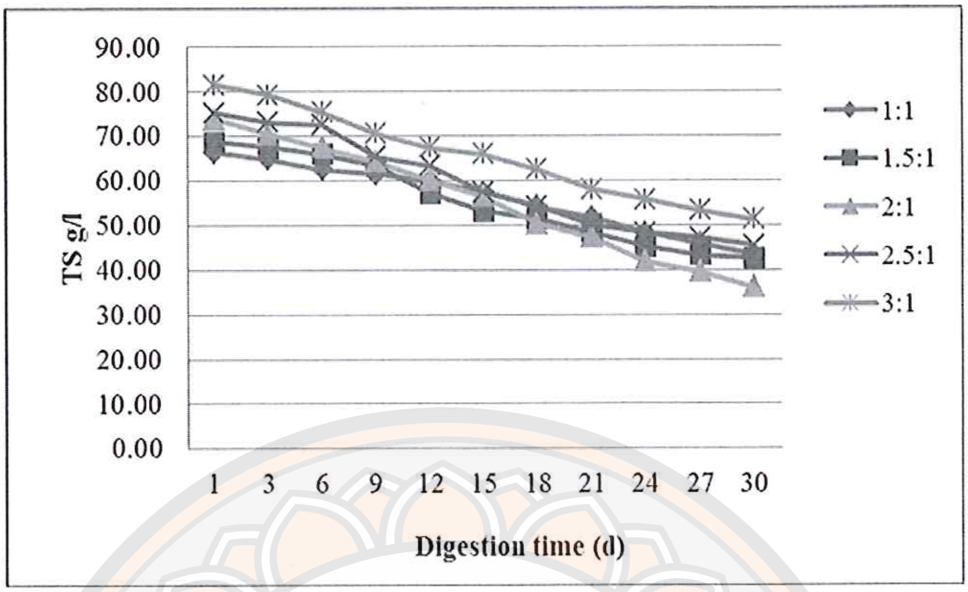


Figure 21 TS profiles at various digestions

5. Volatile solids (VS)

The Volatile solids (VS) were provided to measure of the organic matter content of the co-digestion wastes. The amount of wastes influent being loaded and the percentage of VS of the waste are measured with the digester's organic loading rate at 150 liter (influent mass per time). The different between the VS concentration in the influent and the effluent indicates the percentage of the waste is stabilized (removed) through the co-digestion process. The VS content at the starting of the digestion was in the range of 55.40, 57.63, 64.94, 68.65 and 71.70 g/l respectively. The VS content at effluent were in the range of 31.24, 32.85, 29.76, 35.70 and 37.29 g/l respectively. That means it decreased by 43.61%, 43%, 54.17%, 48% and 47.99% respectively. The most VS reduction as in the ratio of 2:1 found to be producing the highest biogas production. The VS profiles at various digestions were shown in Figure 22.

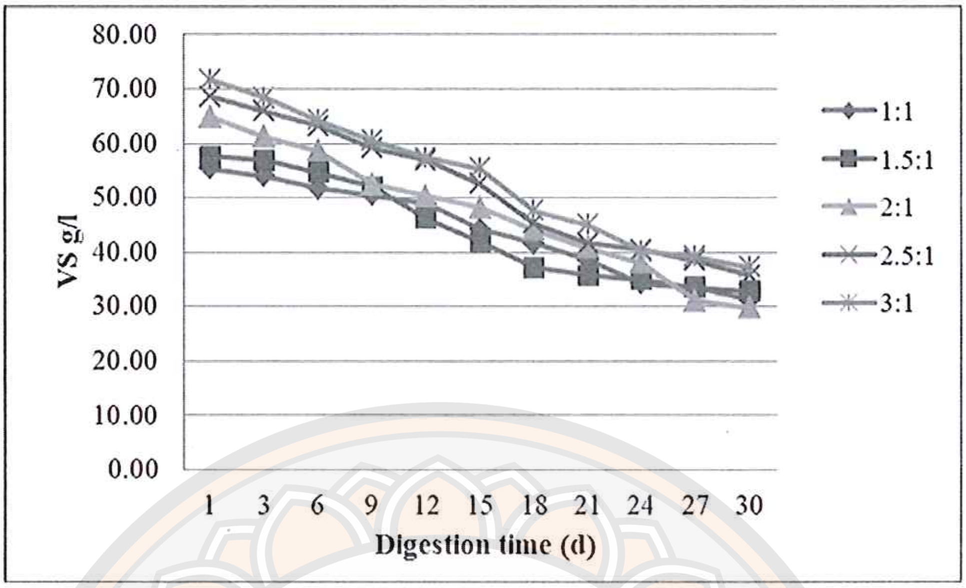


Figure 22 VS profiles at various digestions

At the starting of digestion process shown the constant characteristics, in which the higher of VS stabilized, the lower of the VS found in the effluent and the greater the reduction of odors. The extent of the organic matter stabilization primarily depends on the co-digestion system configuration and the substrate's physicochemical characteristics. The percentage of VS removed in the manure is in the range of 30-42% [77], in the systems co-digestion manure and additional high-strength substrates, the percentage of removed waste is typically higher, but the magnitude varies according to the co-digestion material.

6. Total Alkalinity and VFA

As one of the processing performance indicator, the VFA concentration is probably the most sensitive parameter to monitor. When the VFA is under an inhibitory condition, the co-digestion process may lead to a system failure. VFA is required in a small amount as an intermediary step for the metabolic pathway of methane production by the methanogens [78]. The result in Table 23 was shown the alkalinity and VFA ratio during the co-digestion in the reactors of the 5 different ratios. The VFA/ alkalinity ratios at effluent value were found in the range of 0.42, 0.38, 0.42, 0.52 and 0.51 respectively, thus indicating that the process operated favorably without the risk of acidification [79].

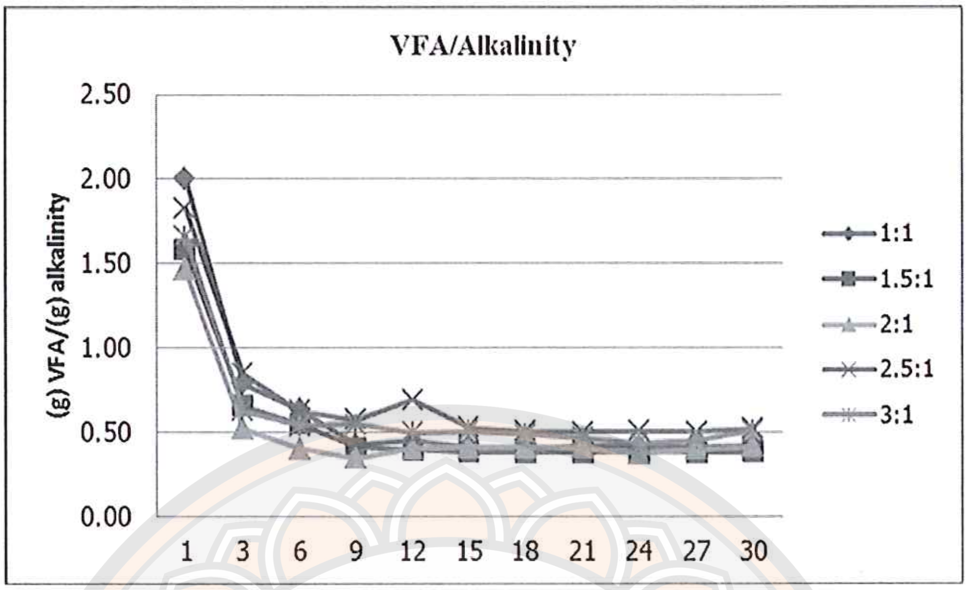


Figure 23 Total Alkalinity and VFA profiles at various digestions

7. Biogas production

The biogas production is probably the most important parameter to monitor the anaerobic digesters. Biogas is almost completely composed of methane gas, carbon dioxide gas and also including other gases. The ultimate biogas yield of the 5 ratios experiments, plotted was shown in Figure 24. The 30 days biogas production yield of each ratio were 2581, 2377, 3401, 2695, and 2638 liter respectively as shown in Figure 24. The daily biogas production for different ratio was shown in Figure 25. The highest biogas porduction was in the ratio of 2:1 at 3401 liter, whereas the production start from day 2 with 42 liter production, and the highest daily production was 149 liter on day 17. As shown in Figure25, the trend of daily biogas production with ratio of 2.5:1 and 3:1 were similar. If the biogas production dropped below the average daily values, it is most likely that the other indicators, as discussed above, may have changed as well, and it is a strong indication that the digester process was upset.

