CHAPTER 2
THEORIES

2.1 Mango Processing

Mango processing presents many problems as far as industrialization and market expansion is concerned. The trees are alternate bearing and the fruit has a short storage life. The large number of varieties with their various attributes and deficiencies affects the quality and uniformity of processed products. Many of the processed products require peeled or peeled and sliced fruit. The lack of mechanized equipment for the peeling of ripe mangoes is a serious bottleneck for increasing the production of these products. A significant problem in developing mechanized equipment is the large number of varieties available and their different sizes and shapes. The cost of processed mango products is also too expensive for the general population in the areas where most mangoes are grown (FAO, 2011).

2.1.1 Ripe Mango Processing

Mangoes are processed into purée for re-manufacturing into dehydrated products. The purée can be preserved by chemical means, freezing, canning or storing in barrels. This allows a supply of raw materials during the remainder of the year when fresh mangoes are not available (FAO, 2011). Mango purée can be frozen, canned or stored in barrels for later processing. In all these cases, heating is necessary to preserve the quality of the mango purée (FAO, 2011).

"Mamuang Phaen" (Mango Sheet)

Mango sheets are another product made from ripe mango. These are thin sheets of concentrated mango pulp, chewy and eaten like candy. This is a traditional product that growers use to preserve their surplus mangoes. This product, if not made into sheet, is called "Mamuang Kuan" (Mango Paste). Both are eaten as desert (DOA, 2009). The dry mango sheet production process consists of a series of steps, which can be classified into 8 operations as shown below in Figure 2.1. The usable waste generated in peeling process.

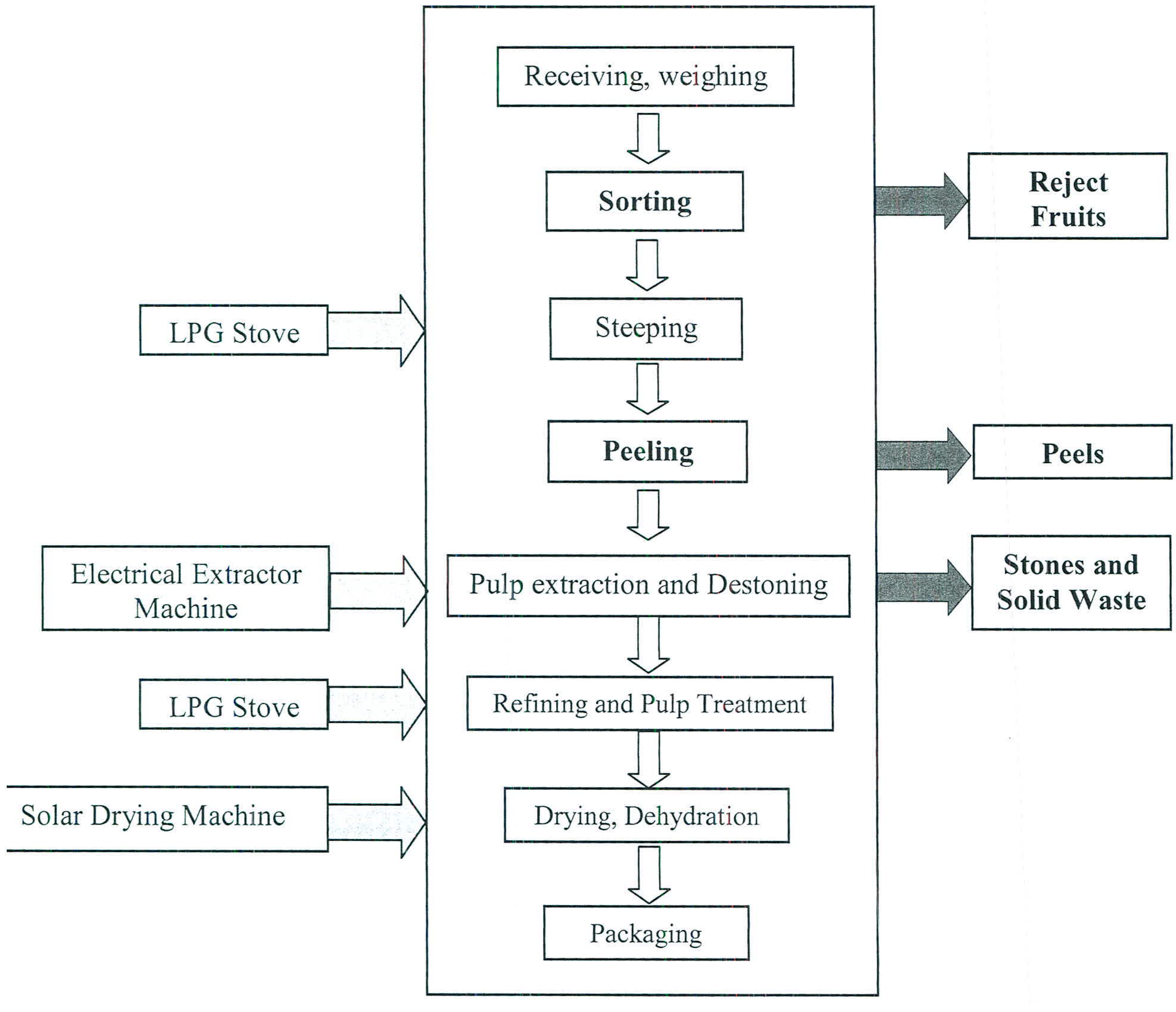


Figure 2.1 Process flow chart of dry mango sheet production base on Charassaeng Limited Partnership (site factory)

Figure 2.2 shows the time schedule of one-year of dry mango processing factory. The red bar shows harvesting period which lasts from March to June. At the same time, the pulp extraction process takes place, as shown by the yellow bar. This means that the mango waste including, mango peel and mango seeds, are generated only during these 4 months of activities. The mango season then ends and no such mango processing waste are generated until the next season. During the remaining eight months of the year, only the drying processing operation continues as shown by the green bar.

