BIOGAS PRODUCTION FROM FRUIT AND VEGETABLE WASTES MIXED WITH COW MANURE BY USING A LOW-SOLIDS ANAEROBIC DIGESTER

JARASSRI RUNGVICHANIWAT

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J. Rungvivat

Miss Jarassri Rungvichaniwat
Candidate

Bundit Channarong

Lect.Bundit Channarong,
M.Eng. (Environmental Engineering)
Major-Advisor

Kobkaew M.

Asst.Prof.Kobkaew Manomaipiboon,
Dr.P.H. (Environmental Science)
Co-Adivisor

Rassmi Hoon

Assoc.Prof.Rassmidara Hoonsawat,
Ph.D.
Dean
Faculty of Graduate Studies

C. Yuwaree

Lect.Chumporn Yuwaree,
M.Sc. (Appropriate Technology for Resources Development)
Chair
Master of Science
Programme in Appropriate Technology for Resources and Environmental Development.

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on
June 9, 2003

J. Rungvinat

Miss Jarassri Rungvichaniwat
Candidate

Bundit Chamarong

Lect.Bundit Channarong,
M.Eng. (Environmental Engineering)
Chair

Usa Viseshasumana

Kobkaew M.

Asst.Prof.Usa Viseshasumana,
M.Sc.(Technology of Environmental Management)
Member

Asst.Prof.Kobkaew Manomaipiboon,
Dr.P.H.(Environmental Science)
Member

Assoc.Prof.Rassmidara Hoonsawat,
Ph.D.
Dean
Faculty of Graduate Studies
Mahidol University

Assoc.Prof.Anuchat Poungsomlee,
Ph.D. (Human Ecology)
Dean
Faculty of Environment and Resource Studies
Mahidol University

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Jarassri Rungivchaniwat

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BIOGAS PRODUCTION FROM FRUIT AND VEGETABLE WASTES MIXED WITH COW MANURE BY USING A LOW-SOLIDS ANAEROBIC DIGESTER

JARASSRI RUNGVICHANIWAT 4337313 ENAT/M

M.Sc. (APPROPRIATE TECHNOLOGY FOR RESOURCES AND ENVIRONMENTAL DEVELOPMENT)

THESIS ADVISORS: BUNDIT CHANNARONG, M.Eng. (ENVIRONMENTAL ENGINEERING), KOBKAEW MANOMAIPIBOON, Dr.P.H. (ENVIRONMENTAL SCIENCE)

ABSTRACT

The purpose of this reseaech was to determine the biogas production as well as the efficiency in total solids (TS) and volatile solids (VS) reduction from fruit and vegetable wastes (FVW) mixed with cow manure (CM) by using a low-solids anaerobic digester. The four bench-scale digesters were operated at the same hydraulic retention time of 31.25 days with a digester volume of 12.5 liters. The various ratios of mixed wastes to the volatile solids of FVW and CM were 100:0, 80:20, 60:40 and 40:60 and were used as waste-feed for the digesters.

The results indicated that the efficiency in total solids reduction at various ratios of the mixed wastes were from 36.84-73.12 %, whereas, the volatile solids reduction were in the range of 43.83-80.63 %. The amount of biogas production was varied from 0.67-0.73 m^3/m^3 of digester-day or the equivalent of 0.12-0.30 m^3/kg of VS feed-day. The composition of the biogas, consisted of methane from 48.64-53.26 % and carbon dioxide was in the range of 29.84-41.28 %. Furthermore, the methane production varied from 0.16-0.37 m^3/m^3 of digester-day or the equivalent of 0.07-0.15 m^3/kg of VS feed-day. In all cases, the digesters could be operated without addition of chemicals or nutrients into the system.

These results clearly demonstrated that the digester, which was fed with mixed waste, of FVW and CM, of 80:20 could produce the highest biogas production (0.73 m^3/m^3 of digester-day or 0.30 m^3/kg of VS feed-day). In addition, this digester also produced a large amount of methane (0.37 m^3/m^3 of digester-day or 0.15 m^3/kg of VS feed-day). With a TS and VS reduction of 60.61 % and 66.77 %, respectively.

KEY WORDS: BIOGAS / FRUIT AND VEGETABLE WASTE / COW MANURE / A LOW-SOLIDS ANAEROBIC DIGESTER

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การผลิตก๊าซชีวภาพจากเศษผักและผลไม้ผสมกับมูลโค โดยการใช้ถังย่อยสลายแบบไม่ใช้อากาศประเภทปริมาณของแข็งต่ำ (BIOGAS PRODUCTION FROM FRUIT AND VEGETABLE WASTES MIXED WITH COW MANURE BY USING A LOW-SOLIDS ANAEROBIC DIGESTER)

จรัสศรี รุ่งวิชานิวัฒน์ 4337313 ENAT/M

วท.ม. (เทคโนโลยีที่เหมาะสมเพื่อการพัฒนาทรัพยากรและสิ่งแวดล้อม)

คณะกรรมการควบคุมวิทยานิพนธ์ : บัณฑิต ชาญณรงค์, วศ.ม. (วิศวกรรมสิ่งแวดล้อม), กอบแก้ว มโนมัยพิบูลย์, Dr.P.H. (ENVIRONMENTAL SCIENCE)

บทคัดย่อ

งานวิจัยนี้ มีวัตถุประสงค์เพื่อการศึกษาประสิทธิภาพในการผลิตก๊าซชีวภาพและการกำจัดของแข็งจากเศษผักผลไม้ผสมมูลโค โดยการใช้ถังย่อยสลายแบบไม่ใช้อากาศประเภทปริมาณของแข็งต่ำ ซึ่งกำหนดให้อัตราส่วนระหว่างปริมาณของแข็งระเหยของเศษผักและผลไม้ต่อปริมาณของแข็งระเหยของมูลโคเท่ากับ 100:0 80:20 60:40 และ 40:60 เพื่อป้อนเข้าสู่ถังย่อยสลายแบบไม่ใช้อากาศขนาด 12.5 ลิตร จำนวน 4 ถัง โดยมีระยะเวลาเก็บกัก 31.25 วัน

จากการศึกษาการย่อยสลายแบบไม่ใช้อากาศของของเสียประเภทเศษผัก ผลไม้ ผสมมูลโค ทั้ง 4 อัตราส่วนพบว่าประสิทธิภาพการกำจัดของแข็งทั้งหมดอยู่ในช่วงร้อยละ 36.84 - 73.12 และประสิทธิภาพในการกำจัดของแข็งระเหยอยู่ระหว่างร้อยละ 43.83-80.63 โดยมีประสิทธิภาพในการผลิตก๊าซชีวภาพอยู่ในช่วง 0.67-0.73 ลูกบาศ์กเมตร/ลูกบาศ์กเมตรของปริมาตรถัง/วัน หรือ 0.12-0.30 ลูกบาศก์เมตร/กิโลกรัมของของแข็งระเหยที่เข้าสู่ระบบ/วัน และองค์ประกอบของก๊าซชีวภาพในการทดลองนี้ประกอบด้วยก๊าซมีเทนอยู่ในช่วงร้อยละ 48.64-53.26 และก๊าซคาร์บอนไดออกไซด์อยู่ในช่วงร้อยละ 29.84-41.28 โดยปริมาตรของก๊าซมีเทนที่ผลิตได้อยู่ในช่วง 0.16-0.37 ลูกบาศ์กเมตร/ลูกบาศ์กเมตรของปริมาตรถัง/วัน หรือ 0.07-0.15 ลูกบาศก์เมตร/กิโลกรัมของของแข็งระเหยที่เข้าสู่ระบบ/วัน โดยถังย่อยสลายทั้งหมดสามารถดำเนินระบบได้โดยไม่ต้องเติมสารเคมีหรือสารอาหารใดๆลงในระบบ

สรุปผลการศึกษาได้ว่าถังย่อยสลายที่ป้อนด้วยวัตถุดิบที่มีอัตราส่วนเศษผักและผลไม้ต่อมูลโค 80:20 สามารถผลิตก๊าซชีวภาพได้สูงสุด เท่ากับ 0.73 ลูกบาศ์กเมตร/ลูกบาศ์กเมตรของปริมาตรถัง/วัน หรือ 0.30 ลูกบาศก์เมตร/กิโลกรัมของของแข็งระเหยของวัตถุดิบที่เข้าสู่ระบบ/วัน และสามารถให้ปริมาตรก๊าซมีเทนสูงสุด 0.37 ลูกบาศ์กเมตร/ลูกบาศ์กเมตรของปริมาตรถัง/วัน หรือ 0.15 ลูกบาศก์เมตร/กิโลกรัมของของแข็งระเหยที่เข้าสู่ระบบ/วัน โดยมี ประสิทธิภาพในการกำจัดของแข็งทั้งหมดและของแข็งระเหยเท่ากับร้อยละ 60.61 และร้อยละ 66.77 ตามลำดับ

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CHAPTER I
INTRODUCTION

From the energy crisis of the increasing of the energy consumption. In 2001, the energy consumption increased 3.8 percent from 2000. As the local energy resource could not support this demand, Importation of crude oil and fuel from aboard was the only way to solve this problem. However, this way resulted in loss of a large amount of money and the environmental problems from the transportation (Chirapol, 2000). The research and development of renewable energy were the alternative way to reduce these problems .The renewable energy, which is clear energy, has no bad effect on the environment and their resource is easy to find locally. Biogas technology, which is one type of renewable energy, is a favorable technology at present because of the benefit of energy and fertilizer. Besides that, biogas technology can reduces the environmental problem by transformation organic wastes to energy.

Fruit and vegetable wastes (FVW) are the biodegradable wastes that generate everyday. In the year 2001, biodegradable wastes approximate 6.4 million-ton generated from the community of Thailand. A lot of environmental problems resulted from these wastes such as the bad odor and disease; however, these wastes can be use for producing biogas. Sakchai(1983) presented that the biodegradable wastes 1 kg of VS feed could produce biogas production between 0.25-0.67 m^3 with the energy content of around 23 $MJ/m^{3.}$

Cow manure (CM) is an animal waste from farm that was generated every day. Department of Alternative Energy Development and Efficiency (Thailand) reported in 1997 that cow manure was generated 107.532 million-ton total dry weight per year. This quantity can produce energy 5305.78 TJ by biogas technology. Although some amount of cow manure was used for produce the energy, but the remains was discharged to river and the caused of water pollution.

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The biodegradable waste of FVW and CM were available to use for producing the biogas and co-digestion is the alternative operation to improve the quality and quantity of biogas. This operation can producing biogas by using mixed wastes (two or more waste mixed together). The co-digestion improves the biogas yields due to positive synergism of the microorganism, which is established in the digestion process and the addition of inadequate nutrients (J.Mata-Alvarez,2000).So using co-digestion with CM and FVW is the alternative way to improve biogas technology. For these reasons, the biogas production by anaerobic digestion from FVW mixed with CM was studied.

1.1 Objectives

1.2.1. To study in quantity and quality of biogas production from fruit and vegetable wastes (FVW) mixed with cow manure by using a low-solids anaerobic digester.

1.2.2 To study in the efficiency of solids reduction by a low-solids anaerobic digestion.

1.2 Concept of study

Biogas production technology is the biological processes which using several group organisms to digest. The appropriations of nutrient and condition for each group are different. Therefore, preparing nutrient and appropriate condition is the way to improve the reaction rate and biogas yield. The co-digestion is the method that purposes to improve the positive synergism in the group of organism process and the supply of inadequate nutrient.

In this study, using fruit and vegetable wastes (FVW), and cow manure (CM) as a mixed waste for feeding the system. The various ratio of mixed waste feed were prepared for studying about the quantity and quality of biogas production.