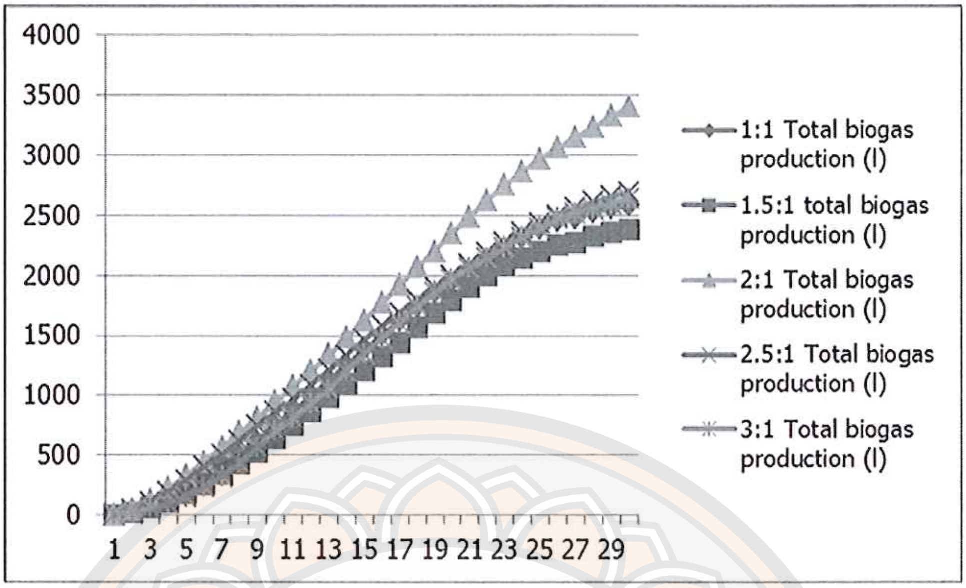


Figure 24 Biogas productions at various digestions

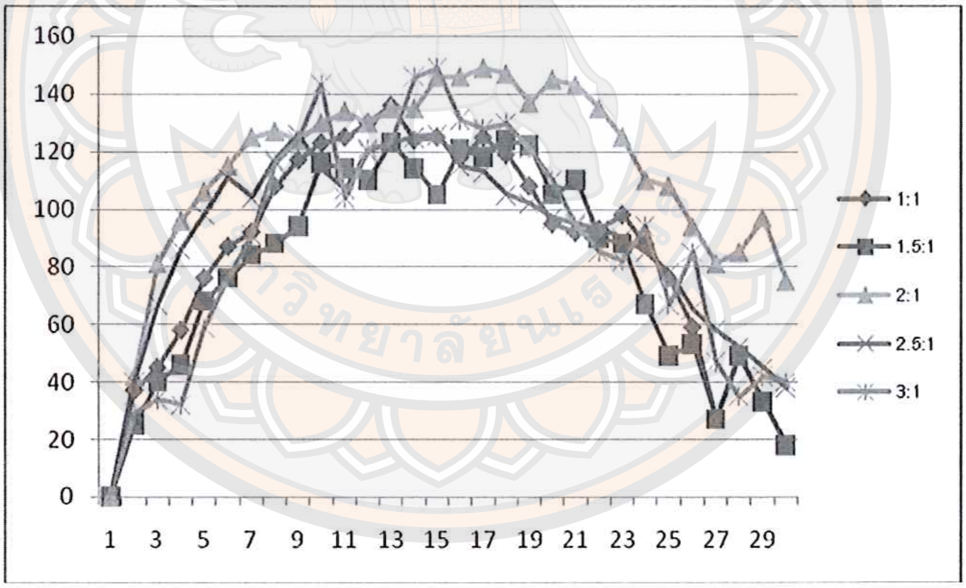


Figure 25 Daily biogas productions

8. Biogas characteristic

The biogas production was measured by the percentages of methane (CH_4), carbon dioxide (CO_2) and other gases were determined by gas chromatography (GC). The methane production is the final product of anaerobic digestion process. It's a measurement on how well the digester process was performed. The amount of the methane production during the digestion process was directly related to the amount of organic matter (VS) that has been removed (destroyed). The more important thing, the more methane is produced, the more renewable energy can be generated. The detail of the biogas analysis methane gas and other gas was shown in Table 16.

Table 16 Analysis of biogas components

Component (Mole %)		1:1	1.5:1	2:1	2.5:1	3:1
Methane	(CH_4)	51.20	52.35	55.51	52.18	53.43
Carbon Dioxide	(CO_2)	44.61	43.47	40.25	43.28	42.33
Nitrogen	(N_2)	2.19	2.24	2.16	2.54	2.21
Other		2.00	1.94	2.08	2.00	2.03

According to Table 16 the biogas components shown the result of 5 laboratories at the ratio of 1:1, 1.5:1, 2:1, 2.5:1 and 3:1 Methane (CH_4) were 51.2%, 52.35%, 55.51%, 52.18% and 53.43% respectively, The Carbon Dioxide (CO_2) were 44.61%, 33.47%, 40.25%, 43.28% and 42.33% respectively and The Nitrogen (N_2) were 2.19%, 2.24%, 2.16%, 2.54% and 2.03% respectively. The other gases were found in between 1.94% to 2.08%. The methane yield from the 2:1 ratio was the most optimal.

9. Biogas storage and used

Biogas was compressed in the 15 kg LPG tank by a 3HP electrical motor generator pump. The time used to compressed biogas was10 minute with the pressure of 150 psi, that can be consumed to power the stoves for 44.30 minutes to boil the water using tuna boiling pot. The relationship of the various parameters in the thermo dynamics can be calculated as the mass of biogas m=4.84 kg. And the measurement of thermo dynamics found that the pressure inside the gas tank P = 413 kPa. The biogas was stored in the 15 kg LPG tank before being sent to the tuna production process to be utilized.

10. Biogas by-product characteristics

The Biogas by-product was analyzed as a fertilizer that the result found nitrogen (N) 3.43%, Phosphate (P_2O_5) 4.31%, potassium (K_2O) 0.36%, Calcium (Ca) 0.38%, magnesium (Mg) 0.02%, iron (Fe) 0.28% and manganese (Mn) 0.6% (the laboratory results shown in Table 17). At the laboratory scale, the biogas's by-product, which is fish emulsion for fertilizer material was produced of140 liters in each batch. The current price of bio-fertilizer from marine fish is 25 baht per liter as ex-factory retail price.

Table 17 Characteristics of fertilizer (biogas by-product)

Component	Unit	
Total Phosphate (P_2O_5)	4.31	g/100g
Total Nitrogen (N)	3.43	g/100g
Potassium (K_2O)	0.36	g/100g
Calcium (Ca)	0.38	g/100g
Magnesium (Mg)	0.02	g/100g
Iron (Fe)	0.28	g/100g
Manganese (Mn)	0.60	g/100g

Energy output from waste

The comparison of equivalent energy and cost of biogas 1m^3 is shown on Table 18. The main component of biogas is 50-75% methane which is flammable gas, so it can be used as renewable energy. In addition, the biogas also includes carbon dioxide gas approximately 36-39% which is inflammable gas, so the property of biogas is depending on the amount of the methane gas. The laboratory scale of 2:1 ratio produced the most biogas during the production that 3,403 liters was produced, and its obtained the methane gas of 55.51% and 4,626 kcal, that equal to diesel amount of 0.55 liter, in which accounted for 16.49 baht/1m^3. The biogas production generated from the tuna waste and banana crop residue waste of 60 kg was 3,403 liter that equals to 56.11 baht or 1.87 liters of diesel. 1 liter of diesel price was approximately 29.99 baht.

Table 18 Comparison of equivalent energy and cost of biogas 1m^3

1m^3 biogas composed methane 60% Equivalent energy	Unit	Estimated cost (Baht) (estimated on Dec. 2012)
Firewood	3.47 kg	3.47
Charcoal	1.40 kg	3.86
Petrol	0.80 liter	35.00
Diesel	0.52 liter	15.59
Kerosene	0.62 liter	21.95
LPG	0.46 kg	9.20
Electricity	4.70 kWh	16.45

Analysis of Economic Value

The method used to collect data in this study was data collection from Halla Food (Thailand) Co., Ltd. and it described the results that obtained from the biogas productions analysis by using a computer program (Microsoft Excel). The information collected was divided into 5 ratios, in which at laboratory scale of co-digestion 1:1, 1.5:1, 2:1, 2.5:1 and 3:1 ratio respectively. The total cost of laboratory scale consists of 3 major costs, i.e.: the investment cost, the operating cost and the management cost. In the investment cost it is including initial investment cost, in which covers the land cost, infrastructure cost and biogas equipment costs. While other costs are the office equipment, processing equipment, etc. The operating cost is including maintenance and reparation costs. The Management and wages are including the administrative cost, management cost and wages. The income of the biogas production at laboratory scale is based on 2 types of income: The consumption of biogas that the price is compared to diesel and the selling of fertilizer.

Table 19 Comparison heating value between biogas 1 m^3 obtained from biogas and amount of diesel

Laboratory	Methane gas amount obtained (%)	Obtained heating value (kcal)	Equal to diesel amount (liter)	Calculated Price (baht)
1:1	51.20	4,267	0.51	15.30
1.5:1	52.35	4363	0.52	15.64
2:1	55.51	4626	0.55	16.59
2.5:1	52.18	4349	0.52	15.59
3:1	53.43	4453	0.53	15.97

Nont: 1 liter of diesel equal 29.99 baht.

According to the Table 19 the comparison between methane gas that obtained from biogas production and the amount of diesel, it shown as follow:

Ratio 1:1 the methane gas obtained was 51.20% at heating value approximately 4,267 kilocalories in which equals to diesel of 0.51 liter and calculated at diesel price of 15.30 baht/m^3.

Ratio 1.5:1 the methane gas obtained was 52.35% at heating value approximately 4,363 kilocalories which equals to diesel 0.52 liter or calculated as diesel price 15.59 baht/m^3.

Ratio 2:1 the methane gas obtained was 55.51% at heating value approximately 4,626 kilocalories which equals to diesel 0.55 liter and calculated at diesel price of 16.49 baht/m^3.

Ratio 2.5:1 the methane gas obtained was 52.18% at heating value approximately 4,349 kilocalories which equals to diesel 0.52 liter and calculated at diesel price of 15.59 baht/m^3.

Ratio 3:1 the methane gas obtained was 53.43% at heating value approximately 4,453 kilocalories which equals to diesel 0.53 liter and calculated at diesel price of 15.89 baht/m^3.