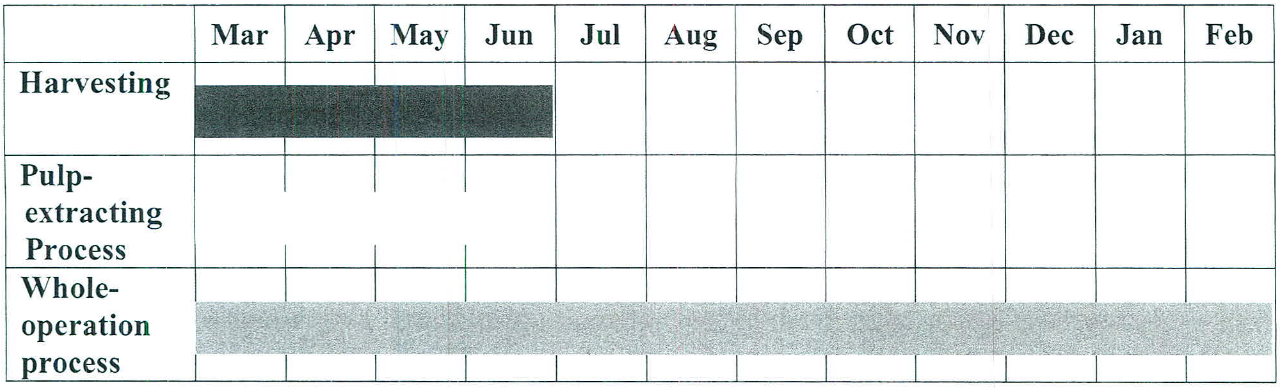


Figure 2.2 Schedule of annual operation of a dry mango processing factory (starting since March)

2.1.2 Waste Characteristics from Mango Processing

All compositions of waste are not equally degraded or converted to gas through anaerobic digestion. Anaerobic bacteria do not degrade lignin as well as some other hydrocarbons (Dennis and Burke, 2001). During processing of mango, the composition of mango wastes is given in Table 2.1. Nagle *et al.* (2011) reported composition by weight of mango analyzed in the laboratory (Nagle *et al.*, 2011). Kittiphoom (2011) examined component of mango obtained during mango pulp extraction (Kittiphoom, 2011).

Table 2.1 Mango residues composition in term of peel and seed

Component	**Percent by Weight (%)**	
Mango Peel	13-18*	15-20**
Mango Seed	6-12*	10-20**

*Source: * Adapted from Nagle et al., 2011, ** Kittiphoom, 2011*

Nagle *et al.* (2011) analyzed the characteristics of mango peel, including how moisture content (MC), ash content (AC), volatile solid (VS), and fixed carbon (FC) varies by type as illustrated in Table 2.2. Bulk density of mango peel according to their study was examined to 650 – 700 kg/m^3. Average value density used in this study is 675 kg/m^3. Other elemental analyze are presented in Table 2.3.

Table 2.2 Characteristics of mango peel from three varieties of mango

Mango Peel	**MC**	**AC**	**VS**	**FC**
	%wb	wt.%db	wt.%db	wt.%db
'Chok Anan'	73.21	4.86	70.14	24.99
'KhiewSawoey'	71.43	3.43	72.69	23.86
'MahaChanok'	74.32	4.36	71.75	23.89
Average	72.99±1.46	4.22±0.73	71.53±1.29	24.25±0.63

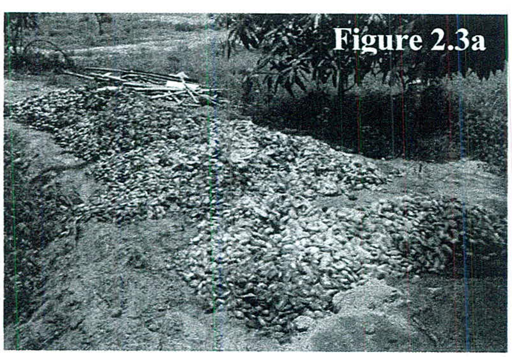
Table 2.3 Main elements found in mango peel such as carbon, hydrogen, oxygen, and nitrogen, etc.

	C	**H**	**O**	**N**	**K**	**P**
	wt.%db	wt.%db	wt.%db	wt.%db	mg kg^{-1}	wt.%db
Mango peel*	41.6	7.04	51.4	0.91	13,400	-

** Source: Nagle et al., 2011*

2.1.3 Waste Management

In Thailand, Maisuthikul and Phasuk (2008) examined the mango waste management of 103 Thai food manufacturers'. The results showed that 42.1% of mango processing factories in Thailand are small and medium enterprises which generated wastes in amount to 1,063 kg per week by means. About 73.7% of mango seed is used for sale, while, 26.3% had various management problems. From this study, the reference factory discards mango waste in nearby field as open dumping.