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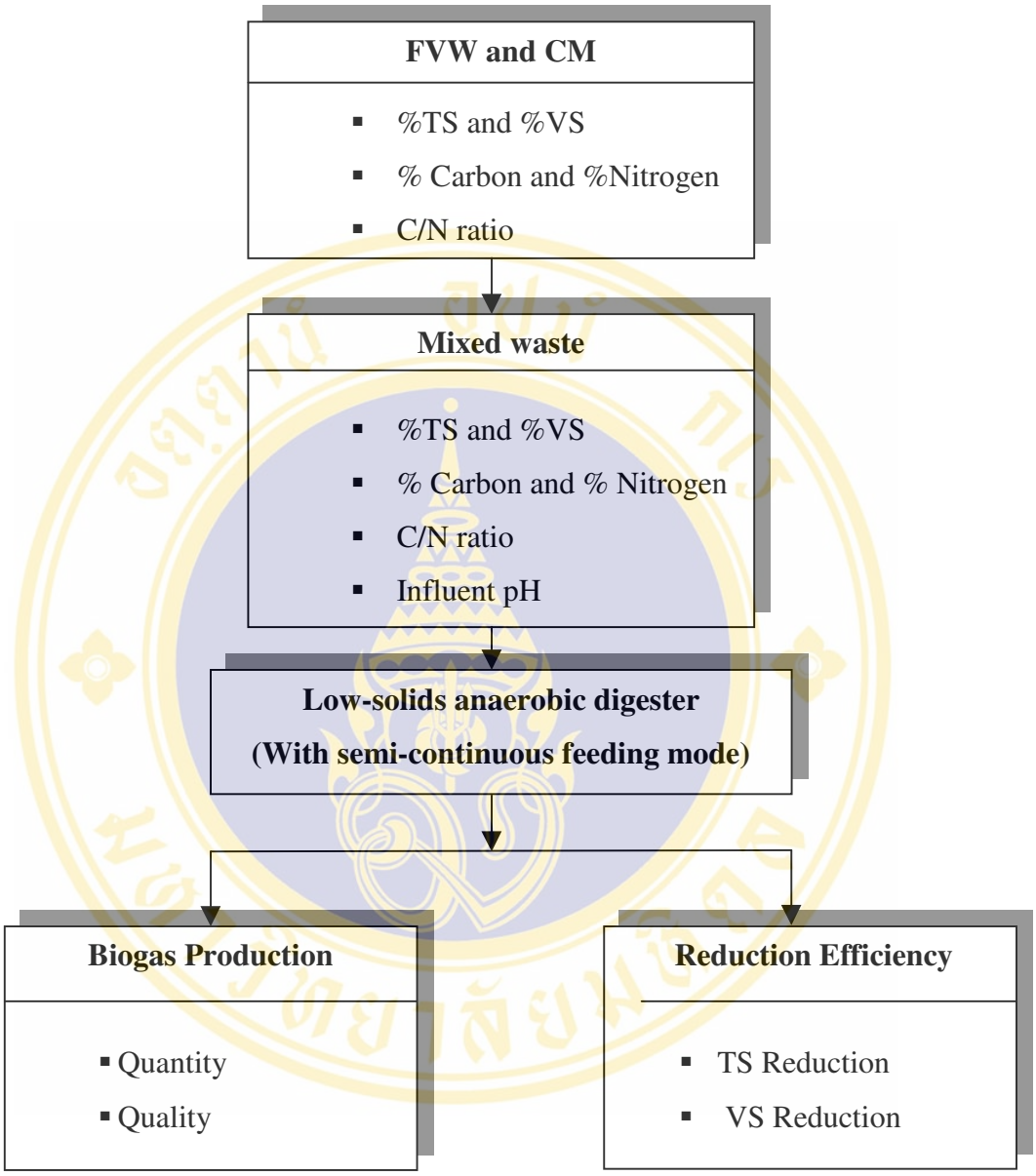

Figure 1-1 Conceptual framework

1.3.Scope of study

This study will be emphasized on the biogas production and the efficiency in total solids and volatile solids reduction by using a bench-scale low-solids anaerobic digester. In all case, the digester could be operated without addition of chemicals or nutrients into the system

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1.4 Definitions

1.4.1 Fruit and vegetable wastes (FVW): The fruit and vegetable wastes used in this study, consisted of pineapple peel, lpomoea, cantalope peel, luffa peel, chinese kale, cabbage and asparagus

1.4.2 Mixed wastes : recorded materials, used in this study, consisted of fruit and vegetable wastes (FVW) mixed with cow manure (CM)

1.4.3 Biogas production :The volume of biogas which was generated from the digester

1.4.4 Methane production :The volume of methane gas which was generated from the digester

1.5 Expected outcomes

1.5.1 The quality and quantity of biogas production from mixed fruit vegetable wastes (FVW) mixed with cow manure (CM) by using a low-solids anaerobic digester.

1.5.2 The percentage of total solids and volatile solids reduction by a low-solids anaerobic digester.

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CHAPTER II
LITERATURE REVIEW

2.1 Fruit and vegetable wastes (FVW)

Fruit and vegetable wastes (FVW) are biodegradable wastes, which are the major composite of municipal wastes. In the year 2001, a 14.2 million ton municipal wastes were generated form the community of Thailand. Approximate 6.4 million-ton were biodegradable wastes. The less part of this, 0.3 million ton, were used for make fertilizer. (Pollution Control Department, 2003) as the minority wastes were collected with other kinds of waste or accumulated in heap and rot with out proper disposal. The biodegradable wastes are easy fermentation so the accumulate of this wastes incubate disease and create obnoxious odor

The physical, chemical and biological properties of FVW that were studied from various researchers are show in table 2-1

The characteristics of FVW (table 2-1) can use for producing biogas by biological process. David A. (1980) supported this idea that much of the cellulose in the garbage are a good source of methane gas produced from anaerobic digestion.

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Table 2-1 The physical and chemical properties of fruit and vegetable wastes (FVW)

Researchers	**George (1993)**	**Nirmala (1966)**	**F.J.Callaghan (1999)**	**Somchai, (1987)**
Type of wastes	Fruit Wastes	Pineapple Wastes	Fruit and vegetable wastes	Vegetable wastes
Moisture	78.7	*	*	*
Total solids	*	7.80	167g/l	12 %
Volatile Solids	*	89.40 [a]	156 g/l	86 %
Volatile matters	16.6	*	*	*
Organic Carbon	*	51.85	*	*
Carbon	48.5	*	*	*
Nitrogen	1.4	0.95	*	*
Total Carbohydrate	*	35.00	*	*
Cellulose	*	19.80	*	*
Hemicellulose	*	11.70	*	*
C/N	*	55	*	35
Ash	4.2	10.60	*	*
NH_4-N	-	*	< 10mg/l	*

Remark * not available data
[a] Percent total solid unless otherwise mention

2.2 Cow manure (CM)

Cow manure is the agricultural waste that amount and composites per unit of time also vary widely. The several of factors have affected them such as cow size and age, feed, water intake, climate and management practices etc. The study of animal wastes treatment should be taken samples at the farm site or similar site. For use in planned purpose, Taignides(1978) (references by Chongrak,1989) suggested that the general guideline value in waste production of milk cows is 44 kg/head/ day (average weight 590 kg).

The characteristics of cow and cattle manure which, were studied from literature show in table 2-2.

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Table 2-2. The physical and chemical properties of cow manure (CM)

Researchers	**Chongrak, (1989)**	**Somchai, (1983)**	**Golueke, (1972)[a]**	**Nusara, (1994)**	**David fulford, (1988)**
Waste types	Dairy cattle	Cow manure	Cow manure	Cow manure	Cattle waste
Moisture	*	*	*	77	
Total solids (% of wet weight)	9.3	16	*	*	16-20
Total solids (mg/g)	*	*	*	69.18	*
Volatile Solids (% Total solids)	80.3	13	*	*	77
Volatile Solids(mg/g)	*	*	*	43.64	
Carbon (%)	*	*	*	*	35-40
Total nitrogen (% Total solid)	4.0	*	1.7	0.260	3-4[b] 1-2[c]
C/N ratio	*	10-20	18	*	20-30[b] 25-35[c]
Phosphorus %	*	*	*	0.038	
Copper %	*	*	*	2.945×10^{-4}	

Remark: * not available data

[a] references by Chongrak,1989

[b] Grass/Grain fed

[c] Straw fed

[b, c] Data for fresh dung .All dung will lose water and nitrogen on keeping, especially of air humidity is low

Andrew (1990) presented that the animal excreta contains highly–lignin residues of the leaves, stalks, grain and husk of animal feed which have resisted microbial degradation in the animal rumen or hid gut. Although the animal wastes are much more difficult to bacteria degradation than the fiber from cooked vegetable wastes used as human food, some characteristic is usefulness for the anaerobic digestion.

David A (1980) commented that the percent of the anaerobic bacteria in a digester would be influenced in number by the input from sewage or farm waste. Supporting by David (1988), showed that the group of bacteria live in the gut of ruminate animal are the same and similar to the bacteria in the biogas digester. As Chalo (1987) presented that the bacteria lived in the animal rumen can found in excreta approximate 20-40 percent depended on type and composite of animal feeds.

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In conclusion, the cow manure is the appropriate source for finding the anaerobic bacteria that used in a biogas digester.

2.3 Biogas

2.3.1 Definitions

Biogas refers the natural gas is produced from degradation of the organisms with out oxygen condition. (Somchai, 1987).

Biogas (marsh gas) is the by-product of anaerobic decomposition of organic matter. (Chongrak, 1989).

Biogas or digester gas is the gas that produced during anaerobic digestion of natural organic material. The biogas consists of a mixture of gas. The notably gas is methane (CH_4) and carbon dioxide (CO_2) with small amounts of other gases, such as hydrogen sulfide (H_2S) and hydrogen (H_2).

The physical constant of the principal gases (methane and carbon dioxide) is the main composition of biogas were listed in table 2-3.

Table 2-3 Some physical constants of methane and carbon dioxide

Physical constant	Methane	Carbon dioxide
Molecular weight	16.04	44.01
Boiling point at 1 atm	-164.0 °C	*
Freezing point at 1 atm	-182.5 °C	*
Triple point at 5.11 atm	*	- 56.5 °C
Sublimation point at 1 atm	*	-78.5 °C
Density at 0 °C 1 atm	0.7172 kg /m^3	1.976 kg /m^3
Flammable limits in air	5.3-14% by volume	*
Calorific value at 15 °C and 101.325 kPa	37.71 Mj/m^3	*

Source: David A.Stfford, 1980
Remark: * not available data

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2.3.2 Production and composition of biogas

The production and composition of biogas depend on various factors such as the composition of raw materials, organic loading, type of digester, the time and temperature of anaerobic decomposition. The approximate composition of biogas in various literatures were showed in table 2-4

Table 2- 4 the approximate composition of biogas

Researcher	Chongrak, (1989)	David A.Stfford, (1980)	FAO, (1996)	Pollution Control Department' (1995)
CH_4 (%)	55-65	60-70	50-80	60-80[a]
CO_2 (%)	35-45	40-30	20-50	≤50[b]
N (%)	0-3	*	*	*
H (%)	0-1	*	*	*
H_2SO_4	0-1	*	*	

Remark: [a.] flammability
[b] <50 not flammability

FAO (1996) present that if a cubic foot (0.028 cubic meters) of biogas yields was burn, the heat energy will generate about 10 Btu (2.52 kcal) per percentage of methane composition. For example, Burning biogas composed of 65% methane yields,the heat energy 650 Btu per cubic foot (5,857 kcal/cubic meter) was generate.

The pollution control department (1995) commented that the percent of carbon dioxide in biogas involved the capable of ignition. If the biogas compose of carbon dioxide higher than 50%, biogas will not ignite.

2.4 Anaerobic digestion

2.4.1 Biochemical reaction and microbiology

The biogas is produced by various groups of anaerobic bacteria that digest organic wastes to methane, carbon dioxide and water. In general, anaerobic digestion is considered to occur in three stages. The reactions of each state are

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deference and depend on the bacteria that worked in each stage. The reaction and microbial of each stage was show.

Stage 1 Liquefaction or Hydrolysis

In this stage, the extracellulose enzymes from hydrolytic bacteria break down the complex organic waste components such as proteins, fats, carbohydrate, cellulose, lignin, etc. This reaction changes the complex and insoluble form of waste to the simple, soluble and organic components (or monomers) such as Amino acid, polysaccharides, long-chain fatty acid which are easily available to any acid-producing bacteria in next stage(Donald L W, 1987).

This stage dependent on substrate and bacteria concentrations, as well as on pH and temperature. This condition will be the rate-limiting step in anaerobic digestion, if the groups of bacterial action in this stage are much slower than stage 2 or stage 3 (Chongak, 1989).