Table 20 Total of Cost – Benefit – Analysis for each method

					Amount (baht)
Item	Laboratory 1:1	Laboratory 1.5:1	Laboratory 2:1	Laboratory 2.5:1	Laboratory 3:1
Initial Investment	22,280.00	22,280.00	22,280.00	22,280.00	22,280.00
Operation and Maintenance costs	1,336.80	1,336.80	1,336.80	1,336.80	1,336.80
Management and Wages	35,706.00	35,706.00	35,706.00	35,706.00	35,706.00
Annual Saving and Benefits	42,473.88	42,444.72	42,672.96	42,504.24	42,503.04

Table 20 shows the total of cost-benefit-analysis for each method, the initial investment cost was the costs of establishing biogas system at laboratory scale at 5 ratios in the amount of 22,280 baht. The estimated operation and maintenance cost is approximately 6% of the total investment cost, in which 1,336.80 baht/annum and the estimated management and wages cost is 35,706 baht/annum, in which all ratios calculated at the same cost. While the annual saving and benefits of 5 different ratios details as described below:

Laboratory 1:1 the biogas produced in 30 days was 2.581 m^3 which equals to 15.3 baht/m^3, in which the calculation of the return from selling biogas at 473.88 baht/annum and the return from selling fertilizer at retail price of 25 baht/liter multiplied by 140 liters output per laboratory ratio (5 ratios), accounted for 42,000 baht/annum and the total revenue and benefits are accounted for 42,473.88 baht per annum.

Laboratory 1.5:1 biogas 2.377 m^3 which is equal to 15.59 baht/ m^3 in which the calculation of the return from selling biogas at 444.72 baht/annum and the return from selling fertilizer at retail price of 25 baht/liter which resulted in return one laboratory of 140 liters accounting for 42,000 baht/annum and then all accounted for 42,444.72 baht in total per annum.

Laboratory 2:1 biogas 3.401 m^3 which is equal to 16.49 baht/m^3 in which the calculation of the return from selling biogas at 672.96 baht/annum and the return from selling fertilizer at retail price of 25 baht/liter which resulted in return one laboratory of 140 liters accounting for 42,000 baht/annum and accounted for 42,672.96 baht in total per annum.

Laboratory 2.5:1 biogas 2,695 m^3 which is equal to 15.59 baht/m^3 in which the calculation of the return from selling biogas at 504.24 baht/annum and the return from selling fertilizer retail at price of 25 baht/liter which resulted in return one laboratory of 140 liters accounting for 42,000 baht/annum and accounted for 42,504.24 baht in total per annum.

Laboratory 3:1 biogas 2,638 m^3 which is equal to 15.89 baht/m^3 in which the calculation of the return from selling biogas at 503.04 baht/annum and the return from selling fertilizer at retail price of 25 baht/liter which resulted in return one laboratory of 140 liters accounting for 42,000 baht/annum and accounted for 42,503.04 baht in total per annum.

Table 21 Analysis of Economic Statement in 5 different ratios

	Laboratory 1:1	Laboratory 1.5:1	Laboratory 2:1	Laboratory 2.5:1	Laboratory 3:1
Benefit and Cost ratio	1.06	1.06	1.07	1.06	1.06
Net Present Value (baht)	19,593.63	19,368.80	21,128.53	19,827.71	19,818.45
Internal Return Rate	14.86	20.48	15.90	20.81	15.01
Payback Period	3 y 9 m	3 y 9 m	3 y 7 m	3y 8 m	3 y 8 m

According to Table 21 the result of Economic analysis in all ratios of 10-year period at discount rate of 5%, it found out that the Net Present Value (NPV) were 19,593.63, 19,368.80, 21,128.53, 19,827.71 and 19,818.45 baht/annum respectively. This represents the net income or rate of return in the future after repayment of the investment costs. When the NPV is shown positive or above zero indicated that this analysis create profitability to factory investor. The ratio of 2:1 is shown the most benefit in the NPV value. The Benefit and Cost Ratio (BCR) was equal to 1.06 for all ratios except the ratio of 2:1 that was at1.07. This analysis means return revenue from ratio 2:1 whereas the current charges were greater than the total cost. The Internal of Return Rate (IRR) were 14.86%, 20.48%, 15.90%, 20.92% and 15.01% respectively. This means the discount rate used in the project was equal to 5%, it's less than the return of the IRR in this laboratory. The Payback period (PB) is approximately 3 year and 8 month. This means the duration of return of this laboratory approximately 3 year and 7 months to 3 year and 9 months, which less than the time of the project life time of 10 years.

According to the analysis of each laboratory study, it revealed that the results of 5 ratios using various decision criteria by comparing the calculation of values criteria and by measuring cost and benefit, its resulted 5 studies ratios value of money. And when comparing 5 studies ratios, it revealed that the analysis under laboratory ratio 2:1, whereas the calculation of the amount of revenue and expenses in producing biogas to replace the diesel, it found out that this case provides the most value analysis results of NPV and the fastest payback period. Thus 2:1 ratio remained attractive to be invested compared to the other ratios.

The Biogas production provides substantial benefits such as economic and environmental benefits to tuna factory, as its improving the tuna factory waste management system that support tuna factory waste treatment, while its reduced carbon emission and convert the factory waste into a useful substance, such as biogas and high quality fertilizer.

The economic benefits analysis of anaerobic co-digestion tuna waste:

1. To reduce the consumption of fossil fuel such as diesel and electricity that are very costly, in which the biogas is being used to power the factory boiler, that eventually the factory may lead to sustainable renewable energy by using biogas as the core power of the factory to replace fossil fuel altogether.

2. To increase waste value, as the factory generate waste every day, the waste used to be a substance that required more cost to treat, however with the biogas production process, the waste is becoming useful and is a core material to produce biogas and useful substance like fertilizer, and the waste has increased the value that can be calculated as per indicated in this thesis.

3. To reduce fuel consumption in the transporting the waste to outside factory for furthers the treatment. The transporting of the waste required substantial amount of fuel as its normally transported to a long distance of journey (approximately 100Km) to a remote location, In addition, the output of CO_2/carbon emission from the vehicle is also quiet substantial., Thus the fuel consumption and Carbon dioxide output can be reduced by processing biogas production within the factory

4. The reduction of carbon emissions from tuna solid waste. The management of anaerobic co-digestion of tuna solid waste presents many opportunities for reduction greenhouse gas emission. Anaerobic co-digestion of tuna solid waste allows energy recovery to displace fossil fuel diesel used in factory. Diversify of tuna solid waste organic materials by anaerobic digestion process also reduce methane emission from other treatment. The carbon credit is valued in most countries in America and Europe, that the more carbon emission is reduced, the more revenue can be generated. Thus, it's expected to be applied in major countries in Asia Pacific eventually.

5. To save cost in the waste treatment, in which the waste is processed within the factory and converted into useful substance like biogas and high quality fertilizer.

6. To generate revenue from the selling of the fertilizer. The fertilizer produced during the biogas production is very high quality, organic and no chemical content and it's very safe and not hazardous to the farmers as well as to the human when consuming the farm products.

The environmental benefits analysis of anaerobic co-digestion tuna waste:

1. To reduce the odor from tuna solid waste storage. Previously the waste had to wait for hours to be transported outside factory for further treatment, its created foul odor during the waiting period and required further cleaning after the transporting of the waste. With the biogas production within the factory, it's reduced the odors by immediate processing and transfer the waste into the anaerobic digester tank.

2. To reduce health hazards condition within the factory of vectors such as flies, cockroaches, etc. With immediate transferring the waste into the digester tank, no any waste is left outside or on covered, thus there is no any flies or other bugs present that may cause health hazardous to human.

3. To reduce carbon emission generated from diesel consumption in the factory and vehicles that transporting the waste for treatment. That makes the factory a green factory.

4. To improve hygienic of factory. As the waste treated immediately and transferred to the digester tank for biogas production within the factory, the factory hygiene is improved dramatically as there is no any waste scattered in a waste dumping area, no dripping of the waste water, save the water to clean the dumping area, and save the chemical for cleaning agents to clean the dumping area. The factory waste dumping area will be maintained very hygienic and improve the factory environment over all as there is no any odor and flies in it.

5. To improve the waste treatment of the factory. As the waste is treated within the factory, its support the waste treatment of the factory that the waste is no longer required to be transported, not required to be mixed with chemical to reduced odor and toxin, and reducing water and cleaning agents for cleaning as well as reduced cost and man power for the handling.

Tuna factory waste management application system

Biogas production from semi-continuous anaerobic co-digestion process

Based on the batches study experiments, tuna factory can design its waste management by implementing semi-continuous anaerobic co digestion system, by utilizing its solid waste and mixed with banana crop residue, to produce biogas to power the factory boiler. The Semi-continuous anaerobic co digestion system will be managed in 3 different hydroulic retention time (HRT), whereas implementing ratio 2:1, in which as per analysis of previous batches experiments was the most optimal for the biogas production. The results of this study, the effect of hydraulic retention time (HRT) at 10, 6 and 3 days as per shown in Table 22.

Table 22 Steady-state performance of anaerobic co-digestion at different HRT

	10 days	6 days	3 days
Organic loading rate			
COD (g cod/l/d)	2.18	3.63	7.26
TS (%)	2.95	4.92	9.85
VS (%)	2.60	4.33	8.66
Digester characteristics			
pH	7.67	7.72	7.42
VFA/Alkalinity	0.32	0.36	0.37
Ammonium-N (g/l)	1.12	1.18	0.78
TKN (g/l)	11.67	14.52	15.21
Total solid removed			
TS reduction (%)	43.66	50.43	55.06
VS reduction (%)	53.46	59.56	63.09
COD reduction (%)	49.85	55.06	58.59
Specific methane production			
Volumetric biogas production (l/d)	95.25	127.33	127.67
Volumetric CH_4 production (l/d)	52.83	70.67	71.07
CH_4 content (%)	55.46	55.50	55.67
CO_2 content (%)	40.37	40.33	40.16

The semi-continuous co-digestion was initially the mixture of tuna solid waste with banana crop residue at OLR of 2.18 g COD/l 10 days of HRT for 20 days, OLR of 3.63 g COD/l 6 days of HRT for 12 days and OLR of 7.26 g COD/l and 3 days of HRT for 6 days. Upon the acclimation stage, the operation of semi-continuous co-digestion of 2:1 ratio was started at the HRT of 10 days. The co-digestion were operated and monitored under the same condition for around 20 days. Afterwards, the HRT was reduced to 6 days and 3 days respectively and the operation of the co-digester and data collection were continued for 12 days and 6 days respectively. The summarized values of the parameters monitored during the sTable conditions were given in Table 22. The results indicated that the HRT for 3 days achieved the highest methane production at 55.67%, while HRT 10 and 6 days were 55.46% and 55.50% respectively. The longer operation HRT, less amount of total biogas production was contained; however, methane content was higher in biogas composition at longer operation HRT, which implies that the longer operation HRT can improve methanogenesis activity until the ultimate level.