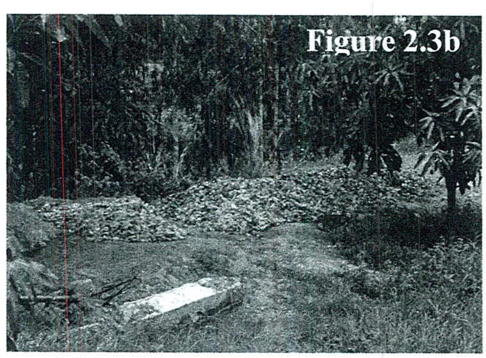


Figure 2.3a, b Mango waste management of reference factory.

2.2 Anaerobic Digesters of Fruit Wastes

Fruit processed waste is highly biodegradable as it is rich in organic matter and has high moisture content. Above 50% of moisture content, it is found that bio-conversion processes are more suitable than thermo-conversion processes (Bardiya, 1991). Biomethanation of fruit waste is the best suited treatment as the process not only add energy in the form of methane, but also results in a highly stabilized effluent which is almost neutral in pH and odorless (Bardiya *et al.,* 1996). The anaerobic digester would converse biodegradable organic material into methane (CH_4), carbon dioxide (CO_2), water and other gases. The microbes that produce methane gas cannot live in the oxygen circumstance. Therefore, the digesters have to be sealed to protect air. The methane producing microbial process is affected by numerous interdependent environmental factors, such as temperature, retention time, loading rate, and agitation. An effective production system must control all these factors through provisions within its structural and equipment components.

2.2.1 Functional Requirements for the Process

The microbes in the process are affected by numerous interdependent environmental factors, such as temperature, retention time, organic loading rate (OLR), and agitation (Persson *et al.,* 1979).

Temperature

The rate of solid conversion and the resultant gas production is closely related to temperature. Methane can be produced best in mesophilic range (29°C - 41°C) and thermophilic range (49°C - 60°C) (Persson *et al.,* 1979; Sorathia *et al.*, 2012). Thermophilic bacteria are very sensitive to changes within the digester, whereas mesophilic bacteria are more stable (Persson *et al.,* 1979; Sorathia *et al.*, 2012).

Retention Time

Substantial time is required for microbial activity to break down organic matter and convert it into gas. Furthermore, determined the size of the digester chamber is necessary for a given daily amount of organic matter input (Persson *et al.,* 1979). With the continuous type digester, new substrate is added at frequent intervals (one or more times daily) in amounts related to the retention time. The calculated retention time will normally not be the same as the actual treatment time for all individual particles in the slurry but will represent the average treatment time (Persson *et al.,* 1979). This period varies from place to place depending upon the climatic conditions and the location of the digester (Sorathia *et al.,* 2012). Retention time in the studied of mango processing waste by Somayaji (1992), was 15 days and to be used for this study.

Solid Concentration and Loading Rate

Solid concentration affects flowability for ease of mixing the slurry within the digester and for flow out of the digester (Persson *et al.,* 1979). The capacity of a digester to convert volatile solids into methane is related to its loading rate, which is defined as the amount of volatile solid fed to the digester per day per unit volume of the digester (Persson *et al.,* 1979). Babaee and Shayegan (2010) reported effect of organic loading rate on anaerobic digestion of vegetable waste in complete mix digester with semi continuous feed system. The reactor showed stable performance with highest biogas production (0.4 m^3/kg VS) and VS reduction of around 88% during loading rate of 1.4 kg VS $m^{-3}d^{-1}$. Kirtane *et al.* (2009) studied optimum OLR for mango peel kernel (MPK). The result was given 1.5 – 3.5 kg VS $m^{-3}d^{-1}$ OLR for MPK. Studies of OLR for fruit and vegetable waste could be summarized in Table 2.4

Table 2.4 OLR studies for fruit and vegetable wastes

	OLR (kg VS $m^{-3}d^{-1}$)	**Conditions**
Vegetable waste	1.4[a]	semi-continuous fed, complete mix reactor, 34°C, 8%TS
Mango peel kernel (MPK)	1.5-3.5[b]	30-35°C,

Source: [a]*Babaee and Shayegan,2010; bKirtane et al., 2009*

2.2.2 Types of Anaerobic Digesters for Solid Waste

Digester design has been found to exert a strong influence on the performance of a digester (William and David, 1999; Khalid *et al.,* 2011). Several types of digesters are currently in use, but the three major groups of digesters commonly in use are: (1) batch reactors, (2) one-stage continuously fed systems, and (3) two-stage or multi-stage continuously fed systems.

Batch Reactors

In a batch system, digesters are filled once with fresh waste, with or without the addition of seed material, and allowed to go through all degradation steps sequentially. Batch system perform like landfill in a box however, they achieve 50-100 fold higher biogas production rate than those observed in landfills (Vandevivere *et al.,* 2003). Batch reactor obtained biogas yield around 40% smaller than that obtained in continuously-fed one stage systems treating the same type of waste according to studies of De Baere (1999) which is the result of leachate channeling. The investment costs of batch system are significantly less than continuous-fed systems but the land area required by batch processes is larger.