Stage 2 Acid formation

In this state, the products of first state simply convert to organic acid, alcohol and new bacterial cells. One important microorganism group in this state is acid forming bacteria the pathway of this acid forming bacteria process are show in equation 2-1, 2-2 and 2-3 (Kreagsak, 2000).

$$C_6H_{12}O_6 \longrightarrow 2CH_3COOH\ (Acetic)+2CO_2+4H_2 \qquad 2\text{-}1$$

$$C_6H_{12}O_6 \longrightarrow CH_3CH_2CH_2COOH\ (Butyric)+2CO_2+2H_2 \qquad 2\text{-}2$$

$$C_6H_{12}O_6+H_2 \longrightarrow 2\ CH_3CH_2COOH\ (Propionic) + 2H_2O \qquad 2\text{-}3$$

After bacteria metabolism, the volatile fatty acid (VFA) that the end product of protein, fat and carbohydrate in which acetic acid (acetate), propionic and butyric were found.

In the condition of the methanogenic bacteria uptake hydrogen and the partial pressure of hydrogen is kept low. The acetogenic bacteria convert some volatile

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fatty acid to acetic acid (acetate) and H_2/ CO_2 (Donald L W, 1987). The pathways of these bacteria are show in equation 2-4, 2-5 (Kreagsak ,2000).

$$CH_3CH_2CH_2COOH\ (Butyric) + 2H_2O \longrightarrow CH_3COOH\ (Acetic) + 2CO_2 + 3H_2 \quad 2\text{-}4$$

$$CH_3CH_2COOH\ (Propionic) + 2H_2O \longrightarrow CH_3COOH\ (Acetic) + 2H_2 \quad 2\text{-}5$$

Sometime the stage 1 refers as acid fermentation (Stage 2) because some waste absorbs with out pass stage 1. For this reason, it hard to distinguish the first stage from the second stage (Chongak, 1989).

State 3 Methane formation

The end products from the acid formation state are converted to biogas (mainly methane and carbon dioxide) by several different species of strictly anaerobic bacteria (Larry D.,1980). Bacteria in this stage are identified in the literature as methane formers or methanogenic bacteria. The mechanism involve in the formation of methane is presented two pathways that are depend on the nature or starting substrates. (Metcalf,1979).

First, if the substrates are acetic and propionic, Methanogenic bacteria will use them to formed methane by the reduction of carbon dioxide that was formed during the oxidation of substrates. This pathway presented in equation 2-6, 2-7, 2-8 and 2-9.

$$4C_2H_5COOH + 8H_2O \longrightarrow 4CH_3COOH + 4CO_2 + 24H^+ \quad 2\text{-}6$$

$$3CO_2 + 24H^+ \longrightarrow 3CH_4 + 6H_2O \quad 2\text{-}7$$

$$4C_2H_5COOH + 2H_2O \longrightarrow 4CH_3COOH + CO_2 + 3CH_4 \quad 2\text{-}8$$

$$CH_3COOH \longrightarrow CH_4 + CO_2 \quad 2\text{-}9$$

Second, if the substrates are ethanol butyrate or hydrogen, Methanogenic bacteria will produce methane from substrate oxidation and form

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reduction of atmospheric carbon dioxide. These paths way show in equation 2-10, 2-11.

$$2C_2H_5OH + CO_2 \longrightarrow 2CH_3COOH + CH_4 \qquad 2\text{-}10$$

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O \qquad 2\text{-}11$$

In addition, Kreagsak (2000) presented that methanogenic bacteria can separate two groups. One is the Acetoclasic methane bacteria, which forms methane gas by using volatile fatty acid (Show in equation 2-12). Another is Hydrogen utilizing methane bacteria, which use H_2 and CO_2 for formed CH_4 (Show in equation 2-13).

$$CH_4COOOH \longrightarrow CH_4 + CO_2 \qquad 2\text{-}12$$

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O \qquad 2\text{-}13.$$

The acid forming stage and the methane forming stage are direct involve to production and composition of biogas so the interaction between them are necessary to keep control of the equilibrium condition. The differences between the cultural requirements of them, are the obstructions to control. Luis F (1982) commented that more specifically the differences between the two groups are as follows.

1.The percent of oxygen does not seriously interfere with acid forming bacteria on the other hand methane forming bacteria are severely inhibited by present of oxygen.

2. The pH range for acid forming bacteria as is 4.5-7.5, while the permissible pH range for methanogenic bacteria is only 6.00 to 7.5.

3. Acid forming bacteria multiply far more rapidly than do the methanogenic and more resistant to shock condition (Over organic loading).

For these reasons, the appropriate quality and quantity biogas production will appearance by control the environmental of anaerobic digestion system in appropriate for both of organism. Controlling the environmental and operation factors are the way to control the equilibrium of two-group material.

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2.4.2 Environmental factors

2.4.2.1 Temperature

The temperature is the factor that affects on the rate of gas production. The optimum temperature ranges for anaerobic digester are the mesophilic range (25 to 40 °C) and thermophilic range (50-65 °C). In rise at around 45 °C and below 10 °C, gas production decreases drastically (Chongrak, 1989). Although the rates of reactions are much greater in the thermophilic rage, the maintenance of higher temperature is usually not economically justifiable (Eckenfelder WW,1989). In addition, The rather long time required adapting a culture of bacteria to thermophilic conditions. These disadvantages of thermophilic range can conclude that the extents of the advantage to be gained from it dose not necessarily warrant. (Luis F. Diaz,1982).

2.4.2.2 pH and Alkalinity

The operational range of pH in anaerobic digesters should be between 6.6 and 7.6 (Chongrak, 1989). This range is appropriate to acid forming bacteria and methane forming bacteria. In general the anaerobic digester have itself pH control that is measurable with the total alkalinity. Matcalf (1979) suggested that the alkalinity would normally range from 1000 to 5000 mg/l.

Ronisaeson (1987) presented that the process has pH 6 to pH 8, the carbon dioxide-bicarbonate system is the major chemical system controlling alkalinity. Under these condition bicarbonate alkalinity is the major component of the total alkalinity. The reaction shows equilibrium equation 2-14.

$$H_2CO_2 \rightleftharpoons H^+ + HCO_3^- \qquad 2\text{-}14$$

Follow this equation bicarbonate alkalinity, pH and carbon dioxide pressure in anaerobic digestion, are interrelation. When the bicarbonate alkalinity falls below 500 mg / l with normal carbon dioxide production, the pH approaches 6.0. This so maintenance of bicarbonate alkalinity above about 2500 mg / l should be promoted to enhance stability of digester. The lime addition to system may

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also increase alkalinity or may be generated through protein degradation to ammonia, which can combine with the carbonic acid in solution to form an ammonium bicarbonate buffer. Although addition chemical compound is the method to improve system, the digesters should be operate under the condition that stable pH with out external additive for reducing the impact of process economic. (Ronisaeson, 1987).

2.4.2.3 Volatile fatty acid (VFA)

Volatile fatty acid or volatile acids (acetic propionic and butyric acid) are the end product of acid forming bacteria when the wastes were digested from them. The concentration of VFA shows the rate of produce gas and the rate of removal VFA of bacteria in system. In well digester, the balance between the amount of VFA produce and the amount removed through conversion by methane forming bacteria will appear. Larry D. (1980) comment the optimum VFA for methane fermentation is 50- 500 mg/l as acetic and 2000 mg/l as acetic acid is considered to be the maximum tolerable value; however, the methane bacteria will be tolerated the maximum VFA concentration depend on numerous factor.

Chongrak(1989) presented that the effect from accumulation of VFA is the lowering of pH and the rate of methane production decrease.

Sakchai (1983) commented that controlling the balance bacteria working by use only pH to control the condition of system, is not solve the problem of system because pH is so slowly changing than VFA concentration. The concentration between VFA and total alkalinity is the other factor that can show the stability of the system. By the ratio of VFA to total alkalinity is 0.1-0.3 show the well stability of anaerobic digestion.

Ronisacson (1987) concluded the cause of VFA accumulation is any factors that the rapid increases of organic loading rate and the introduction of inhibitory substance into the digestion. The way to reduce this problem is controlled operation factor especially loading rate or subjected to otherwise stressful condition.

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2.4.2.4 Ammonium –Nitrogen

Ammonium-Nitrogen exists in aqueous solution in the ammonia or ammonium – ion form. Ammonium ion is the by-product of protein oxidation that the microorganism process used it for an energy source. Urea, waste from animal , is the other way to produce ammonium. Urea was hydrolyzed rapidly in the reaction mediated by the enzyme urease to yield ammonium carbonate. Both of reaction account for the high percentage of ammonium and alkalinity in raw municipal wastewater (Mccalf and Eddy, 1967).

O.P.Chawla (1986) showed the process of ammonia in the anaerobic digester (Show in equation 2-15) that the ammonium ion existed in equilibrium with dissolved ammonia gas and the latter was inhibitory at a much lower concentration than the ammonium. When the hydrogen ion (H^+) concentration in the solution is sufficiently high then the equilibrium is shifted to the left and ammonium ions are the main constituents of the mixture. At higher pH values this equilibrium shifts towards dissolved ammonia gas in solution is the main constituent.

$$NH_4^+ \rightleftharpoons NH_3 + H^+ \qquad 2\text{-}15$$

In the anaerobic digestion ammonium ion is very useful for microorganism. McGraw-hill (1979) showed that many groups of anaerobic and facultative bacteria use the various inorganic ions present in the sludge such as nitrate (NO_3^-) to nitrogen gas (N_2). In addition ammonium ion is the nitrogen source for methanogenic bacteria. Andrew (1990) presented the relationship between the methanogenic bacteria and ammonium ion that in the presence of excess energy source, methanogenic bacteria require 1-10 mM NH_4^+ for optimum growth. Some types of methanogenic bacteria may be able to fix N_2 and could grow in the absence of NH_4^+; however, some species of methanogenic bacteria were reduced when N_2 growth rather than NH_4^+growth. Although this incidence has not been determined but in waste containing low NH_4^+ level, fixation of N_2 dissolved in the waste stream may be a significant reaction.

The limiting of nitrogen is the cause of imbalance between two-group microorganism in anaerobic digestion. Luis F. (1982) presented this bad effect

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that is the condition when the nitrogen begins to be a limiting factor. The acid former, being rapid growers and more vigorous in substrate utilization, are in a better position to complete for the limited nitrogen, and consequently the growth of the methanogens becomes progressively restricted because of nitrogen deprivation.

Larry D. (1980) concluded the effect of ammonia concentration on the rate of methane fermentation (show in table 2-6) and commented free ammonia that is the toxic form is favored by high pH.

Table 2-5 the effect of ammonium concentration on methane fermentation.

Observed effect	Ammonia concentration (mg/l as N)
Beneficial	50-200
No adverse effect	200-1000
Inhibitory at high	1500-3000
Toxic	above 3000

Source: adept from Larry D. (1980).

2.4.2.5 Nutrient concentration of waste.

The nutrient composites of wastes are a major factor affecting the methane production rates from the digestion of waste.

Chongrak (1989) presented that the optimal level C/N ratios, which is using for the anaerobic digester is 25-30 expected because bacteria use up carbon 25-30 times faster than they use nitrogen. For improvement the characteristic wastes propose, the wastes, which have higher or lower than the optimum values, should be mixed with other waste. However, In practice accurate calculations and adjustments of optimum C/N ratios are made difficult cause by the various factors. For example, the cellulose and lignin which parts of the C substrate are highly resistant to biological breakdown so analysis of C concentration be difficult and inaccurate because some type wastes that contains a large portion of plastics. For these reasons, the initial C/N ratios of between 20 and 40 should serve adequately as an optimum range.

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David A.(1980) showed the requirement of nutrient by experiment that isolation the rumen strain M1 of *methanobacterium ruminantium* from complex environment often require extracts of the aqueous phase of their normal environment for growth. The result of this study presented the M1 requires factors present in the rumen fluid, even in the presence of bicarbonate, sulfides, cysteine, yeast extract, and minerals. Many of these factors have been shown to be volatile fatty acids (VFA), one of which (acetate) produced optimum growth at 16-20 mM, suggesting it as a major source of cellular carbon (about 60 %).