As presented in Table 22 the volume biogas operation of 3 different HRT form digesters varied from 95.25, 127.33 and 127.67 l/d respectively, while the volumetric methane productions were 52.83, 70.67 and 71.07l/d respectively. The co-digestion process also indicated higher specific methane production compare to those of batch digesters. This effect was possible due to good buffering capacity provided in the anaerobic co-digestion process scenarios. The methane yield result revealed from 3 HRT time was 55.46, 55.50 and 55.67 % respectively.

The pH suiTable for anaerobic digestion is 6.5-7.5 from Barnes and Bliss [75], while the result in this study was 6.1 to 7.7. If the pH of the substrate is either lower than 6.0 or greater than 8.0, methanogens will be inhibited and volatile fatty acids will then accumulate. The pH profiles of the co-digestion system in this study are shown in Figure 26. The pH of all reactors was well above 7.0 throughout the investigation, but the pH tends to decrease with decreasing HRT (increasing OLRs). The alkalinity suggested for anaerobic digestion range from 1 to 5g $CaCo_3$/l Agdag and Sponza [80].The initial VFA/alkalinity ratio in this study was 0.32 - 0.37. Alkalinity and pH individually are not sufficient to indicate the anaerobic system when it became unsTable. The total VFA to alkalinity ratio is an additional parameter used to indicate whether the anaerobic digestion system has a sufficient buffering capacity to prevent instability (Figure 27).

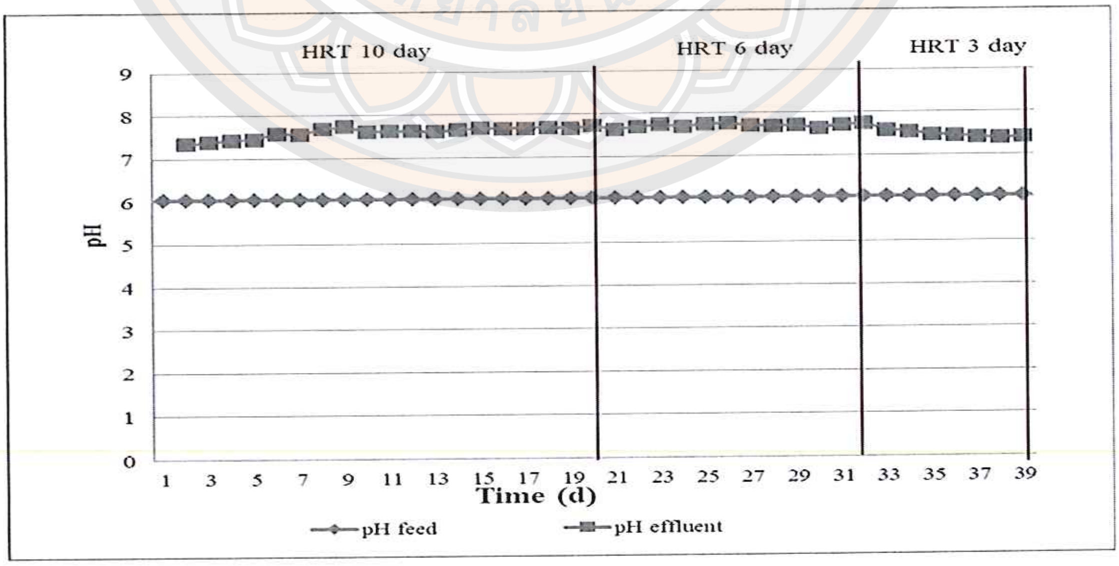


Figure 26 pH profile of 3 HRT (10 days, 6 days and 3 days)

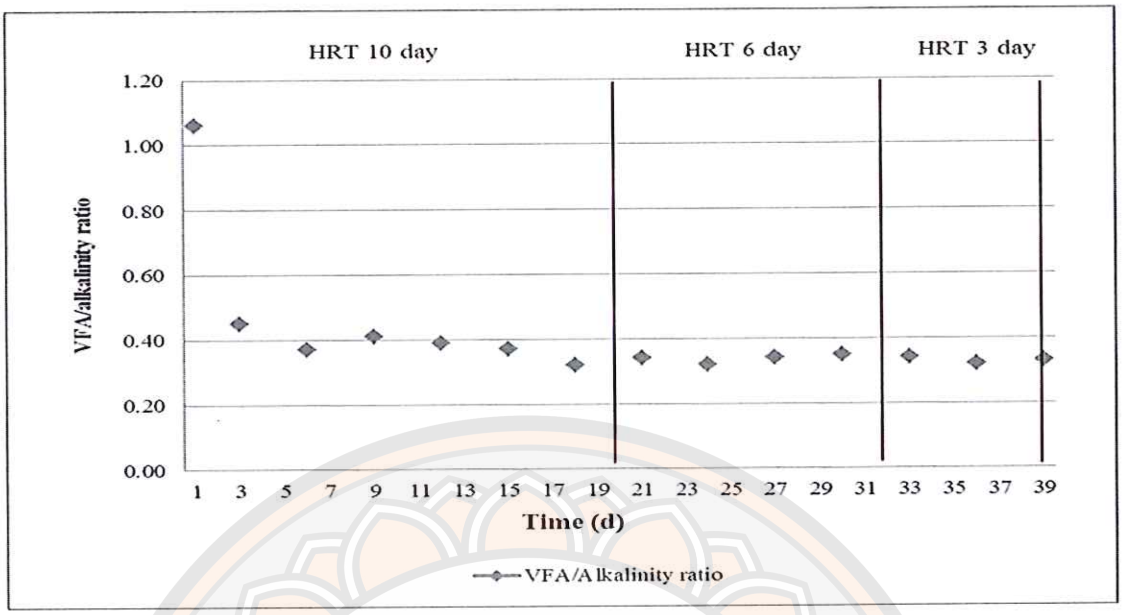


Figure 27 The VFA to alkalinity ratio

It can be seen from the Table 22 that methane production increased with the trend increases in OLR, 2.18, 3.63 and 7.26 g COD/l/day. The methane composition of the digestion was found to be a little bit higher than the sum of the methane composition of 2:1 batch co-digestion system at the HRT of 3 days. The results indicated that the co-digestion process was not only use the reactor volume more effectively, but also created more suiTable environmental condition for the working anaerobic bacteria. However, at HRT of the methane production of HRT 10 days and 6 days were approximately equal to the sum of methane composition of the batch co-digestion system.

Waste management application

According to the results, the best operating conditions of the semi-continuous in co-digestion were achieved to management application scale with a HRT of 6 days and 3 days, that product at nearly the same amount at 127.33 and 127.67 l/day respectively, with the methane component at 55.50 and 55.67 respectively. The addition of ORL from 3.63 to 7.26 g cod/l/d did not result in different efficient on biogas production. The indicator application of waste management, which shown possible highest efficiency to reduce tuna solid waste and benefit it economically, it's found to be the highest disposal of waste to produce the renewable energy. The waste management application criteria were used for many section of this research that resulted for decision making on the tuna solid waste management. Table 23 was shown the co-digestion in batch and semi-continuous co-digestion waste management and biogas production decision for management application scale. From the Table the result of co-digestion system that manage the tuna waste to energy shown in all reactor used 60 kg of waste each in the co-digestion process, within the different duration time of the biogas production. The result in the HRT of 3 day was the most efficient in the used of waste to be digested in the production process, as the HRT's of 60 kg waste digested in 3 days, while the HRT of 10 and 6 day used the 60 kg of waste digested in 10 day and 6 day respectively. In term of the biogas production process the HRT of 3 days, not only the most efficient in consumes the waste but also produce the most optimal in biogas production and methane yield among the other HRT.

Table 23 The co-digestion in batch and semi-continuous co-digestion waste management and biogas production decision for management application scale

co-digestion system	batch	semi continuous		
	2:1	HRT 10 days	HRT 6 days	HRT 3 day
TSW* and BCR** waste load (kg)	60	60	60	60
co-digestion duration time	30	20	12	6
biogas production	3403	1905	1528	766
biogas production / day	113.43	95.25	127.33	127.67
specific biogas yield ($gCOD_{removed}/l$)	0.46	0.65	0.42	0.20
specific methane yield ($gCOD_{removed}/l$)	0.26	0.36	0.23	0.11
CH_4 content (%)	55.51	55.46	55.50	55.67

* TSW were tuna solid waste ** BCR were banana crop residue

Table 24 The analysis of economic statement of HRT 10, 6 and 3 days

HRT time	10 day	6 day	3 day
Benefit and Cost ratio	1.37	2.27	4.53
Net Present Value (baht)	112,840.75	391,876.13	1,085,791.79
Internal Return Rate	78.42	241.10	645.06
Payback Period	1 year 5 month	6 month	2 month

The calculation in the economic analysis of the management application lab scale (shown in Table 24) resulted that the HRT of 3 days provides the most benefit between the 3 HRT time among the HRT of 10, 6 and 3 days. The results shown that within 10 year period at discount rate of 5%, it found out the NPV of HRT of 3 days was 1,085,791.79 baht, while the HRT of 6 day was only 391,876.13 baht, this represent the HRT of 3 days provides the most benefit in value. The BCR was equal to 4.53, the IRR was 645.06 it valued more than the discount rate. The Payback Period, duration of return the capital of the HRT of 3 days was only 2 months, while the project life time is 10 years. While the HRT of 10 and 6 day were show the BCR at 1.37 and 2.27 respectively, and IRR at 78.42 and 241.10 respectively even it valued more than the discount rate, but it is less efficient than HRT of 3 days.