One-Stage Systems

The biomethanization of organic waste is accomplished by a series of biochemical transformations. In one-stage systems, all reactions take place simultaneously in a single reactor. For most organic waste, one-stage systems perform as well as two-stage systems (Weiland, 1992; Vandevivere *et al.,* 2003). Many technical aspects need actually be taken into account and solved in order to guarantee a satisfactory process performance (Westergard and Tier, 1999; Farneti *et al.,* 1999). The pre-treatment necessary to condition the wastes in a slurry of adequate consistency and devoid of coarse or heavy contaminants (Vandevivere *et al.,* 2003). Another technical drawback of the complete mix reactor is the occurrence of short-circuiting, such a passage of a fraction of the feed through the reactor with a shorter retention time than average retention time of the bulk stream which diminish the biogas yield and impairs the proper hygienization of the waste (Vandevivere *et al.,* 2003).

Two-Stage Systems

Optimizing each reaction separately in different stages or reactors may lead to a larger, overall reaction rate and biogas yield (Ghosh *et al.,* 1999). In fact, the main advantage of two-stage systems is not a putative higher reaction rate, but rather, a greater biological reliability for waste, which may cause unstable performance in one-stage systems (Vandevivere *et al.,* 2003). The main advantage of the two-stage system is the greater biological stability it affords for very rapidly degradable waste like fruits and vegetables (Pavan *et al.,* 1999a). Paven *et al.* (1999a) compared the performances of the one-stage and two-stage systems by using pilot complete mix reactor fed with very rapidly hydrolysable bio-wastes from fruit and vegetables markets. The one-stage system failed at

3.3 kg VS m^{-3} d^{-1}, while the two-stage remained stable at an overall system OLR of 7 kg VS m^{-3} d^{-1}

2.2.3 Biogas Yield and Methane Content

There have been a number of reports on the utilization of mango peel waste as feedstock for biogas production (Table 2.5). Somayaji (1992) studied biomethanation of mango peel waste from mango processing factory and recorded 0.33 m^3 kg^{-1} TS added with 53% methane content at an hydraulic retention time (HRT) of 15 days. Microbiological pretreatment of mango peel was studied by Sumithra and Nand (1989). The feed slurry contained 6% TS (w/v), and the temperature was maintained at 30 °C. The biogas contained 58% methane and its yield was 0.36 m^3 kg^{-1} VS. The process was carried out under semi-continuous fermentation conditions (Koumanova and Saev, 2008).

Table 2.5 Biogas production rate and methane content of mango peel waste

Substrate	**Biogas yield**	**Methane content**	**Conditions**	**References**
Mango peel	0.33m^3 kg^{-1} TS*	53%	HRT 15 days	Somayaji (1992)
Mango peel	0.36 m^3 kg^{-1} VS**	58%	6% TS (w/v), at 30 °C, semi-continuous conditions	Sumithra and Nand (1989)

**TS = Total Solid, **VS = Volatile Solid*

2.2.4 Volatile Solid Reduction and Solid Digestate

As digesters are operated under steady state conditions, the influent feed rate is assumed to be the same as the digester wasting rate. This assumption simplified the mass balance calculation because the influent flow rate and effluent flow rate cancel each other out. Dry residual weights are the materials remaining after digestion, and include both inert (non-biodegradable) and refractory (difficult to digest) organic materials. The volume of the effluent is slightly less than the volume of the input, due to biodegradation of some of volatile solids (Persson *et al.,* 1979). Bouallagui *et al.* (2005) studied both fruit and vegetable wastes in anaerobic digestion which presented percent of VS removal in continuous one-stage CSTR are 88% and 83%. Lin *et al.* (2011) examined biochemical methane potentials for typical fruit and vegetable waste (FVW). The result presented percentage of volatile solid removal efficiency is approximately 70%.

2.2.5 Main Components of the System

The principal components of an anaerobic digester system for biogas production on a farm include one or more digester chambers, a facility for slurry preparation, storage for the processed slurry, a gas collecting space, and an area for the mechanical equipment needed for slurry heating and agitation. The flow chart (see Figure 2.4) shows how these functions relate to each other in the digester system. Components should be arranged to permit a simple flow path for the material through the system and to minimize heat loss. Ease of accessibility to the various components should be emphasized, since these and the related equipment will require inspection, adjustment, and maintenance. Safety considerations must be considered in planning a digester system (Persson *et al.*, 1979).

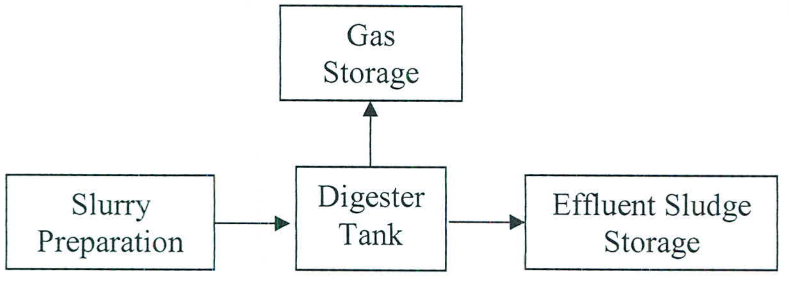


Figure 2.4 Functions in an anaerobic digester.