FAO(1996) commented that the relationship between the amount of carbon and nitrogen present in organic materials is expressed in terms of the Carbon/Nitrogen (C/N) ratio. If the C/N ratio is very high, the nitrogen will be consumed rapidly by methanogens for meeting their protein requirements and will no longer react on the left over carbon content of the material. As a result, gas production will be low. On the other hand, if the C/N ratio is very low, nitrogen will be liberated and accumulated in the form of ammonia (NH_4). NH_4 will increase the pH value of the content in the digester. A pH higher than 8.5 will start showing toxic effect on methanogen population.

2.4.3 Operation factors

2.4.3.1 Retention time and loading rate

Retention time is the important factor for bacteria growth. In the anaerobic digestion, the efficiency of biogas produce depends on the number and concentration of bacteria that have appropriate time to digest the organic material in the digester. David F (1988) commented that if the bacteria were removed with the spent slurry faster than they can replace themselves in the digester, the process of digester would fall. Solid retention time (SRT) is the value which show the time of bacteria live in digester. For the digester with out returning sludge, SRT will equal the hydraulic retention time (HRT) which given by the volume of the digester (V) divided by the volume of the daily feed (Q) show in equation 2-16 (Chaiyot,1981).

$$HRT = SRT = Volume/flow = V/Q \qquad 2\text{-}16$$

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Loading rate is the feeding-rate that shows the organic loading (kg COD or Volatile solid (VS)/ m^3-day). Organic loading is the important factor to controls the process of system in equilibrium dynamic. Chongrak (1989) presented the effect of organic loading rate that a high organic loading will normally result in excessive VFA production in the digester with a consequent decrease pH and will adversely affect the methanogenic bacteria. In contract, a low organic loading will not provide a sufficient quantity of biogas for other uses.

The organic loading rate of a digester is defined as the concentration of chemical oxygen demand (COD), biochemical oxygen demand (BOD) and volatile solid (VS) divided by hydraulic retention time (HRT)(Sakchai, 1983) followed equation 2-17.

$$\text{Organic Loading} = \frac{\text{COD or BOD or VS (kg/l)}}{\text{HRT (day)}} \qquad 2\text{-}17$$

2.4.3.2 Mixing

Mixing digester slurry is helping the contact between the microorganism and organism wastes. Chongrak (1989) presented the advantage of mixing is reducing the settling of solid or accumulation of digested solids at the bottom of the digester and helping to prevent and break up scum formation at the slurry surface. In addition, David A (1980) show that the mixing improve efficient utilization of digester volume by preventing formation of dead spots and stopping pockets of VFA being allowed to form.

2.4.4 Low-solids anaerobic digestion

Low –solids anaerobic digestion is a biological process in which organic wastes are fermented at solids concentration equal to or less than 4-8 percent. This process is used in many parts of the world to generate methane gas from human, animal, and agricultural wastes, and from the organic fraction of municipal solid waste (MSW)(Georage,1993)

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Georage (1993) comment that some of the important design consideration in a low-solids anaerobic digestion is summarized followed.

2.4.4.1 Size of material: wastes to be digested should be shredded to sizes that will most interfere with the efficient functioning of feeding equipment.

2.4.4.2 Mixing equipment: mixing equipment is recommended for avoid scum building.

2.4.4.3 Percent of solid waste mixed with sludge: although amounts of wastes varying from 50 to 90 percent have been used 60 percent appears to be reasonable compromise.

2.4.4.4 Hydraulic and mean cell-residence time: Use 10 to 20 days for design of base design on results of pilot plant studies.

2.4.4.5 Loading rate: 0.6-1.6 kg/m^3-day.

2.4.4.6 Temperature between 30 to 38 °C for mesophilic and between 55 and 60 ° C for thermophilic digester.

2.4.4.7 Destruction of volatile solids wastes: Depend on the nature of the waste characteristics various from about 60 to 80 percent.

2.4.4.8 Destruction of total solids waste: Various from 40 to 60 percent, depending on amount of inert material present originally.

2.4.4.9 Gas production: 0.5 to 0.75 m^3/kg of volatile solid destroyed (methane 55 percent, carbon dioxide 45 percent).

2.4.5 Mode of operations

In the process of anaerobic digestion, modes of operation (the methods to feed) are the important method for design equipment and operate system. Chongrak (1989) classified the mode of operations by type such as batch operation, continuous operation and semi continuous operation the detail of each mode showed.

2.4.5.1 Batch operation

Batch operation is filled completely with organic matter and seed inoculum, Sealing the digester and processing for a long time until gas production is decreased to a low rate

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2.4.5.2 Continuous operation

Continuous operation is the operation that feeding and removal of organic matter take place continuously. The disadvantages of this mode are relive heavily on external energy inputs for pumping and mixing so this mode is not appropriate in the areas that energy resource are limited.

2.4.5.3 Semi continuous operation

Semi-Continuous operation is the feeding method that done usually once or twice a day. The sludge is also removed at the same time intervals. This mode operation is suitable when there is a steady flow of organic matter. By this reason this operation is famous in the field.

2.5 Co-digestion

Co-digestion is producing gas by using mixture, two or more waste mixed together. J.Mata(2000)comment that the co-digestion is the most cases improves the biogas yields due to positive synergism established in the digestion medium and the supply of missing nutrients by the co-substrate. In addition, economic advantages derived from the fact of sharing equipment are quite significant.

F.J Calloghan (1999) studied the biogas production of cattle slurries that were mixed with a range of solid waste allowed to digest in 1-liter batch digester. The result of study showed that the co-digestion with fruit and vegetable waste (20% wet weight basis) mixed with cattle slurry (70% wet weight basis) and digester inoculum (10% wet weight basis), were more effective produce the cumulative methane production than the digest with cattle slurry alone.

Pichit (1979) studied the production of biogas and organic fertilizer by batch loading type with seeding of organism. The result shows the methane production from the cow manure mixed with buffalo manure (ratio 1:1) is higher (69.0%) than using cow manure alone (44.0%). This result similar to the methane production of duck manure mixed with water hyacinth (ratio 1:1) is 57.40 % higher than using water hyacinth alone (39.50).

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D.Trujillo(1993) studied the continuous anaerobic digestion of different volatile solid mixtures of tomato – plant waste and rabbit waste. The result shows that the methane production increase when the volatile solid concentration of tomato-plant waste increases in the mixture, reaching the series 1:1 values slightly higher than the ones obtained from rabbit waste alone. The addition of the tomato plant waste to the latter in proportion higher than 40 percent improves the methane production obtained from the animal waste alone.

F.J Callaghan (2002) studied the mesophilic (35 °C) anaerobic digester to examine the effect of adding the fruit and vegetable wastes (FVW) in to a system, which was digesting cattle slurry (CS). The retention time was kept at 21 days and the loading rate maintained in the range 3.19-5.01 kilogram volatile solid per cubic meter per day (kg VS $m^{-3}D^{-1}$). Increasing the proportion of FVW from 20% to 50% improved the methane yield from 0.23 to 0.45 m^3 CH_4 kg^{-1} VS added and caused the volatile solid reduction to decrease slightly.

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CHAPTER III
MATERIALS AND METHODS

This research studied about the biogas production from the various ratios of fruit and vegetable wastes (FVW) mixed with cow manure. The low-solids anaerobic digesters, bench-scale unit, were used in this research. The research method were presented as follows:

3.1 Bench-scale anaerobic digesters.

The four sets of bench-scale anaerobic digester were used for biogas production. Each set consisted of the digester with mixing paddle, biogas collecting unit and biogas measurement unit as showed in figure 3-1

3.1.1 Low-solids anaerobic digester

The mixing paddle consists of 23 cm diameter of mixing plate, which made of 0.6 thickness of PVC plate jointed with a 65 cm length and 2.5 cm diameter of PVC pipe as a mixing shaft. The mixing unit passing through a 45 cm length and 3.75 cm diameter of PVC pipe sleeve that attached with the middle of the cover.

The digester was made from trapezoid plastic bucket having 35.5 cm. diameter of top bucket, 26 cm. diameter of bottom bucket and 34 cm. height. The total and effective volumes of the digester were 29.7 and 12.5 liter, respectively. A cover made of 0.5 cm. thickness and 32 cm. diameter of PVC plate. On the cover joined with two pipe, with 3.75 cm diameter, one used for waste feeding and/or slurry drained pipe (plugged with a rubber stopper), and other one for mixing shaft sleeve. Both of them were extended below the surface of the liquid in the digester in order to prevent the

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leakage of biogas to the ambient air. The last pipe with a diameter of 1.875 cm., which joined on the cover for connecting to biogas pipe and valve. After the mixing paddle was put into the digester, the cover plate was sealed with a 0.2-mm. gasket inserted between the cover and the top of bucket. Holding the cover and the bucket together with stainless screws, nuts, and sealed with silicon.

3.1.2 Biogas collecting and measurement units

This research used water displacement by gas for measuring the biogas, by using a water syphon gas collection method (David A., 1980). Biogas collecting and measurement units consisted of a biogas collecting bottle and biogas volumetric beaker. The gas-collecting bottle was filled of water and joined with the three-selicone tubes. First tube was connected between the digester and the biogas-collecting bottle for release biogas. Second tube was connected between the bottle and the gas-measured beaker for release water, which was measuring the water volume that was displaced by the biogas. Last tube was connected between collecting bottle and a full glass of water for the biogas releasing and biogas sampling by displacement under water. .

3.2 The mixed waste preparation

3.2.1 Fruit and vegetable wastes (FVW) preparation

The composites of FVW were determined by collected the wastes that generated in seven days from cafeteria of Mahidol University (Salaya Campus). During the waste collecting, the difficult digestible waste such as plastic bone etc. and non-fruit and vegetable waste were separated from the wastes. Then, the FVW were weighed in kind by kind and recording the weight of each day. After seven days of surveying, all of data were arranged in ordering from most appearance to rare appearance and also high-weight to low-weight.

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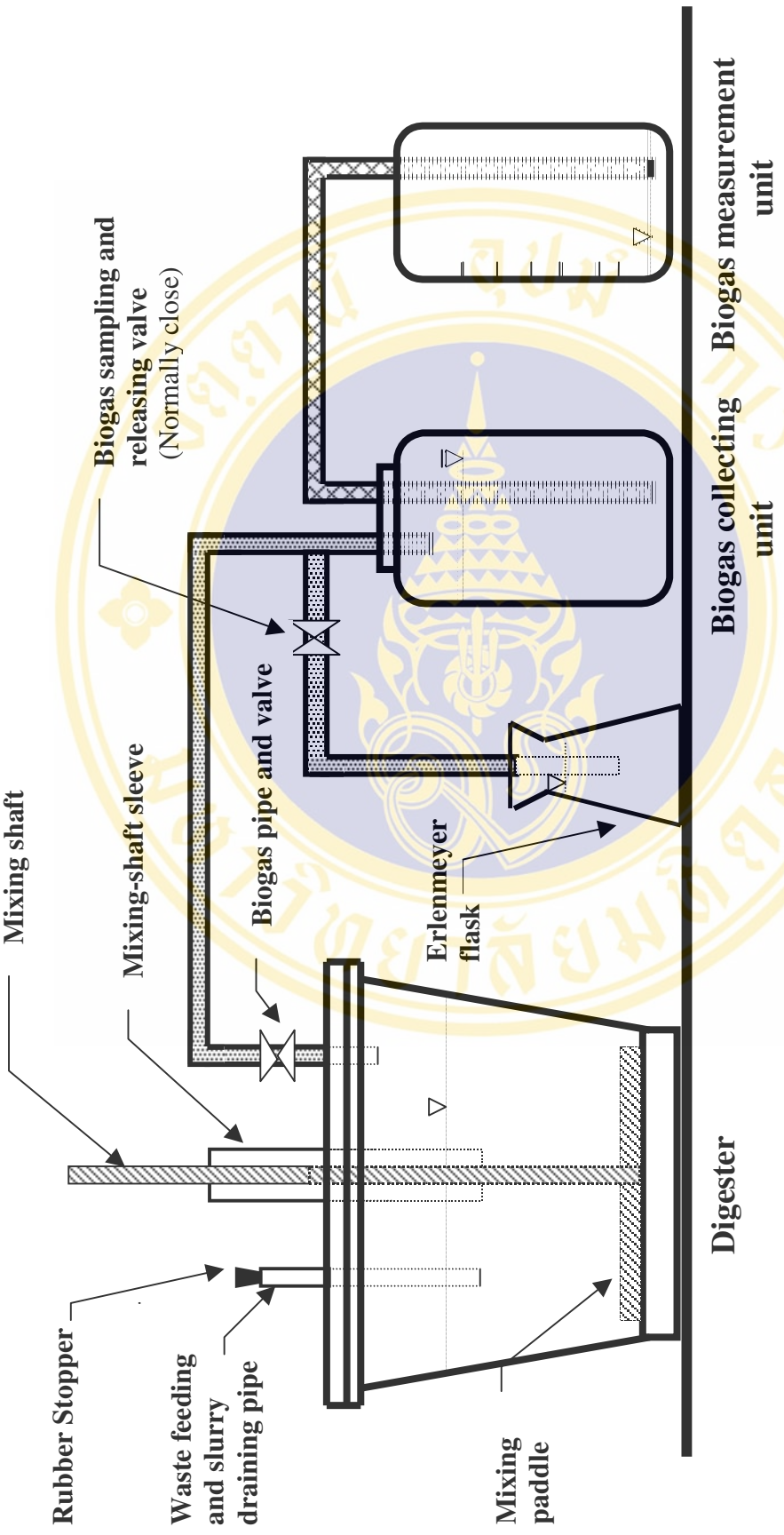