Table 25 The cost and benefit analysis of the HRT 10, 6 and 3 days

Amount (baht)

Item	HRT 10 day	HRT 6 day	HRT 3 day
Initial Investment	22,280.00	22,280.00	22,280.00
Operation and Maintenance costs	1,336.80	1,336.80	1,336.80
Management and Wages	35,706.00	35,706.00	35,706.00
Annual Saving and Benefits	54,568.19	90,759.55	180,761.58

The cost and benefit amount that used to indicate the analysis was shown in Table 25. The result show that the initial investment of 22,280 baht, operation and management costs of 1,336.80 baht and management and wages amount of 35,706 baht were the same cost at all HRT. The annual saving and benefits were 54,568.18, 90,759.55 and 180.761.58 baht respectively. The most benefit was generated from the selling high quality fertilizer or fish emulsion.

The data from the tuna factory shown that in one (1) production day, during the year of 2010 and 2011 the average of tuna solid waste disposal were 672kg/day and 823kgs/day respectively. Therefore to manage the tuna solid waste of the factory that produce approximately of 1,000 kg/day will use the formula of calculation based of above information and to provide the semi-continuous digester tank with capacity size of loading late 1,000 kg/day as the management application scale. The decision on the HRT time will use the most efficient rate in the biogas production from HRT 10, 6 and 3 days that will calculated and find out the most optimum result for the most efficient way to manage the tuna solid waste for tuna factory.

According to the result, it revealed that the HRT of 3 days with OLR of 7.26 g COD/l/d has highest value of criteria to manage the tuna waste and could be used as a pilot scale for tuna factory to produce the biogas to replace the fossil fuel (diesel), in other words to reduce tuna solid waste with semi-continuous process provides value not only in the economic and accounting, but also value in the environmental that producing the renewable energy to reduce Co_2/carbon emission.

Semi-continuous pilot design

To calculate the management application scale to reduce the tuna waste of 1,000 kg/day capacity tank, by using the HRT of 3 day semi-continuous co-digestion process's result as a formula to setup the waste management system. The retention time to use in this management will be 3 days and the waste loading each day will be set up at the maximum 1,000 kg of tuna solid waste mixed with the co-digestion of banana crop residue at ratio of 2:1, in which to process tuna solid waste of 1,000 kg and 500 kg of banana crop residue to load in the system. The total loading waste of 1,500 kg placed in the 3 HRT to be processed the digester size of about 15 m^3.

In Thailand equipment can be found easily and available at specification of size 12 m^3 tank, 15 m^3 and 30 m^3 tank respectively that can be utilized for biogas production without build it from the scratch. At the retention time of 3 days with the loading capacity of 1500 liter waste a day, to be using 15 m^3 tanks to setup the biogas production system in the research. The digestion tank with volume of 15 m^3 and the installation of automatic stirring system of 2 x 2 HP motor and the biogas storage tank size of 20 m^3 will cost of 1.2 million baht.

The initial investment cost also including land cost, gas compression system, LPG gas storage 5 tanks (for purpose of transferring the biogas to the tuna production process) and 2 grinding machines. The operation and maintenance costs estimated at 6% of the initial investment cost. The management and wages costs are utilities expenses, other management cost and wages. The management of the biogas production process, one manager and one worker are required, that will work for 8 hours a day in the process of collecting the waste and to transfer to the processing tank and to manage the entire biogas production, as well as to manage the biogas by product generated after the biogas process for further handling such as packing and selling. There 2 types of benefit generated from the biogas production, such as: the benefit in biogas consumption price against diesel consumption, and the selling of the biogas by product such as high quality fish emulsion fertilizer.

Based on this scale, the total investment cost is approximately 3,454,941 baht, the operation and maintenance costs 147,296.40 baht, management and wages cost 2,106,000 baht, annual saving and benefits 4,879,038.93 baht, with in the 10 year and the payback period was 1 year and 5 month.

This scale can be implemented as it's a simple model, friendly to the environment and it's relatively easy to establish as the equipment for making of the biogas production system is readily available. This biogas production system provides the supports to the waste treatment, and reducing carbon emission as well as reducing cost as indicated above substantially.

Tuna factory waste management system has benefitted the factory on its waste solution in which waste management is becoming easier to do, as the waste doesn't need to be treated it chemically, and doesn't need to be transported it to other location, and that all can be done within the tuna factory. In addition, with this system, enable the factory to produce green renewable energy biogas that reduce the cost of fossil fuel substantially as well as reducing carbon emission of the factory. In the experiments, the system is proven to be successfully converted tuna factory's waste into a renewable energy that currently powers the factory's boiler. Figure 28 was shown the process of the co-digestion waste management of tuna waste into renewable energy power the factory's boiler.

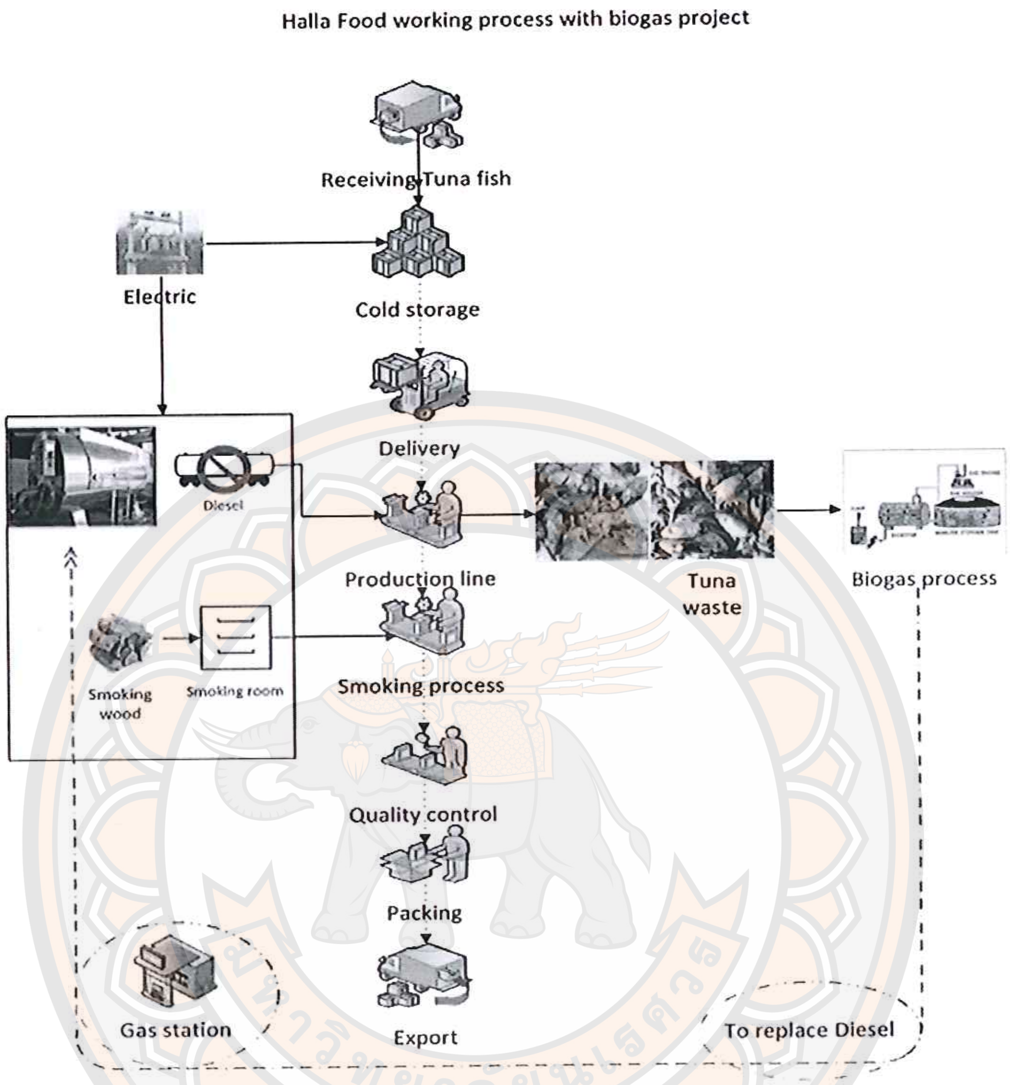


Figure 28 The co-digestion waste management of tuna waste into renewable energy power the factory's boiler

This study was to show why biogas production in tuna or food industry is worth considering for the manufacturers and food producers the following list gives an impression of the benefits:

1. Renewable energy production
2. Climate protection and Reduce carbon emission
3. No food competition when using legumes, catch crops, conservation material, residues and by-products as biomass sources

4. Optimizing of crop rotation and cropping system
5. Increased crop yields and quality and produce fertilizer
6. Support waste treatment
7. Save transportation of waste treatment cost and the waste treatment cost
8. Alternative source of income
9. Independent energy supply
10. Increase factory hygiene
11. Reduce odor and flies or bugs, etc.

CHAPTER V

CONCLUSIONS

Conclusion

The objectives of this research were to produce biogas by the co-digestion of tuna factory waste and banana crop residue, then analyze the economic and environmental benefits. In this research the biogas production supports tuna factory waste management system in which the tuna factory waste treated and converted into a useful substance, such as biogas and high quality fertilizer.