A biogas system consists of a series of units, including an intake tank, a digester tank, a digested slurry tank, a gas storage tank, and a biogas handling system, which includes inlet and outlet piping, a pressure regulator, and a gas meter. The detail of each unit is provided below.

Slurry Preparation: A slurry preparation area should have adequate space for operation and maintenance work, which could be determined from the daily amount of waste generated and mixing water to preparing flowing slurry and also include space for mechanical feeding system.

Digester Tank: The size of the digester tank would be evaluated by input slurry feed per day times the retention time plus space for temporary gas storage.

The volume of a digester tank can be derived from the following formulas:

V_{req} = $V_{gas} + V_{dig}$ ....Equation (1)

where

V_{req} = Required volume of digester tank (m^3)

V_{gas} = Gas volume in digester tank (m^3)

V_{dig} = Slurry volume in digester tank (m^3)

and

V_{gas} = $h_1 S$ .... Equation (2)

where

h_1 = Clear distance between cover slab and liquid surface in the digester tank (m), normally be 30-40 cm

S = Projection area of bottom slab of the digester tank (m^2)

and

V_{dig} = T x V_{dm} .... Equation (3)

where

T = Retention time of the slurry in the digester (days)

V_{dm} = Daily amount of slurry waste fed in the digester (m^3/day)

However, the volume of gas generated during the digestion, which collects in the space provided in the digester, is temporary storage. This space should be about 10 to 20 percent of the total digester volume. This minimum size of 10 to 20 percent is frequently inadequate for intermittent gas use. However, it is usually less expensive to provide other forms of gas storage than it is to construct and oversized digester tank (Persson *et al.*, 1979). The results of the sizing of the large-scale and bench-scale biogas systems and biogas production potential are presented and discussed in the next chapter.

Gas Storage: The capacity of the storage has to be considered differently from daily gas production and gas usage per day. Typically, the storage must be adequate to meet factory need. For small scale factory, the gas storage should be as storage at approximately atmospheric pressure.

2.2.6 Controls and Safety Devices

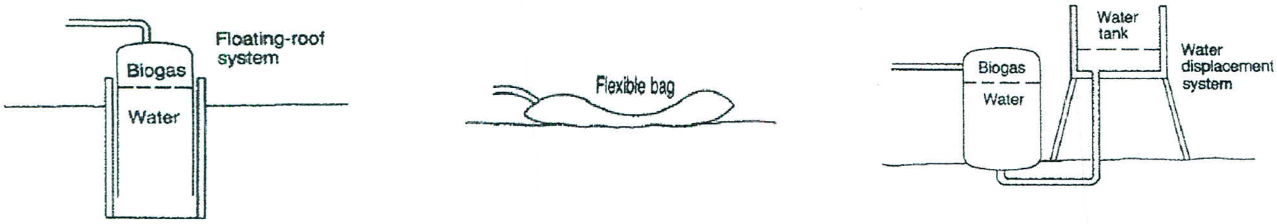
Since the anaerobic digester for biogas production is a complex biochemical processing system, it requires accurate control of many components for high efficiency and safety. It should be assumed that any component of the system can fail at a critical moment, requiring the availability of a substitute method of maintaining proper operation until the malfunctioning component can be repaired. In order to limit the need for manual labor and supervision, manual control of operations should be confined to the initial starting of the process and overseeing that the system functions properly. Proper controls and alarms should be installed to keep equipment and process functioning within design limits and to call the operator's attention to malfunctions.

Gas System: Control devices are needed to avoid excessively high or low pressures within the digester. A floating roof automatically eliminates the danger of excessive pressure in the digester. If more gas is produced than is used, the roof will rise and allow excess gas to escape under the edge of the roof. As an alternative, the upper limit of gas pressure in the system can be controlled by a pressure sensor coupled to a solenoid valve.

Slurry System: Daily feeding of the anaerobic digester is a routinely repeated operation. Slurry handling conveyors and pumps should be equipped with pressure relief and flow limit control devices to guard against slugs of material entering the slurry system and causing overflow, stoppage, or breakage of the equipment.

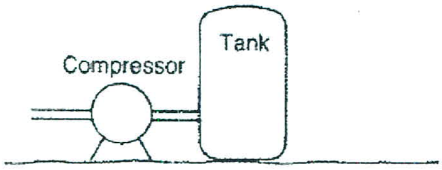
2.2.7 Gas Storage

The digester produces gas continuously, making it well suited for use where fuel is needed continuously, such as in space heating systems. However, the storage volume under a floating roof is normally considerably less than the daily gas production from the digester. Therefore, larger storage volumes are desirable for the best possible use of the gas. Several types of gas storage systems are illustrated in Figure 2.5.

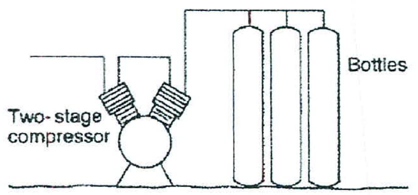


A.1 A.2 A.3

A. Storage at approximately atmospheric pressure



B. Medium pressure storage



C. High pressure storage

Figure 2.5 Biogas storage systems. Sizable gas storage systems require a considerable investment (Persson *et al.,* 1979).