Figure 3-1. Low-solids anaerobic digester
Note : ▨ biogas line ⊠ water line

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Therefore, the first to seventh orders of total waste were selected for using in mixed FVW wastes. The composites of FVW were the percentage of each waste, which calculated according to the total wet weight of seven kinds waste

The second step was improvement the physical property of FVW for feedstock by reducing the size of FVW. First step is preparation FVW follow the composite. Then, the FVW were chopped to about 2-5 mm in size for feeding into the digester. After, the size-reduction waste was sampled and analyzed the waste characteristics. The rest of all was preserved in the 4 °C refrigerator for feeding with the period of 15-days.

3.2.2 Cow manure

Cow manure (without urine and bedding material), which was not more than duration of 1 day, was collected from the Reproductive Biological of Economic Animals in Salaya Campus. The cow manure was analyzed and preserved in the 4 °C refrigerator for 30 days feeding.

3.2.3 Preparation of mixed wastes

Determination the volatile solids of mixed wastes which might feed per day (approximate1 kg /m^3 of digester/day) equivalent to 100 %. Calculating the wet weight of FVW and CM that might used per day, base on the percentage of volatile solids ratio in composite of the mixed waste (show in table 3-1). Preparation the FVW and CM follow the result of calculation and making the mixed waste feed by mixing the waste with tap water.

Table 3-1 composite of the mixed waste for feeding

Digester	Composite of the mixed waste (%VS of mixed wastes)	
	FVW	CM
1	100	0
2	80	20
3	60	40
4	40	60

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The various ratios of mixed waste were determined from the comment by George (1993) who suggested that the feeds, which use in low-solids anaerobic digestion should be mixed with sludge 10-50% of total waste. In addition, F.J Callagnan (2002) found that increasing FVW from 20% to 50% mixed with cattle slurry (CU) improved the methane yield.

3.2 Experiment

3.3.1 Start-up

In this research used fresh cow manure 30 % mixed with 70% of tap water as the slurry (totally 12.5litre) for start-up the digester for 30 days.

3.3.2 Feeding and operating to steady state

Before feeding in each digester, mixing the slurry was mixed by stroking up and down of mixing paddle in digester for 1 minute. And draining the mixed slurry from the digester equal the designed feed volume of each day. Then feeding the mixed waste into the digester and also mixing for 1 minute again. After mixing the digester feed pipe was plugged with a rubber stopper. The feeding of mixed waste feed and draining of mixed slurry would be slowly increased from 0.2 to 0.4 liters / day within one month (after start up process).

Feeding the slurry in the operation condition of organic loading rate (OLR) approximate 1 kgVS/$m^3$of digester-day. The feeding volume is 0.4 l/d (equivalent to the hydraulic retention time (HRT) of 31.25 day). This operation condition was used continuous in this research.

The mainly criterion for the steady state in this study was a constant rate of total solids reduction, volatile solids reduction and constant rate of biogas production

3.3.3 Data Collecting and analysis method

The FVW and CM were sampling every 5 days to analysis of physical and chemical characteristics. The physical characteristic are total solids, volatile solids

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by the Standard Method for the examination of Water and Waste water (APAH,1989). The chemical characteristic are percent of total nitrogen by Kjeldahl method, percent of carbon by calculating (Gotaad,1956) and C/N ratio by calculating (Chongrak,1989)

The temperature in each digester was measure every day as the same as slurry of each digester was sampling to analysis pH everyday. The slurry was sampling for analysis of physical and chemical every two days in start up and steady state duration. These characteristics are pH, total solids (TS), volatile solids (VS), total alkalinity, volatile fatty acid (VFA) and ammonium nitrogen (NH_3-N). The analytical methods of TS, VS and NH_3-N were conformed to Standard Methods for the Examination of Water and Waste Water (APHA, 1998) as the total alkalinity and VFA were analyzed by direct method.

Biogas production was monitored ten hours per day (9.00-14.00A.M and 14.15-19.15 P.M) by the water displacement of the biogas (David A.Stafford, 1980). The calculations of biogas and methane production were presented as liter/hour, m^3/m^3 of digester-day, m^3/kg of VS feed-day. The collecting biogas for analyzes composite (percentage of methane and carbon dioxide) by used replacing of water under the water surface method. And biogas was analyzed by gas chromatography procedure. Gas Chromatography that used in this study was Hewlett Packard Series 2 Chromatograph fitted a thermal conductivity detector. The column was porapack Q. The oven temperature was 70 °C, the injection temp 120 °C and the detector temperature 120. °C. Carrier gas (Helium) flow rate was 35 ml/min. It could identify methane and carbon.

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CHAPTER IV
RESULTS AND DICUSSION

4.1Compositions and characteristics of the wastes

The composition and characteristics of the wastes were presented as follows

4.1.1 Fruit and vegetable wastes (FVW)

4.1.1.1 The composition of FVW

The composition of FVW used in this study were the seven kinds of FVW, which was generated during the seven days of surveying period and the composition of FVW consisted of pineapple peel (69.44 % of total wet weight), lpomoea(8.66% of total wet weight), catalope peel (7.93 % of total wet weight), luffa peel (5.37% of total wet weight), chinna kale (3.66% of total wet weight), cabbage (2.95% of total wet weight) and asparagus(2.01% of total wet weight) as show in table 4-1.

Table 4-1 Composition of fruit and vegetable wastes (FVW)

Component	**Percent by weight (% w/w)**
Pineapple peel	69.44
Lpomoea	8.66
Cantaloup peel	7.93
Luffa peel	5.37
Chinese kale	3.66
Cabbage	2.95
Asparagus	2.01
Total	100.00

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4.1.1.2 The characteristics of FVW, CM and mixed wastes

The characteristics of fruit and vegetable wastes were presented in table 4-2 as follow: Total solids (TS), 12.52 % of wet weight; volatile solids (VS), carbon and nitrogen were 93.23 % of total solids, 51.81 %of total solid and 1.24 % of total solids, respectively. In addition, the C/N ratio of the fruit and vegetable wastes (FVW) is 41.85.

Table 4-2 Characteristic of fruit and vegetable wastes

Waste characteristic	Range	Mean	SD
Total Solids (%of wet weight)	9.13-27.33	12.52	4.19
Volatile Solids (%of TS)	91.07-97.02	93.27	1.47
Ash(% of TS)	2.95-8.92	6.73	1.47
Carbon (% of TS)	50.57-53.90	51.81	0.81
Nitrogen (% of TS)	1.14-1.36	1.24	0.06
C/N Ratio	39.63-44.36	41.81	1.94

4.1.2 Cow manure

The characteristics of cow manure were presented in table 4-3 as follow: total solids (TS) was 18.88 % of wet weight; volatile solids (VS), carbon and nitrogen were 79.28 %, 44.02 % and 1.10 %, respectively and the C/N ratio 40.02.

Table 4-3 Characteristic of cow manure

Waste characteristic	Range	Mean	SD
Total Solids (%of wet weight)	16.21-24.37	18.88	2.85
Volatile Solids (%of TS)	76.17-83.45	79.28	1.83
Ash(% of TS)	16.55-23.83	20.72	1.83
Carbon (% of TS)	42.31-46.36	44.02	1.02
Nitrogen (% of TS)	1.03-1.36	1.10	0.03
C/N Ratio	34.09-41.08	40.02	0.23

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4.1.3 Mixed wastes

The characteristics of mixed wastes were consisted with various ratio between CM and FVW. The characteristics of mixed waste were presented, in table 4-4 ,as follow:

The average total solids (%by wet weight) of mixed wastes, used as waste feeds, for digester 1, 2, 3 and 4 were 3.21, 3.32, 3.47 and 3.68 %, respectively. And the average total solids for digester 1, 2, 3 and 4 were 32.08, 33.22, 34.67 and 36.78 g/l, respectively. The average total volatile solids (weight by volume) of mixed wastes for digester 1, 2, 3 and 4 were 29.91, 29.92, 30.17 and 30.96 g/l, respectively. The results showed that total volatile solids of various FVW and CM ratios were nearly 30 g/l. The average carbon contents of mixed wastes for digester 1, 2, 3 and 4 were slightly decrease from 6.19, 6.01, 5.85 and 5.69%of TS, respectively. In addition,the average nitrogen content of mixed wastes for digester1, 2, 3, and 4 were nearly the some amount around 0.16 % of TS. Therefore, the trends of C/N ratio of mixed waste for digester 1,2,3 and 4 decreased from 38.89, 37.35, 35.81 and 34.75,respectively. These C/N of all mixed waste were in the optimum range between 20 and 40 for anaerobic digestions process (Chongrak, 1989). The average pH of mixed wastes in digester 1, 2, 3 and 4 had slightly increased from 4.09, 4.44, 5.05 and 5.92, respectively. For all results showed that increasing of %CM in the mixed wastes increase pH and decrease C/N ratio.

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Table 4-4 Characteristics of mixed wastes

Waste characteristic		Digester 1 FVW:CM 100:0	Digester 2 FVW:CM 80:20	Digester 3 FVW:CM 60:40	Digester 4 FVW:CM 40:60
Total Solids	Range	3.20-3.22	3.31-3.33	3.46-3.47	3.67-3.68
(% by wet	Mean	3.21	3.32	3.47	3.68
weight)	SD	0.01	0.01	0.01	0.01
Total Solids	Range	32.16-32.04	33.07-33.31	34.64-34.72	36.75-36.80
(g/l)	Mean	32.08	33.22	34.67	36.78
	SD	0.05	0.08	0.03	0.01
Volatile Solids	Range	29.88-30.01	29.78-29.99	30.14-30.93	30.93-30.98
(g/l)	Mean	29.91	29.92	30.17	30.96
	SD	0.05	0.07	0.03	0.01
Carbon	Range	6.18-6.21	5.97-6.01	5.85-5.86	5.68-5.69
(% of TS)	Mean	6.19	6.01	5.85	5.69
	SD	0.01	0.01	0.01	0.01
Nitrogen	Rang	0.158-0.159	0.159-0.16	0.163-0.164	0.163-1.64
(% of TS)	Mean	0.16	0.160	0.16	0.16
	SD	0.03	0.01	0.01	0.01
C/N	Range	38.89-38.90	37.34-37.36	35.80-35.81	34.74-34.75
	Mean	38.89	37.35	35.81	34.75
pH	Range	4.06-4.12	4.36-4.51	4.57-5.31	5.76-6.32
	Mean	4.09	4.44	5.05	5.92
	SD	0.02	0.06	0.27	0.02

Remark: g/l = gram/liter

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4.2 The efficiencies of total solids and volatile solids reduction

The steady state of anaerobic digester in this study occurred after 47 days of the start-up process.

During the steady state, the efficiencies of total solids (TS) and volatile solids (VS) reduction of each digester was showed in table 4–5.