Anaerobic digestion was a natural process that converts biomass into renewable energy. A great option for improving yields of anaerobic digestion of solid wastes was the co-digestion of multiple substrates. If co-substrates are used in anaerobic digestion system it improves the biogas yields due to positives synergisms established in the digestion medium and the supply of missing nutrients. Anaerobic co-digestion aims at treating different organic residues that can be blended for optimal energy and resources recovery. Anaerobic treatment of fish wastes is possible with co-digestion. The main issue for co-digestion process lies in balancing several parameters in the co-substrate mixture: macro- and micronutrients, C:N ratio, pH, toxic compounds, biodegradable organic matter and dry matter. The anaerobic co digestion provides other environment advantages such as: supports the waste treatment, reduce health hazard condition within the factory, odor reduction, energy saving in term of the waste treatment transportation and the greenhouse gas reduction from the co-digestion process, as well as reduced carbon emission.

The aim of this work was to find optimal co-digestion substrates to enhance biogas production from fish wastes. The investigation give the answer about useful for determining the most proper ratios of different co-substrates that provide an optimized biodegradation potential or enhance methane potential.

In the experiments of 5 ratios at 1:1, 1.5:1, 2:1, 2.5:1 and 3:1.respectively, with co-digestion of tuna factory waste mixed with banana crop residue in the anaerobic digester capacity of 150 liters for 30 production days, at temperature operated at mesophilic condition of 30-35°C, the pH performance range was 6.5 to 7.5, while the startup COD was 54.46 g/l., the 30 day evolution in meshopholic digestion the COD reduce up to 57%. The ratio of 2:1 provides most optimal result in the biogas production whereas 3,403 liters produced in which the methane production was 55.51% that equal to 0.55 liter of diesel. The anaerobic co-digestion of 10 year period at the discount rate of 5%, found out that the NPV were 19,593.63, 19,368.80, 21,128.53, 19,827.71 and 19,818.45 baht/annum respectively, that all ratios provide profitability to the investor. The BCR in all ratios was equal to 1.06 only 2:1 ratio show the most value at 1.07, which IRR 15.90%, and PB period is approximately 3 year and 8 months.

Based on the batches study experiments, tuna factory can design its waste management by implementing semi-continuous anaerobic co-digestion system, by utilizing its solid waste and mixed with banana crop residue, to produce biogas to power the factory boiler. The Semi-continuous anaerobic co digestion system will be managed in HRT of 10, 6 and 3 days at ratio 2:1, in which as per analysis of previous batches experiments was the most optimal for the biogas production.

The final result of tuna waste management was to manage tuna solid waste as a material of renewable energy production the semi-continue anaerobic co-digestion was applied in the process. The research shown the most optimum of biogas production was the HRT of 3 day co-digestion waste at ratio of 2:1 with 60 kg of waste in the OLR of 7.26 g COD/l was provided biogas of 109.43 liter/day, the methane production of 55.67%. The economic benefit in this semi-continuous process with 10 year life project was shown the payback period of 2 months with the benefit saving was 180,761.58 baht.

The waste management provides the economic benefits such as: to reduce the consumption of fossil fuel, to increase waste value, to reduce fuel consumption in the transporting the waste, the reduction of carbon emissions, to save cost in the waste treatment and to generate revenue from the selling of the fertilizer. In addition its provide the environmental benefits such as: to reduce the odor from tuna solid waste storage, to reduce health hazards condition within the factory, to reduce carbon emission generated from diesel consumption, to improve the factory hygiene and to improve the waste treatment of the factory.

Recommendation

From this research, the result of the study showed that co-digestion of tuna solid waste and other waste are feasible. To optimize the methane production rates, the experiments should be done in the semi continuous reactors. The research operation due to the C:N ratio of the co-digestion is the most important.

The biogas production supports the waste treatment of the waste management system it offers many advantages to the fish industry specifically and to other food industry over all.

The financial analysis indicated that the venture of bio-digester program with tuna factory waste is thus feasible to manufacturers or fish industry for the production of biogas.

This study showed that methane gas is quite possible to obtain from fish waste with different substrate under anaerobic conditions. The results from these experiments showed that a mixture of tuna waste with banana crop residue provide the high value for methane production in relation to the amount of organic material present in the process. The banana crop residues used for the experiments did not contain sufficient amount of biodegradable carbon, which could compensate the high levels of ammonia nitrogen in the fish. The obtained results are consistent with expectations.

The results of the experiments will form the basis for the design of a large-scale biogas plant for the anaerobic utilization of tuna factory. The biogas can be upgraded into fuel for the whole factory power and ultimately to achieve sustainable renewable energy for the tuna factory.

Last but not least, the final destination of this research is to take this outcome into action as the full-scale. Therefore, some operating parameters like OLR, retention time and utilization of equipment should be analyzed in order to make sure the digestion process smoothly. In addition, the way of upgrading biogas should be taken into consideration further to obtain the relative pure CH_4 as alternative fuels of factory

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APPENDIX

Table 26 The amount of production and waste report year 2010

Halla Food (Thailand)Co.,Ltd.
Production and waste report year 2010 (Kgs.)

	January			February			March			April	
Date	Fresh fish	solid waste	Date	Fresh fish	solid waste	Date	Fresh fish	solid waste	Date	Fresh fish	solid waste
1			1			1	3,382	1,219	1		
2			2			2			2		
3			3			3			3	3,024	1,075
4	3,024	1,063	4			4			4		
5	3,024	1,086	5			5			5	3,872	1,393
6			6	3,024	1,083	6			6		
7	3,024	1,087	7			7			7		
8	4,088	1,543	8	2,916	1,010	8	2,520	908	8		
9			9	3,024	1,045	9	3,528	1,258	9		
10			10			10			10		
11	3,024	1,049	11			11	2,509	869	11		
12			12			12	4,094	1,441	12		
13			13			13	3,024	1,077	13		
14	3,024	1,097	14			14			14		
15	3,024	1,072	15			15	3,024	1,084	15		
16	3,080	1,027	16			16	2,050	743	16		
17			17			17			17	2,913	1,068
18	2,854	976	18	2,660	969	18			18		
19			19	2,520	870	19			19	3,024	1,096
20	1,880	705	20	2,520	897	20	4,100	1,449	20	3,659	1,268
21			21			21			21		
22	2,100	786	22	2,520	921	22	3,535	1,234	22	3,024	1,038
23			23	2,633	943	23	3,528	1,242	23	3,472	1,235
24			24	3,500	1,249	24			24	3,472	1,288
25	1,980	711	25			25	4,032	1,426	25		
26			26	2,520	871	26	3,070	1,050	26	3,136	1,120
27	2,068	769	27	2,520	910	27	4,200	1,483	27	3,024	1,047
28			28			28			28		
29	3,096	1,070	29			29	3,080	1,107	29	3,080	1,073
30	3,213	1,167	30			30	3,528	1,271	30	3,080	1,090
31			31			31	3,024	1,061	31		
	42,503	15,208		30,357	10,768		52,864	19,922		38,780	13,791

Table 26 (cont.)

Halla Food (Thailand)Co.,Ltd.

Production and waste report year 2010 (Kgs.)

Date	May Fresh fish	May solid waste	Date	June Fresh fish	June solid waste	Date	July Fresh fish	July solid waste	Date	August Fresh fish	August solid waste
1			1	3,024	1,060	1			1		
2			2	3,024	1,094	2	4,020	1,420	2		
3			3	3,010	1,030	3	4,100	1,451	3		
4	3,500	1,253	4			4			4		
5	3,320	1,186	5	2,895	1,025	5			5		
6			6			6	3,520	1,236	6		
7	2,650	936	7			7	3,080	1,098	7		
8	3,080	1098	8	2,600	924	8	2,896	1,010	8		
9			9			9			9	2,520	860
10	4,200	1487	10	3,024	1,088	10			10	2,650	900
11			11	3,100	1,101	11			11		
12	3,080	1060	12			12			12		
13			13			13	3,024	1,030	13		
14	3,024	1055	14			14	3,024	1,051	14		
15	3,190	1120	15	3,100	1,091	15	2,897	1,010	15		
16			16	2,850	1002	16			16		
17	3,080	1065	17			17	3,136	1,100	17		
18	3,080	1054	18			18			18	3,024	1,050
19	2,970	1061	19			19	3,136	1,010	19	3,024	1,034
20	2,850	1006	20			20	4,088	1,440	20		
21			21			21	4,210	1,057	21	3,024	1,088
22			22			22			22		
23			23			23			23	3,080	1,091
24	2,890	1024	24			24			24	3,145	1,113
25	3,080	1089	25			25			25		
26	3,024	1077	26			26	3,024	1,080	26		
27			27			27	2,410	820	27	2,492	880
28	3,024	1080	28			28			28	2,818	956
29	2,870	1025	29			29			29		
30			30			30			30		
31			31			31			31	3024	1085
	52,912	18,676		26,627	9,415		46,565	15,813		28,801	8,972

Table 26 (cont.)

Halla Food (Thailand)Co.,Ltd.
Production and waste report year 2010 (Kgs.)