2.2.8 Anaerobic Digester (AD) Products

Biogas: If the net output of biogas from the digester is used for heating purposes, its value should be compared to the heating value of natural gas, LPG, or fuel oil. Net biogas output (60% CH_4) content has equivalent fuel values for uses other than heating the digester (Smith *et al.,* 2001).

Processed Sludge as Fertilizer: The liquid from the process could be used as a liquid fertilizer if the quality was high enough. The solid digestate is usually treated by composting aerobically for one or two weeks to stabilize the waste. This reduces odor and produces a compost-like material. If the composted digestate quality is sufficiently high, it can be used for agriculture, in which case the climate change impacts are considered to be the same as aerobically-produced composts. After these digested slurries are applied to orchard, it continues to degrade, releasing more carbon dioxide and forming humic compounds. Digestate applications may increase the store of soil organic matter. This sink should be accounted for in the calculation of GHG emission as a negative contribution to the emission total. The use of digestate in the orchard substitute inorganic (chemical) fertilizers would bring GHG emission benefits.

The GHG emissions concerned with fertilizer manufacturing that are avoided through the use of digestate slurry would be calculated. The estimation of the amount of the GHGs avoided if the nutrient in digestate slurry completely substitutes for the use of mineral fertilizer are shown in Table 2.6.

Table 2.6 Potential greenhouse gas emissions avoided in fertilizer manufacturing if compost displaces mineral fertilizers

Nutrient element	**$kgCO_{2eq}$/kg element**	**Nutrient content in compost kg/tonne fresh weight**	**Avoided emission $kgCO_{2eq}$/tonne of compost (1:1 replacement)**
N	5.29	6.2	-32.8
P	0.52	2	-1.0
K	0.38	4.5	-1.7
Total			-35.5

Source:Smith et al., 2001.

2.2.9 Costs of Anaerobic Digestion and Biogas Production

There are three main expenditure types connected with the implementation of a biogas plant:

- capital costs
- manufacturing and material costs (production costs)
- operation and maintenance costs (running costs)

Capital Costs

Capital costs consist of redemption and interest for the capital taken up to finance the construction costs. Interest rates for loans in Thailand were assumed by using the average interest rate in 2012 (BOT, 2012), which was 7%.

Production Costs

The production costs include all expenses and lost income, which are necessary for the erection of the plant e.g.: the land, excavation-work, construction of the digester and gas holder, the piping system, the gas utilization system, the dung storage system and other buildings. The construction costs comprise wages and material. The production costs of biogas plants are determined by the following factors:

- purchasing costs or opportunity costs for land that is needed for the biogas plant and slurry storage
- model of the biogas plant
- size and dimensioning of the biogas unit
- amount and prices of material
- labor input and wages

Operating Costs

The operation and maintenance costs consist of wage and material costs for:

- acquisition (purchase, collection and transportation) of the substrate
- water supply for cleaning the stable and mixing the substrate
- feeding and operating of the plant
- supervision, maintenance and repair of the plant
- storage and disposal of the slurry
- gas distribution and utilization
- administration

The operating costs of a biogas plant are just as important as the construction costs, and normally amount to no more than 4% of the initial biogas plant costs per year.

Average Cost

For a rough calculation of the typical cost of a simple biogas plant in a small industry, the following values can be used: overall cost of the plant not counting land costs constitutes 15,000 Baht per cubic meter of digester. Around 30 – 40% of overall cost comes from the cost of metal digester vessel.

The cost of biogas plants per volume unit decreases with an increase in digester volume. However, with increase of plant size cost of gas piping is increased and overall cost stays approximately the same per unit of digester volume. Plants with no-heating are more suitable for tropical zone countries as Thailand. Individual prices are calculated for every project separately depending on current material prices and availability and labor costs.

2.2.10 Lifetime of Plants

The economic life span of plants can be estimated to be up to 15 years, provided maintenance and repair are carried out regularly. Some parts of the plant have to be replaced after 8 - 10 years. Therefore, real prices and interest rates should be used in the calculations. For cost calculation inflation rates are irrelevant as long as construction costs refer to one point of time. However, in calculating the cash reserves put aside for servicing and repair the inflation rate must be considered.

2.3 Wastes Disposal and GHG Emissions

2.3.1 General Concept

Greenhouse Gases (GHGs) are emitted by burning or burial. The most important GHGs in waste management are CO_2, CH_4, N_2O, and perfluorocarbons (PFCs). CO_2 is by far the most common. Carbon dioxide emitted from waste disposal is not considered to represent a man-made source of greenhouse gas, because the process returns to the atmosphere, which has been stored as biomass. This may be contrasted with the burning of fossil fuels, where carbon is released back to the atmosphere after underground storage, as coal, oil or gas, for hundreds of millions of years. Consequently, the conversion of atmospheric carbon dioxide to atmospheric methane through the waste life cycle will have a man-made influence on the natural greenhouse effect, and global climate. Most CO_2 emissions result from energy use, particularly fossil fuel combustion. A great deal of energy is consumed when a product is manufactured and then discarded. This energy is used in the following stages: (1) extracting and processing raw materials, (2) manufacturing products, (3) managing products at the end of their useful lives, and (4) transporting materials and products between each stage of their life cycles. The energy consumed during use would be about the same whether the product is made from virgin or recycled inputs.