Table 4–5. Efficiencies of total solids and volatile solids reduction

Type of solids	**Reduction efficiency (%)**				
		Digester 1 FVW:CM 100:0	**Digester 2 FVW:CM 80:20**	**Digester 3 FVW:CM 60:40**	**Digester 4 FVW:CM 40:60**
TS	Range	70.43-77.89	58.26-62.97	43.00-51.53	29.20-42.58
	Mean	73.12	60.61	48.79	36.84
	SD	2.67	1.93	3.35	4.38
VS	Range	78.37-89.91	64.59-69.37	50.61-59.25	36.97-48.77
	Mean	80.63	66.77	56.41	43.83
	SD	1.84	2.08	3.15	3.92

Remark: TS = total solids FVW= Fruit and vegetable wastes
VS = total volatile solids CM = Cow and manure

The results in table 4-5 expressed the average efficiencies of total solids reduction of digest 1, 2, 3 and 4 were 73.12, 60.61,48.79 and 36.84, respectively. The average volatile solids reduction of digester 1, 2, 3 and 4 were 80.63, 66.77, 56.41 and 43.83 % receptively.

The results showed that the highest solids reduction efficiency produced by the digester 1.Where as, the efficiency of solids reduction of digester 2,3,4 quite lower than the results from digester 1. Because the fiber in cow manure that more difficult to degraded than the fruit and vegetable wastes (Andrew,1990).

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4.3 Biogas Production

During the steady state the biogas quantity and quality of each digester was examined and shown in table 4 –6

The average biogas production quantity of digester 1, 2, 3 and 4 were 0.35,0.38, 0.33 and 0.16 liter / hour (l/hr), respectively. And expressed in term of biogas and digester volume, were or 0.67, 0.73, 0.62 and 0.30 m^3/ m^3 of digester/day , respectively. The biogas production expressed according to the volatile solids feed for the digester1, 2, 3 and 4 were 0.28,0.30,0.26 and 0.12 m^3/kg of VS feed-day), respectively.

For the results and in figure 4-1 presented that the average biogas production from digester 2, 0.73 m^3/ $m^3$of digester-day was the highest. In addition, the biogas production from digester 2 was slightly higher than the production from the digester 1 (0.67 m^3/ m^3 of digester-day) and digester 3 (0.62 m^3/ m^3 of digester –day). The average biogas production from digester 4 was the lowest (0.30 m^3/m^3 of digester -day).

Table 4-6. Biogas production from digesters

Biogas production rate		**Digester 1 FVW:CM 100:0**	**Digester 2 FVW:CM 80:20**	**Digester 3 FVW:CM 60:40**	**Digester 4 FVW:CM 40:60**
Liter/hour	Range	0.29-0.39	0.35-0.42	0.30-0.36	0.14-0.18
	Mean	0.35	0.38	0.33	0.16
	SD	0.04	0.03	0.31	0.13
m^3/m^3 of digester-day	Range	0.57-0.75	0.62-0.81	0.58-0.74	0.28-0.34
	Mean	0.67	0.73	0.62	0.30
	SD	0.07	0.07	0.06	0.02
m^3/kg of VS feed -day	Range	0.24-0.31	0.26-0.34	0.24-0.31	0.11-0.14
	Mean	0.28	0.30	0.26	0.12
	SD	0.03	0.03	0.02	0.01

Note: the biogas production were collected during 9.00A.M-14.00 P.M and 14.15-19.15 P.M.(totally 10 hours)

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Table 4-7,figure 4-2 showed the average percentage of methane and carbon dioxide under steady state. The average methane concentration from biogas of digester 1, 2, 3 and 4, were 48.64, 50.48, 51.16 and 54.26%, respectively. As The average carbon dioxide concentration from digester 1, 2, 3 and 4 were 41.28, 30.78, 31.43 and 29.84 %, respectively. The highest percentage of methane was found in the biogas of digesters 4. (54.26% of total gas), which was slightly higher than percentage of methane found in digester 2 and 3. Whereas, the percentage of methane concentration of the digester 1 was the lowest (48.64% of biogas) and it was quite slightly lower than the regulary percentage of methane found in the biogas,50-60%of biogas (FAO,1996).On the other hand, the carbon dioxide concentration in biogas of digester 1, 2, 3 and 4 were in the regulary percentage for ignition(≥ 50% of biogas).

Table 4-7. Composition of biogas in steady state

Composition of biogas		**Digester 1 FVW:CM 100:0**	**Digester 2 FVW:CM 80:20**	**Digester 3 FVW:CM 60:40**	**Digester 4 FVW:CM 40:60**
Methane	Range	46.99-51.69	44.69-54.29	50.59-51.47	50.24-57.80
(% methane)	Mean	48.64	50.48	51.16	54.26
	SD	4.72	5.09	0.49	2.62
Carbon dioxide	Range	35.77-44.07	21.81-38.39	23.95-36.57	26.46-35.29
(% Carbon dioxide)	Mean	41.28	30.78	31.43	29.84
	SD	4.77	8.37	6.63	4.77

Note: the biogas production were collected during 9.00 A.M-14.00 P.M and 14.15-19.15 P.M.(totally 10 hours)

The methane production of digester 1, 2, 3 and 4 (showed in table 4-8) were 0.32,0.37,0.32 and 0.16 m^3/ m^3 of digester-day, respectively and could be calculated as the heat energy in term of 29.13, 33.03, 28.74 and 14.57 Kcal/m^3 of digester -day, respectively. Therefore, the methane production and heat energy generated from digester 2 was highest (0.37 m^3 /m^3 of digester–day). In contract, the methane production and heat energy from digester 4 was lowest (0.16 m^3 /m^3 of digester–day) (Figure 4-3)

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Table 4-8 Methane production and heat energy

Methane production rate		Digester 1 FVW:CM 100:0	Digester 2 FVW:CM 80:20	Digester 3 FVW:CM 60:40	Digester 4 FVW:CM 40:60
	Range	0.28-0.37	0.31-0.40	0.29-0.38	0.15-0.18
m^3/ m^3 of	Mean	0.32	0.37	0.32	0.16
digester-day	SD	0.04	0.03	0.03	0.01
m^3/kg of VS	Range	0.15-0.17	0.13-0.17	0.12-0.16	0.06-0.07
feeding-day	Mean	0.14	0.15	0.13	0.07
	SD	0.02	0.01	0.00	0.01
Heat energy	Range	25.13-32.91	28.31-36.67	26.76-34.05	13.56-16.54
(kcal m^3 of	Mean	28.8	33.3	28.8	14.4
digester-day) [a]	SD	3.29	3.05	2.79	1.27

Remark: [a] Burning 0.028 cubic meter of methane production about 2.52 kcal (Adapt from FAO,1996)

There were quite interested that higher proportion of CM in mixed wastes could, also produce higher percentage of methane in the biogas. Therefore, the increasing of percent methane from the digester 2,3 to 4 (50.48%, 51.16% to 54.26%) seem that there were highly effective work between acid formers and methane formers. Moreover, the reducing of carbon dioxide percentage showed the highly effective work of hydro utilizing methane bacteria (Pollution Control Department, 1998)

The increasing of methane production and reducing of carbon dioxide production due to the increased population of bacteria in digester 2,3,4;by added cow manure into the mixed waste. As presented by David(1988) that many of anaerobic bacteria were found in the stomachs of ruminant are similar to the bacteria in biogas digester and 20-40% of bacteria in stomach ruminant were found in excreta (Chalo,1987)

From the results of methane concentration and carbon dioxide concentration in biogas showed that the co-digestion (cow manure mixed with FVW) could improved the quality of biogas production

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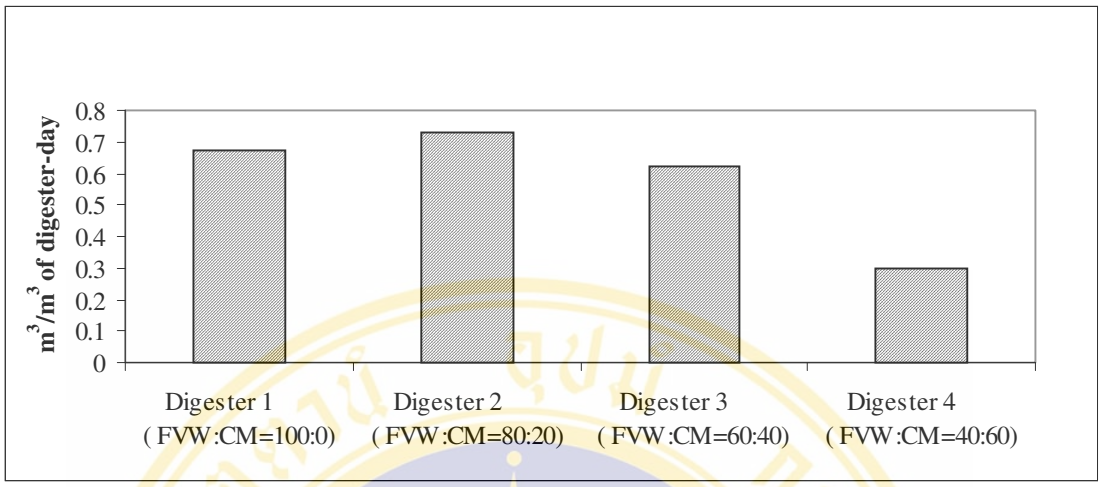

Figure 4 –1 Biogas production from the digesters

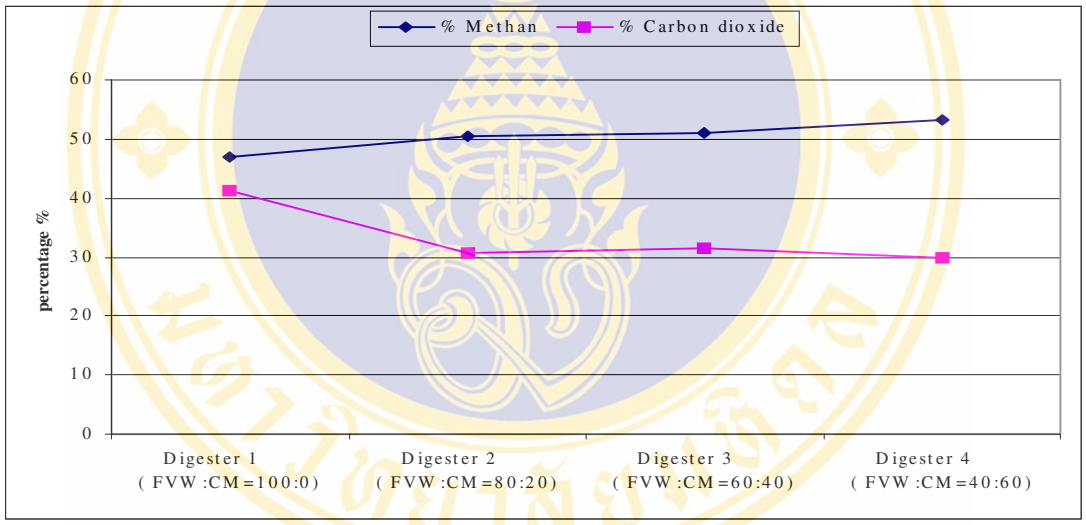

Figure 4-2 Methane concentration and carbon dioxide concentration of biogas from the digesters

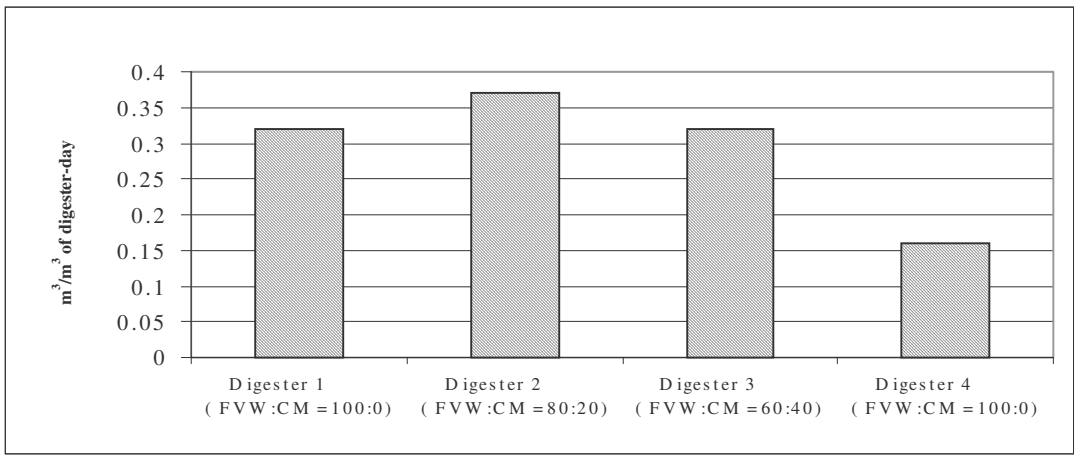

Figure 4-3 Methane production from digesters

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Comparison between the efficiency of solid reduction and biogas production in Figure 4.7 showed that the biogas production of the digester 2 (0.73 $m^3/m^3$of digester-day) was higher production than the digester 1 (0.67 m^3/m^3 of digester-day). However, the biogas production of digester 3 and 4 were decrease according to the higher CM content in the mixed wastes. The results showed that the mixed waste of FVW: CM = 80:20 was the suitable ratio for the systems. In addition, the more CM content in the mixed wastes caused the less VS reduction of the system.