Date	September Fresh fish	September solid waste	Date	October Fresh fish	October solid waste	Date	November Fresh fish	November solid waste	Date	December Fresh fish	December solid waste
1	3,080	1,070	1	3,024	1,060	1			1	3,024	1,080
2	2,240	777	2	3,110	1,088	2	3,080	1,066	2	3,024	1,095
3			3			3	3,080	1,081	3		
4			4	2,150	755	4	2,408	830	4		
5			5			5	2,290	789	5		
6			6			6			6		
7			7			7			7	3,024	1,088
8			8	4,032	1,410	8	2,408	803	8	2,464	844
9			9	4,032	1,421	9	2,510	886	9		
10			10			10			10		
11			11	3,218	1,215	11			11		
12			12			12	2,464	888	12		
13			13			13	2,408	820	13	3,976	1,415
14			14	2,520	880	14			14	2,349	810
15			15	2,520	880	15	2,800	987	15		
16			16	2,548	900	16	2,800	999	16	3,080	1,088
17			17			17	2,856	1,010	17	3,080	1,104
18			18			18	2,856	1,020	18	3,080	1,050
19			19	3,042	1,054	19	2,856	973	19		
20			20	3,205	1,112	20			20	2,760	960
21			21			21			21		
22			22	3,080	1,090	22			22	2,185	768
23			23			23	3,042	1,044	23		
24			24			24	2,464	847	24	3,140	1,100
25			25	3,080	1,076	25	2,856	996	25		
26			26	3,119	1,051	26	2,856	989	26		
27			27			27			27	3,200	1,112
28			28			28			28	3,080	1,057
29	2,560	900	29			29	3,500	1,230	29	3,024	1,04[illegible]
30	3,080	1,098	30			30			30		
31			31			31			31		
	10,960	3,845		42,680	14,992		49,534	17,258		44,490	15,614

Table 27 The amount of production and waste report year 2011

Halla Food (Thailand)Co.,Ltd.

Production and waste report year 2011 (Kgs.)

	January			February			March				
Date	Fresh fish	solid waste	Date	Fresh fish	solid waste	Date	Fresh fish	solid waste	Date	Fresh fish	solid waste
1			1	4,000	1,407	1			1	2,832	1,011
2			2			2			2	2,964	1,031
3			3	3,024	1,052	3	2,680	950	3		
4			4	3,024	1,064	4	2,680	931	4	4,000	1,389
5			5			5	2,704	958	5	3,080	1,039
6			6			6			6	3,080	1,064
7			7	3,080	1,081	7	3,024	1,031	7	3,256	1,142
8			8	3,024	1,068	8	3,164	1,123	8	4,032	1,408
9			9	3,024	1,073	9			9	3,080	1,097
10			10			10	3,528	1,208	10		
11			11	3,000	1,025	11			11	4,032	1,387
12			12	3,024	1,059	12	3,528	1,229	12	3,080	1,074
13	4,250	1,502	13			13			13		
14			14	3,080	1,087	14	4,032	1,416	14		
15	4,000	1,438	15			15			15		
16			16	3,472	1,258	16	3,024	1,015	16		
17			17	3,516	1,290	17	4,032	1,401	17		
18			18	3,024	1,065	18			18	3,080	1,085
19	1,544	517	19			19	4,032	1,411	19	3,360	1,186
20			20			20			20	3,080	1,091
21			21	3,036	1,067	21	3,024	1,129	21	4,200	1,429
22			22	3,024	1,054	22	3,024	1,137	22		
23			23	2,528	902	23	4,027	1,376	23	6,170	2,143
24			24	3,024	1,049	24	2,549	934	24		
25	3,235	1,096	25			25			25	3,183	1,141
26	2,383	825	26	3,000	1,028	26	3,024	1,048	26		
27			27			27			27	3,225	1,173
28	1,450	510	28	3,976	1,381	28			28	3,074	1,098
29			29			29	3,024	1,065	29		
30	2,919	1,008	30			30	3,024	1,026	30	3,036	1,158
31	4,260	1,442	31			31	2,598	918	31		
	24,041	8,338		56,880	20,010		60,722	21,306		65,844	23,146

Table 27 (cont.)

Halla Food (Thailand)Co.,Ltd.
Production and waste report year 2011

(Kgs.)

	May			June			July			August	
Date	Fresh fish	solid waste	Date	Fresh fish	solid waste	Date	Fresh fish	solid waste	Date	Fresh fish	solid waste
1			1	3,136	1,110	1			1		
2	4,263	1,483	2	3,781	1,353	2			2		
3	3,014	1,049	3			3			3		
4	4,145	1,389	4	2,926	1,012	4			4		
5	4,290	1,490	5			5			5	3,024	1,055
6			6	3,206	1,221	6			6	3,080	1,094
7	3,080	1,107	7			7			7		
8			8			8			8	3,082	1,084
9	4,200	1,476	9			9			9	3,024	1,039
10	4,200	1,424	10	3,080	1,071	10			10	4,032	1,433
11			11	3,080	1,080	11			11	3,080	1,098
12	3,080	1,091	12			12			12		
13			13	3,080	1,099	13			13		
14	2,942	1,009	14	2,032	750	14			14		
15			15	2,976	1,056	15			15	3,032	1,021
16	2,984	1,054	16	2,980	1,073	16			16	3,024	1,024
17	2,323	821	17			17			17		
18	2,942	1,050	18	3,080	1,090	18			18	3,023	1,043
19	3,088	1,090	19			19			19	3,080	1,098
20			20	2,144	790	20			20	3,032	1,082
21			21	3,080	1,054	21			21		
22			22	3,080	1,092	22			22	3,024	1,054
23	2,029	800	23	3,100	1,110	23			23	3,043	1,073
24			24			24			24	3,059	1,093
25	3,144	1,124	25	3,200	1,136	25			25	3,024	1,061
26	3,080	1,056	26			26			26		
27			27			27			27		
28	3,200	1,100	28			28			28		
29	3,080	1,099	29	3,080	1,080	29			29	3,519	1,356
30	3,176	1,108	30	3,240	1,138	30			30	3,584	1,376
31	3,200	1,143	31			31			31	3057	1074
	65,460	22,963		54,281	19,315					56,823	20,158

Table 27 (cont.)

Halla Food (Thailand)Co.,Ltd.
Production and waste report year 2011

(Kgs.)

September			October			November			December		
Date	Fresh fish	solid waste	Date	Fresh fish	solid waste	Date	Fresh fish	solid waste	Date	Fresh fish	solid waste
1	3,024	1,032	1			1	3,195	1,148	1		
2			2			2	3,080	1,035	2		
3	2,500	903	3	3,080	1,092	3	3,080	1,052	3	4,144	1,431
4			4	3,200	1,142	4			4		
5	2,017	748	5			5			5		
6			6			6			6		
7			7			7	4,032	1,436	7		
8			8			8			8		
9			9			9	3,080	1,061	9		
10			10			10	3,000	1,067	10	2,184	775
11			11			11	3,080	1,044	11		
12			12			12	4,032	1,469	12	3,024	1,085
13			13			13			13		
14			14	3,032	1,076	14	4,032	1,437	14	2,349	896
15			15	3,164	1,039	15	3,024	1,040	15		
16	2,766	1,011	16			16	3,065	1,084	16		
17	4,042	1,423	17	4,074	1,437	17			17		
18			18	4,032	1,496	18			18		
19			19	3,024	1,089	19	3,024	1,045	19		
20			20	3,022	1,037	20			20	3,050	1,083
21	3,822	1,348	21			21	3,080	1,087	21	3,050	1,092
22			22			22	3,024	1,098	22	2,185	794
23			23			23	3,024	1,064	23		
24	3,888	1,386	24	3,360	1,201	24			24		
25			25	4,032	1,449	25	3,024	1,086	25		
26	3,263	1,116	26	3,080	1,081	26			26		
27	3,523	1,288	27	3,080	1,125	27			27	4,265	1,524
28			28	3,080	1,153	28	4,200	1,501	28	4,018	1,421
29	3,024	1,073	29	4,032	1,432	29	4,024	1,391	29		
30	4,126	1,469	30			30			30		
31			31	4032	1468	31			31		
	35,995	12,797		51,324	18,317		60,100	21,145		28,269	10,101

บริษัท ห้องปฏิบัติการกลาง (ประเทศไทย) จำกัด
Central Laboratory (Thailand) Co. Ltd.
Chachoengsao Branch
Accreditation No. 1063/49

วันที่ออก : 28 สิงหาคม 2555
เลขที่รายงาน : TR (CH) 55/11892
หน้า : 1 ถึง 1

ใบรายงานผลการทดสอบ

ชื่อและที่อยู่ลูกค้า	บริษัท ฮากาฟู้ด (ไทยแลนด์) จำกัด 120 ม. 3 ถ.เขากคร ต.บ้านฉาง อ.บ้านฉาง จ.ระยอง 21130
รายละเอียดตัวอย่าง	Biogas by-product
รหัสตัวอย่าง	CH/55/04127-001
ลักษณะและสภาพตัวอย่าง	ประเภทตัวอย่าง : วัตถุดิบปุ๋ย ภาชนะบรรจุ : ขวดพลาสติก, จำนวน : 1 ขวด, น้ำหนัก/ปริมาตร : 1 ลิตร อุณหภูมิ : อุณหภูมิห้อง, สภาพตัวอย่างปกติ
วันที่รับตัวอย่าง	21 สิงหาคม 2555
วันที่ทดสอบ	22 สิงหาคม 2555 - 28 สิงหาคม 2555

ผลการทดสอบ

รายการทดสอบ	ผลการทดสอบ	หน่วย	LOD	วิธีทดสอบอ้างอิง
Total Phospbhate (P_2O_5)	4.31	g/100g	-	Manual on Organic Fertilizer Analysis, APSRDO, DOA:4/2551
Total Nitrogen (N)	3.43	g/100g	-	Manual on Organic Fertilizer Analysis, APSRDO, DOA:4/2551
Potassium (K_2O)	0.36	g/100g	-	Manual on Organic Fertilizer Analysis, APSRDO, DOA:4/2551
Calcium (Ca)	0.38	g/100g	-	Manual on Organic Fertilizer Analysis, APSRDO, DOA:4/2551
Magnesium (Mg)	0.02	g/100g	-	Manual on Organic Fertilizer Analysis, APSRDO, DOA:4/2551
Iron (Fe)	0.28	g/100g	-	Manual on Organic Fertilizer Analysis, APSRDO, DOA:4/2551
Manganese (Mn)	0.6	g/100g	-	Manual on Organic Fertilizer Analysis, APSRDO, DOA:4/2551