Methane, a more potent GHG, is produced when organic waste decomposes in an anaerobic environment, such as a landfill. One tonne of biodegradable waste produces between 200 and 400 m^3 of landfill gas. Methane is also emitted when natural gas is released into the atmosphere during the production of coal or oil, the production or use of natural gas, and agricultural activities. However, fifty percent of landfill emissions include methane, a more potent greenhouse gas. Global emissions of methane from landfilled waste have been estimated at approximately 40 million tonnes per year.

N_2O results from the use of commercial and organic fertilizers and fossil fuel combustion, as well as other sources. Although the quantities of perfluorocarbons emitted are small, these gases are significant because of their high global warming potential.

Table 2.7 Values for global warming potential in the AR4 WG1, technical summary reflect radiative forcing estimates and lifetimes

Designation or Name	**Chemical formula**	**100 yr GWP (SAR)**	**100 yr GWP (AR4)**
Carbon dioxide	CO_2	1	1
Methane	CH_4	21	25
Nitrous oxide	N_2O	310	298

Source: IPCC, 2007

2.3.2 Assessment of Methane Emissions from Solid Waste Disposal Sites

Organic waste in solid waste disposal sites (SWDSs) is broken down by bacterial action in the formation of CH_4 and CO_2. Landfill gas contains approximately 50 percent CH_4 by volume. SWDSs are considered different between regions (IPCC, 1996). Even though, understanding of significant influence factor to CH_4 generation from land disposal can reduce the uncertainty with emission estimates.

The IPCC (1996) method is the simplest one for calculating CH_4 emissions from SWDSs. It is based on a mass balance approach, and does not incorporate any time factors into the methodology. Rather, this methodology assumes that all potential CH_4 is released from waste in the year that the waste is disposed of. Although this is not what actually occurs, it gives a reasonable estimate of the current year's emissions if the amount and composition of the waste disposed of has been relatively constant over the previous several years. If, however, there have been significant changes in the rate of waste disposal, this simple method will likely not provide a good estimate of current emissions.

As mentioned above, the default methodology is a mass balance approach that involves estimating the degradable organic carbon (DOC) content of the solid waste, i.e., the organic carbon that is accessible to biochemical decomposition, and using this estimate to calculate the amount of CH_4 that can be generated by the waste and the application of different DOC values to the waste generated within each of these regions. It is the most widely accessible, easy to apply methodology for calculating country-specific emissions of CH_4 from SWDSs. It requires the least amount of data to perform the calculations, and it can be modified and refined as the amount of data available for each country increases. This approach was provided as the default methodology in the IPCC Guidelines (IPCC, 1995). The revised default methodology provided here modifies the IPCC Guidelines (IPCC, 1995) in three important ways:

- Rather than distinguishing between "landfills" and "open dumps", the methodology uses a continuum of solid waste disposal sites, characterized by the degree of waste management and depth.
- A methane correction factor (MCF) is assigned to each of the categories referring to the degree of waste management and depth (see Table 2.8)
- Default DOC values are provided for different waste streams so that countries can calculate the DOC content of their waste rather than relying on single default values.
- Emphasizing the fact that this methodology estimates CH_4 generation rather than emission, and that oxidation often occurs in the upper layers of the waste mass and onsite cover material. A CH_4 oxidation factor (OX) is included in the equation (currently equal to 0, pending the availability of further data).

The determination of annual CH_4 emissions for each country or region can be calculated by Equation 4:

$$Methane\ emissions\left(\frac{Gg}{yr}\right) = \left(MSW_T * MSW_F * MCF * DOC * DOC_F * F * \frac{16}{12} - R\right) * (1 - OX)$$

Equation (4)

where: MSW_T = total MSW generated (Gg/yr)

MSW_F = fraction of MSW disposed to solid waste disposal sites

MCF = methane correction factor (fraction)

DOC = degradable organic carbon (fraction)

DOC_F = fraction DOC dissimilated (default is 0.77)

F = fraction of CH_4 in landfill gas (default is 0.5)

R = recovered CH_4 (Gg/yr)

OX = oxidation factor (fraction - default is 0)

Table 2.8 SWDS classification and methane correction factors

Type of site	Methane correction factor (MCF) default values
Managed	1.0
Unmanaged – Deep (≥ 5 m. waste)	0.8
Unmanaged – Shallow (< 5 m. waste)	0.4
Default value – uncategorized SWDSs	0.6

To assist countries in calculating the DOC of waste streams, a set of default DOC values for different waste types is given in Table 2.9. Note that these values are for wet waste.

Fraction of CH_4 in generated landfill gas (F) is typically assumed to be 50 percentage of CH_4. Only material including substantial amounts of fat or oil can generate gas with substantially more than 50 percent CH_4. The use of the IPCC default value for the fraction of CH_4 in landfill gas (0.5) is therefore encouraged.