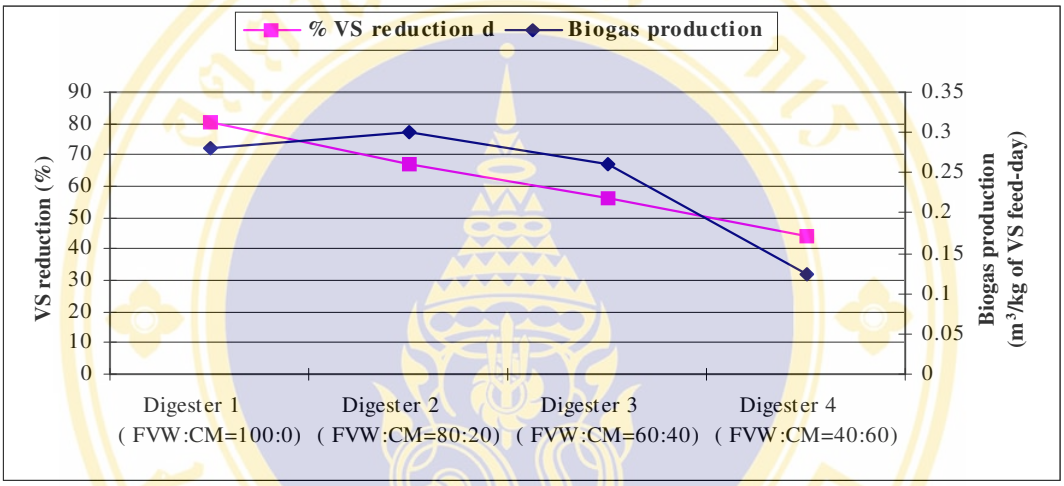

Figure 4-4 Efficiency volatile solid reduction and biogas production of digesters

4.4 The environmental factors of the digesters

The average value of air temperature, temperature in the digester and pH of slurry, in the steady state, were showed in table 4-8

4.4.1 Temperature

The average temperature in the digester 1, 2, 3 and 4 were 28.0, 28.1, 27.7 and 27.6 °C, respectively. The temperature of each digester was in the range of mesophilic, 25-40 °C (Chonkrak,1993) and slightly higher than the air temperature from the air temperature(27.9 °C).

4.4.2 pH

From the results in table 4-5, the average pH of slurry from digester 1, 2, 3 and 4 were 6.70, 6.72, 6.78 and 6.74, respectively. Therefore, all of them were in

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the optimum range, between 6.6 and 7.6 (Chongrak, 1993). Whereas, the pH of mixed wastes, in various ratios, quite different These results showed that the pH of mixed waste feeds did not caused the affect of the pH in the digesters. Moreover, the pH of slurry from digester 1,2 and 3 slightly more stable than pH of slurry in the digester 4.

Table 4-9 Air temperature, temperature in the digester and pH of slurry in the steady state

Environmental factor		**Digester 1 FVW:CM 100:0**	**Digester 2 FVW:CM 80:20**	**Digester 3 FVW:CM 60:40**	**Digester 4 FVW:CM 40:60**
Air temperature (°C)	Range	25.5-30	25.5-30	25.5-30	25.5-30
	Mean	27.9	27.9	27.9	27.9
	SD	1.58	1.58	1.58	1.58
Temperature in digester (°C)	Range	25.8-29.0	26.0-29.2	26.0-29.0	26-28.5
	Mean	28.0	28.1	27.7	27.6
	SD	0.1	1.1	1.1	0.9
pH of slurry	Range	6.66-6.74	6.67-6.72	6.75-6.81	6.66-6.88
	Mean	6.70	6.72	6.78	6.74
	SD	0.03	0.04	0.02	0.08

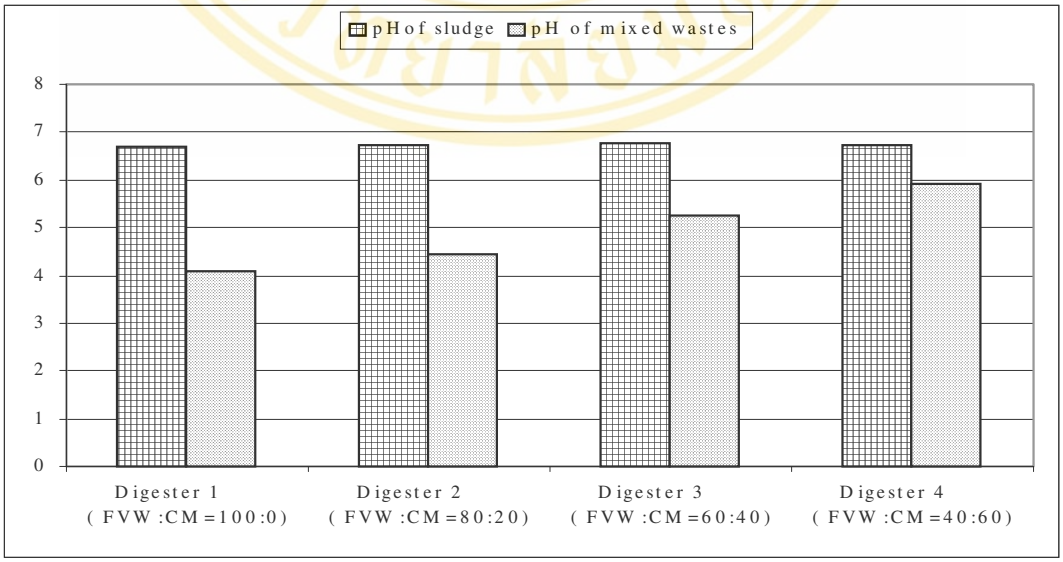

Figure 4–5. The pH of mixed waste and slurry of each digester

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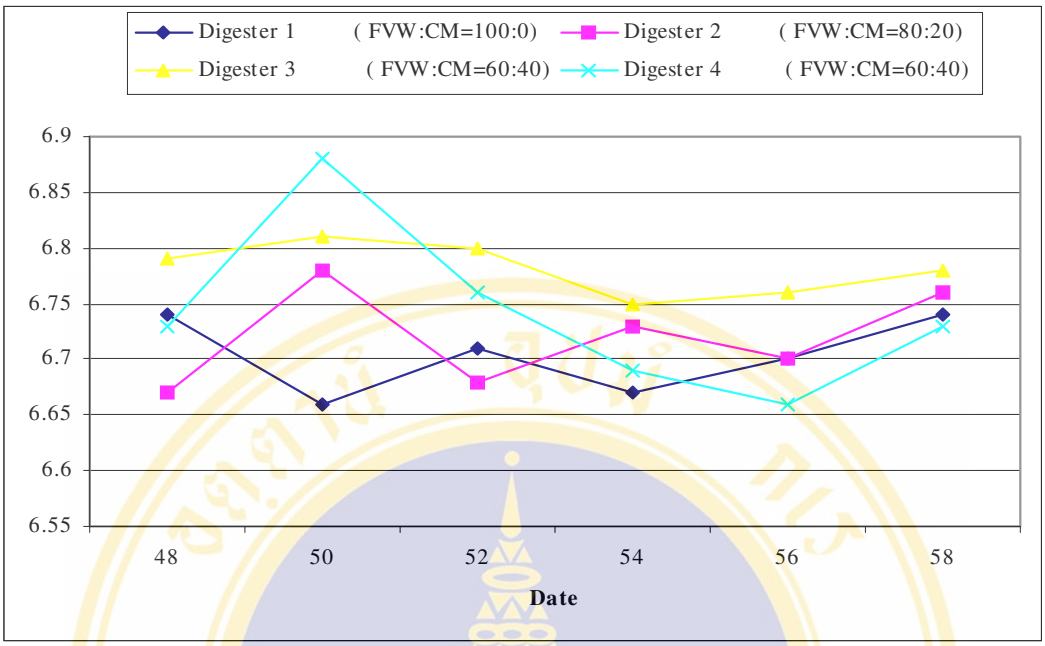

Figure 4-6 The pH of slurry from digesters under steady state

Average value of volatile fatty acid (VFA), total alkalinity and pH of slurry in steady state was showed table 4-10

Table 4-10 Volatile fatty acid, total alkalinity and ammonium nitrogen of slurry in steady state

Environmental factors		Digester 1 FVW:CM 100:0	Digester 2 FVW:CM 80:20	Digester 3 FVW:CM 60:40	Digester 4 FVW:CM 40:60
Volatile Fatty Acid(mg / l as CH_3COOH)	Min	1024.38	790.23	1068.29	1229.25
	Max	1350.00	1080.00	1155.00	1434.14
	Mean	1213.10±	923.43	1106.7	1342.9
	SD	117.54	102.82	31.45	173.66
Total Alkalinity (mg /l as $CaCO_3$)	Min	3080.00	2920.00	3400.00	3330.00
	Max	3400.00	3140.00	3900.00	3940.00
	Mean	3265	2993.33	3703.33	3584.16
	SD	127.87	81.40	172.24	200.86
NH_3-N(mg/l)	Min	12.12	1.47	3.86	0.73
	Max	17.26	7.34	6.24	1.47
	Mean	15.30	3.95	4.92	1.13
	SD	1.86	2.14	0.81	0.24

Remark: VFA = Volatile fatty acid
NH_3-N=Ammonium –Nitrogen

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4.4.3 Volatile fatty acid (VFA)

The volatile fatty acid (VFA) of the slurry from digester 1, 2, 3 and 4 were 1213.10, 923.43, 1106.7 and 1342.91 mg/l asCH_3COOH (in table 4-10)

The volatile fatty acid (VFA) concentration of digester 2, 923.43 mg/l as CH_3COOH, was lowest. In contract, the VFA concentration of digester 4 was highest (1342.96 mg/l as CH_3COOH). Although the results presented that all VFA concentration of digester, in this research, were not exceed 2000 mg/l as CH_3COOH (Larry d.,1980), however; the high VFA concentration presented the imbalance between acid forming bacteria and methanogenic bacteria that poisoned to work and grow up of methanogenic bacteria (Chongrak, 1989). For this reason, the lowest biogas production and solids reduction of digester 4 may be result from the high VFA concentration. On the other hand, the highest biogas production of digester 2 and lowest VFA concentration showed the balance of the system between the methanogenic bacteria and acid forming bacteria(figure 4-7).