อนุมัติผลโดย :

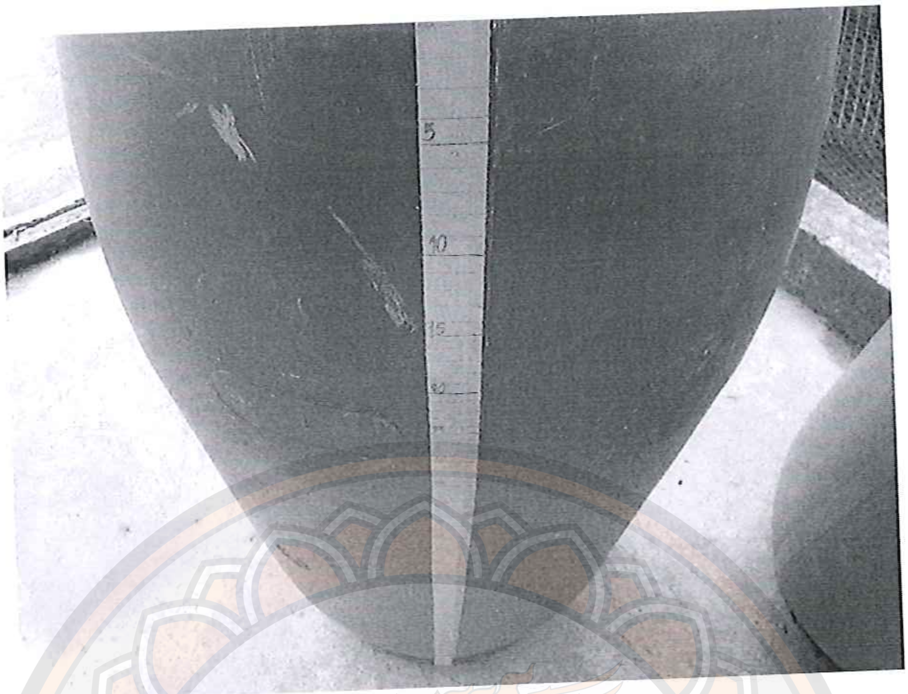
(นายเกียรติ ผาไสม)
ลงนามแทนผู้อำนวยการห้องปฏิบัติการ
สาขา ฉะเชิงเทรา
CERTIFIED

รายงานฉบับนี้มีผลเฉพาะกับตัวอย่างที่นำมาทดสอบเท่านั้น

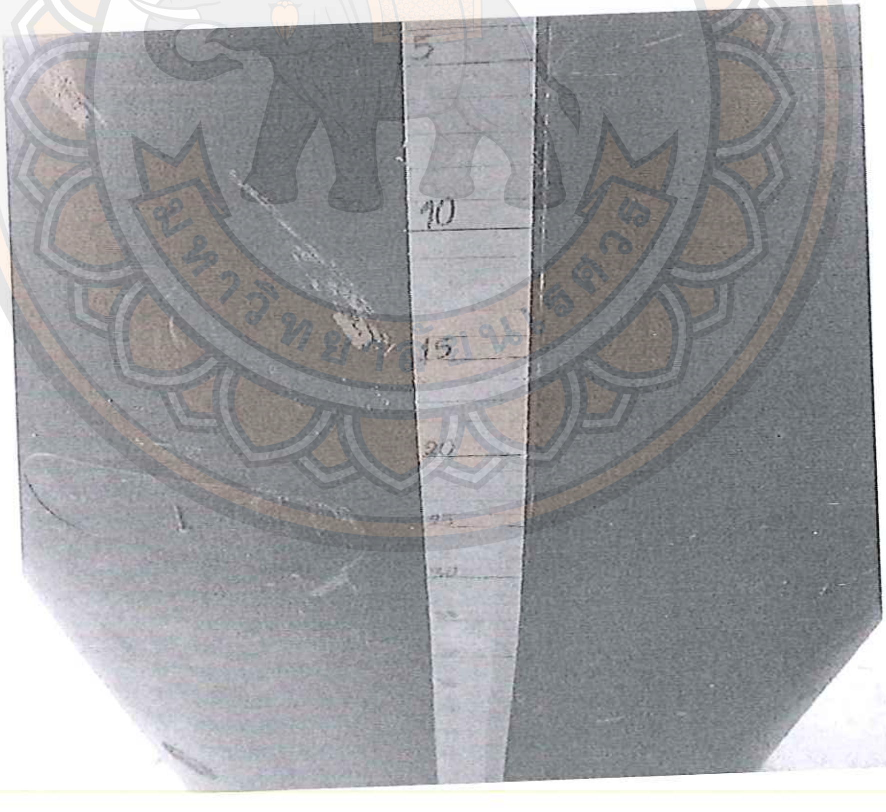
รายงานผลการทดสอบต้องไม่ถูกทำสำเนาเฉพาะเพียงบางส่วน โดยไม่ได้รับความยินยอมเป็นลายลักษณ์อักษรจากห้องปฏิบัติการ ยกเว้นทำทั้งฉบับ

FM-QP-24-01-001-R02(14/09/52)P1/1-CH

Figure 29 Analysis of biogas by-product



A



B

Figure 30 Biogas ollection assembly tank scale

Figure 31 Biogas tank temperature check point

Figure 32 Gas storage bag

Figure 33 Tuna solid waste mix and grinding

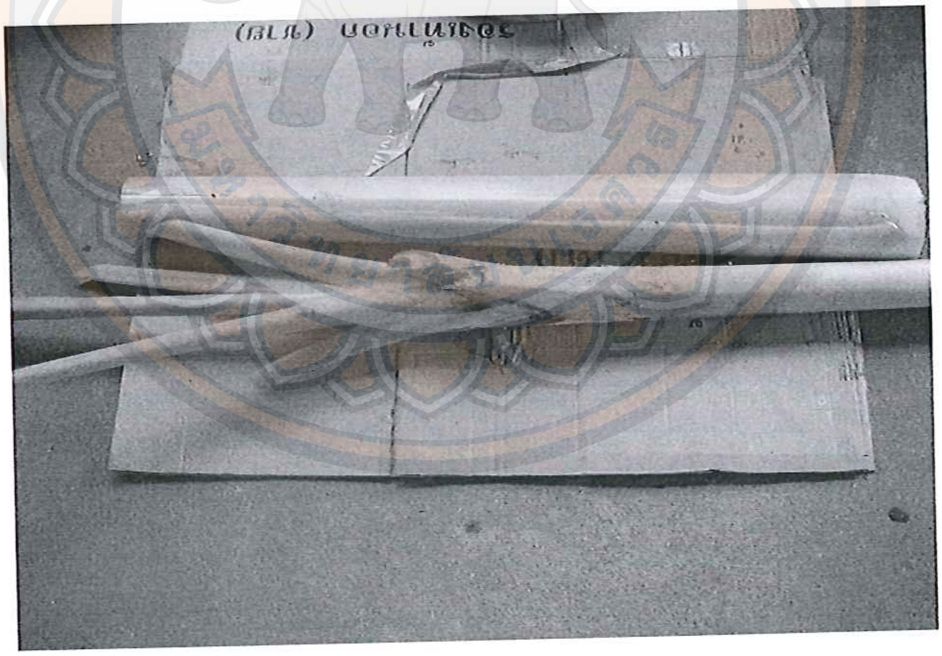


Figure 34 Banana crop residue tree

Figure 35 Banana crop residue tree grinding

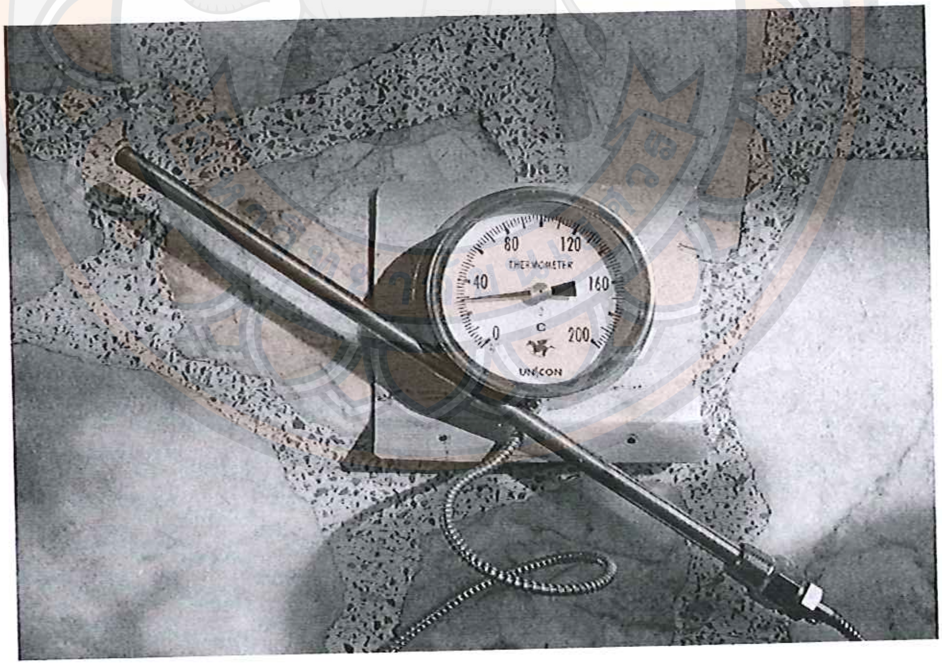


Figure 36 Thermometer