Table 2.9 Default DOC values for major waste streams

Waste stream		Percentage DOC (by weight)
A.	Paper and textiles	40
B.	Garden and park waste, and other (non-food) organic putrescibles	17
C.	Food waste	15
D.	Wood and straw waste [a]	30

[a] excluding lignin C
Source: Bingemer and Crutzen, 1987.

Methane recovery (R) is the amount of CH_4 generated in SWDS that is recovered and burned in a flare or energy recovery device. CH_4 oxidation is by methanotrophic micro-organisms in cover soils and can range from negligible to 100 percent of internally produced CH_4. The thickness, physical properties and moisture content of cover soils directly affect CH_4 oxidation (Bogner and Matthews, 2003). Studies show that sanitary, well-managed SWDS tend to have higher oxidation rates than unmanaged dump sites. The oxidation factor at sites covered with thick and well-aerated material may differ significantly from sites with no cover or where large amounts of CH_4 can escape through cracks/fissures in the cover.

Field and laboratory CH_4 and CO_2 emission concentrations and flux measurements that determine CH_4 oxidation from uniform and homogeneous soil layers should not be used directly to determine the oxidation factor, since in reality, only a fraction of the CH_4 generated will diffuse through such a homogeneous layer. Another fraction will escape through cracks/fissures or via lateral diffusion without being oxidized. Therefore, unless the spatial extent of measurements is wide enough and cracks/fissures are explicitly included, results from field and laboratory studies may lead to over-estimation of oxidation in SWDS cover soils. The default value for oxidation factor is zero (see Table 2.10). The use of the oxidation value of 0.1 is justified for covered, well-managed SWDS to estimate both diffusion through the cap and escape by cracks/fissures. The use of an oxidation value higher than 0.1, should be clearly documented, referenced, and supported by data relevant to national circumstances. It is important to remember that any CH_4 that is recovered must be subtracted from the amount generated before applying an oxidation factor.

Table 2.10 Oxidation factor (OX) for SWDS

Type of site	**Oxidation factor (OX)** **Default value**
Managed [1], unmanaged and uncategorized SWDS	0
Managed covered with CH_4 oxidizing material [2]	0.1

[1] Managed but not covered with aerated material
[2] Example: soil, compost

2.4 Financial Assessment

A financial assessment is a technique used to determine whether a planned action will turn out good or bad. It is most commonly done on financial questions. Since the financial analysis relies on the addition of positive factors and the subtraction of negative ones to determine a net result.The set of costs concern in the analysis occur throughout the entire useful life of the asset. The cost categories for analysis can be separated into the following parts: (1) investment, (2) operation, (3) maintenance, and (4) revenues. Financial assessment can be applied to any capital investment decision. It is most relevant when high initial costs are traded for reduced future cost (Chirarattananon, 2013).

2.4.1. Plan Financial Assessment

The initial planning phase allows the specific objectives of the financial assessment to be defined and specified, along with any assumptions that must be made regarding the assets and their associated costs. Typically, the objectives of the analysis are specified in terms of the outputs that are required by management for decision making, a process that relates back to the above notion of shaping the analysis for the particular application in question.

The planning phase is also used to identify any limitations, assumptions or constraints that may affect the set of options which are involved in the decision problem. As the analysis proceeds, changes in these constraints may in turn increase or decrease the number of possible project alternatives.

2.4.2. Select/Develop Financial Model

Once the objectives have been determined, the appropriate financial model can be selected. This step is where differences between financial assessment applications usually become evident, as different applications call for different analysis frameworks to be employed. The financial assessment can be broken down into a structure as simple as the four stages of capital investment cost, operation cost, revenues, or a more complex breakdown can be applied.

An important factor in developing the financial model is the collection of the appropriate data. Identifying the required data and the sources of this data can often take up a large proportion of the development process, and as will be discussed below, this can sometimes be deterrence in the application of financial assessment.

2.4.3. ApplicationFinancial Model

Net Present Value (NPV)

The net present value for single costs occurs at one or more times during the study period at non-annual intervals. Initial investment cost, replacement costs, residual values, maintenance cost scheduled at intervals longer than one year, and repair costs are usually treated as single costs. The single present value (PV) factor will be used to calculate the present value, PV, of a future cash amount occurring at the end of year n, F_n, given a discount rate, I (Chirarattananon, 2013).

The net present value (NPV) can be calculated using the following Equation (5):

$$NPV = \frac{F_n}{(1+i)^n} \qquad \text{Equation (5)}$$

Decision Rule of NPV

NPV > 0 : Accept the project

NPV < 0 : Reject the project

Internal Rate of Return (IRR)

The internal rate of return (IRR) is another time-discounted measure of investment worth. The IRR is a rate of return used in capital budgeting to measure and compare the profitability of investments. The internal rate of return on an investment or project is the "annualized effective compounded return rate" or "rate of return" that makes the net present value (NPV) of all cash flows (both positive and negative) from a particular investment equal to zero. It can also be defined as the discount rate at which the present value of all future cash flow is equal to the initial investment or in other words the rate at which an investment breaks even.

In more specific terms, the IRR of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment.

The internal rate of return (IRR) can be calculated using the following Equation (6):

$$NPV = \sum_{n=0}^{n} \frac{C_n}{(1+r)^n} = 0$$

Equation (6)

where

n = year,

C = cash flow,

r = internal rate of return (IRR), and

NPV = net present value.