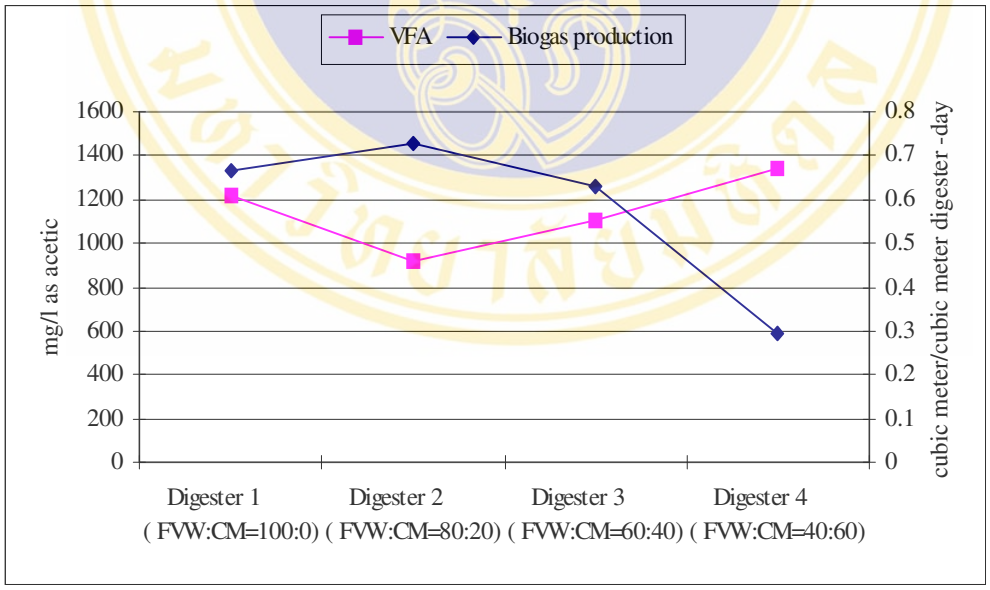

Figure 4 -7 Biogas production and VFA concentration

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4.4.4 Total alkalinity

The total alkalinity of slurry in digester 1, 2, 3 and 4 were 3265, 2993.33, 3703.33, 3584.16 mg / l as $CaCO_3$ respectively. All of digesters, in the research, had the total alkalinity between normally range from 1000 to 5000 mg/l. (Matcalf and Eddy,1979).

4.4.5 Ammonium -Nitrogen

The ammonium nitrogen of slurry from digester 1,2,3 and 4 were 15.30, 3.95, 4.93 and 1.13 mg/l, respectively. Although slurry of every digesters in this study showed that the ammonium nitrogen concentration was quite lower than the beneficial range of 50-200 mg/l (Larry, 1980), but all of digesters could produce biogas. It may be cause by some type of methanogenic bacteria could growth in condition of absent in amino acid (David A,1980).

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CHAPTER V
CONCLUSION AND RECOMMENTDATION

5.1 Conclusions

The results obtain in this study research was concluded as follows:

5.1.1 The solids reduction efficiency

The efficiency in total solids reduction at various rations of mixed wastes to the volatile solids of FVW and CM, were 100:0, 80:20, 60:40 and 40:60, were from 36.95-73.12 % and the volatile solids reduction were in the range of 43.83-80.63 %

5.1.2 The quantity and quality of biogas

The amount biogas production from the low-solids anaerobic digesters that fed by the various ratio of mixed waste (the mixed wastes made from FVW/CM ratios of 100:0,80:20,60:40 and 40:60 base on volatile solid of total waste) was varied from 0.67-0.73 m^3/m^3 digester/day. The percentage of methane and percentage of carbon dioxide in biogas produced range from 48.64-53.26 % and 29.84-41.28%, respectively. The methane productions of digesters were range from 0.16-0.37 m^3/m^3 digester/day.

The biogas production (0.73 m^3/m^3digester/day), methane production (0.37 m^3/m^3digester/day) and heat energy under steady state of digester 2 was the highest.

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5.1.3 The environmental factor

Temperatures during this study were mesophilic ranges. The pH, volatile fatty acid and total alkalinity of slurry from digesters have optimum range.

The ammonium nitrogen of slurry from these digesters was lower than benefic range but did not cause a serious affect to the biogas production.

In conclusion, the useful of co-digestion between the FVW and CM that the increasing percentage of cow manure in the mixed wastes would have the affect to the quality and quantity of biogas production. Therefore, the appropriate ratio of the mixed waste between FVW and CM was 80:20, under organic loading of 0.957 kgVS/m^3-day, HRT of 31.25 day and no need of nutrient or chemical addition to the system.

5.2 Recommendations for future study

5.2.1 The appropriate organic loading operated with FVW mixed with CM should be study. Because of the results of this study showed that the methane concentration of biogas from digester 4 was the highest that showed the good quality of biogas but still have a high VFA concentration in the digester. The way to solve this problem was by adjustment organic loading to reduce the excessive VFA that reported by Chongrak (1989)

5.2.3 The relationship between nutrients composite of FVW and CM that effect to quantity and quality of biogas production should be study. The ammonium concentration of slurry in this study was lower than benefit range. This condition may cause of low production of biogas that reported by FAO (1996). So the system improvement by the nutrient in mixed waste was the interesting way to improve biogas production.

5.2.4 Study about the biogas production by using FVW mixed with CM in the pilot- scale digesters.

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APPENDIX A
Experimental results and Apparatus

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Table A-1 the kind and quantity of FVW (Collecting between21-27 August 2002)

No.	kind	FVW (Kg/d)							AVG (Kg/d)	%
		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7		
1	Pineapple peel	104.5	5.7	10.8	7.98	9.25	11.82	12.19	23.18	52.89
2	Ipomoea	0.4	7.91	3.4	1.04	4.15	1.22	1.71	2.83	6.46
3	Catalope peel	2.45	2.65	2.49	2.83	2.44	2.10	2.36	2.47	5.64
4	Luffa peel	2.58	3.25	1.11	1.68	0.68	0.27	2.02	1.65	3.79
5	Cabbage	0	1.00	1.78	0.83	1.575	0.975	0.470	0.947	2.16
6	Chinese kale	2.65	1.20	1.69	0.69	0.97	0	0.430	1.09	2.49
7	Asparagus	0.5	0	1.05	1.39	0.29	1.715	0.29	0.748	1.71
8	Carrot peel	0.41	0	0.56	0.155	0.510	0.320	0.510	0.352	0.80
9	Lettuce plant	0	0	1.40	0.275	0.660	0.830	0.950	0.587	1.34
10	Tara roots peel	0.6	0.27	0.96	0	0	1.75	0.30	0.555	1.27
11	Spring onion peel	0.9	0	0.25	0.26	0	0.19	0.05	0.235	0.54
12	Onin peel	0	0.12	0.37	0.12	0.445	0	0.175	0.175	0.40
13	Papaya	6.2	1.85	1.06	3.32	0	0	0	17.75	4.05
14	Pumpkin	1.11	0.15	0	0	0.165	0.550	0	0.493	1.12
15	Celery	0	0.30	0.16	0	0	0.12	0.265	0.263	0.60
16	Cucumber peel	0	0	0.24	0	0.225	0.18	0.15	0.113	0.26
17	Bird pepper	0	0	0.13	0	0.285	0.10	0.08	0.085	0.19
18	Lemon grass	0.11	0	0.05	0.05	0.08	0	0	0.041	0.09
19	Chinese chives	0	0	0	0	10.5	0.895	1.165	0.444	1.01
20	Water melon peek	3.54	0	0	0	2.84	0	0	0.911	2.07
21	Water mimosa	0	0.5	0	1.85	0	0	0	0.335	0.77
22	Potato	0.5	0	0	0	0	0	0.58	0.154	0.35
23	Pandanus leave	0	0	0.48	0	0.2	0	0	0.097	0.22
24	Boesenbergia rotunda (Linn) Mansf	0	0.3	0	0	0.35	0	0	0.092	0.21
25	Parsley	1.5	0	0	0	0.07	0	0	0.224	0.51
26	String bean	0	0	0.10	0	0	0.18	0	0.04	0.09
27	Lime	0	0	0	0	3.375	0	0	0.482	1.09
28	Wax gourd	0	0	0	1.85	0	0	0	0.264	0.60
29	Corn	0	0	0.81	0	0	0	0	0.115	0.26
30	Banana peel	0.91	0	0	0	0	0	0	0.13	0.30
31	Hairy basil	0	0	0	0	0.42	0	0	0.060	0.14
32	Mango peel	0	0	0	0	0	0	340	0.048	0.11
33	Ocimum basilicum Linn	0.3	0	0	0	0	0	0	0.043	0.10
34	Leucaena Leucocephalade wit.	0	0.3	0	0	0	0	0	0.043	0.10
35	Holy basil	0	0.1	0	0	0	0	0	0.014	0.03
36	Etc.	13.05	0.77	16.60	12.25	12.80	0.365	7.20	2.72	6.21
	Total	142.2	26.4	31.6	25.5	32.79	23.59	24.76	41.11	100

Remark: FVW =Fruit and vegetable waste
Kg/d = kilogram per day

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Figure A-1 Fruit and vegetable waste

Figure A-2 Fruit and Vegetable waste and cow manure after preparation.

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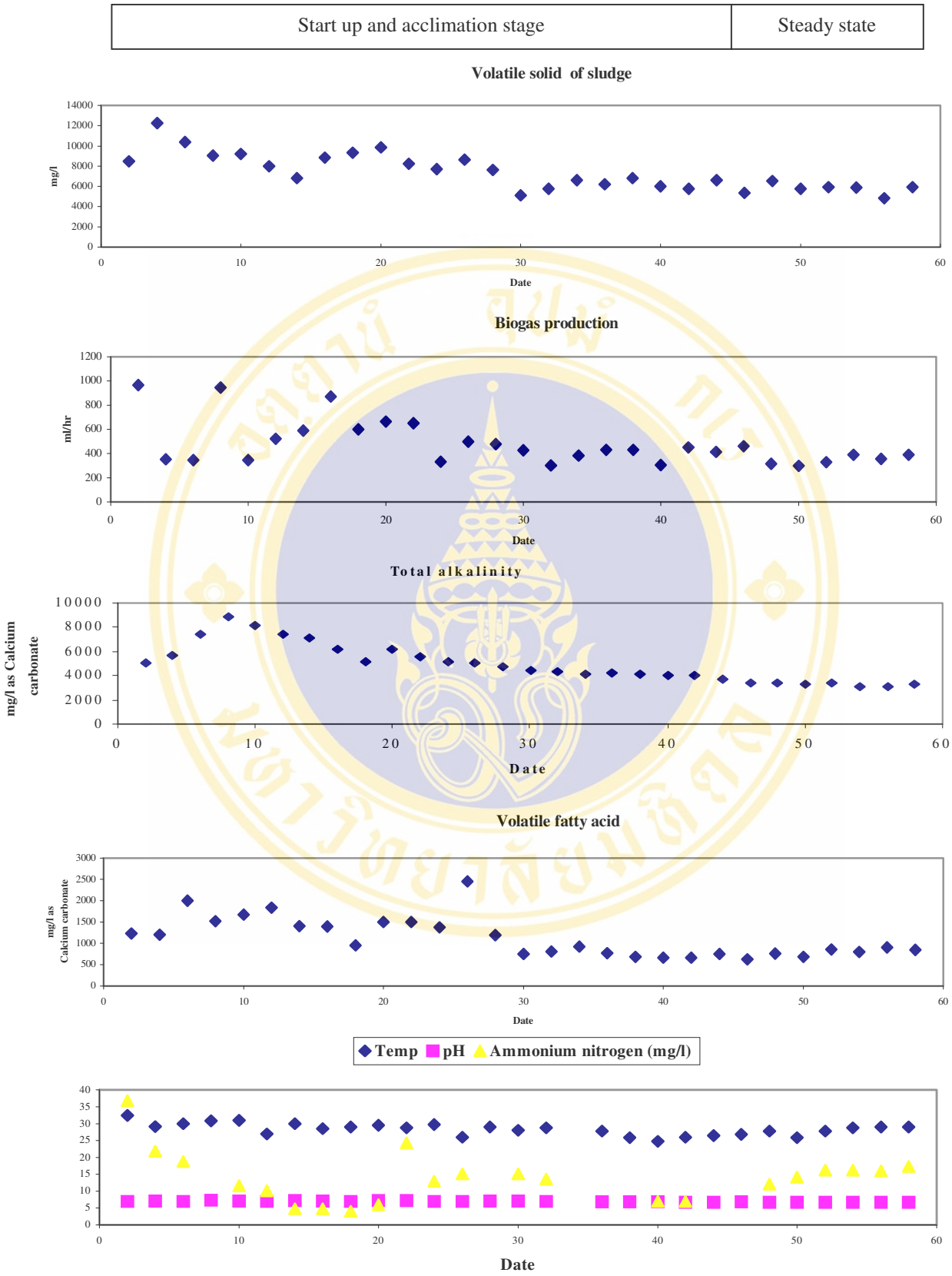

Figure A-3 The change of gas production, volatile solid of slurry and environmental factors in digester 1(FVW:CM =100:0)

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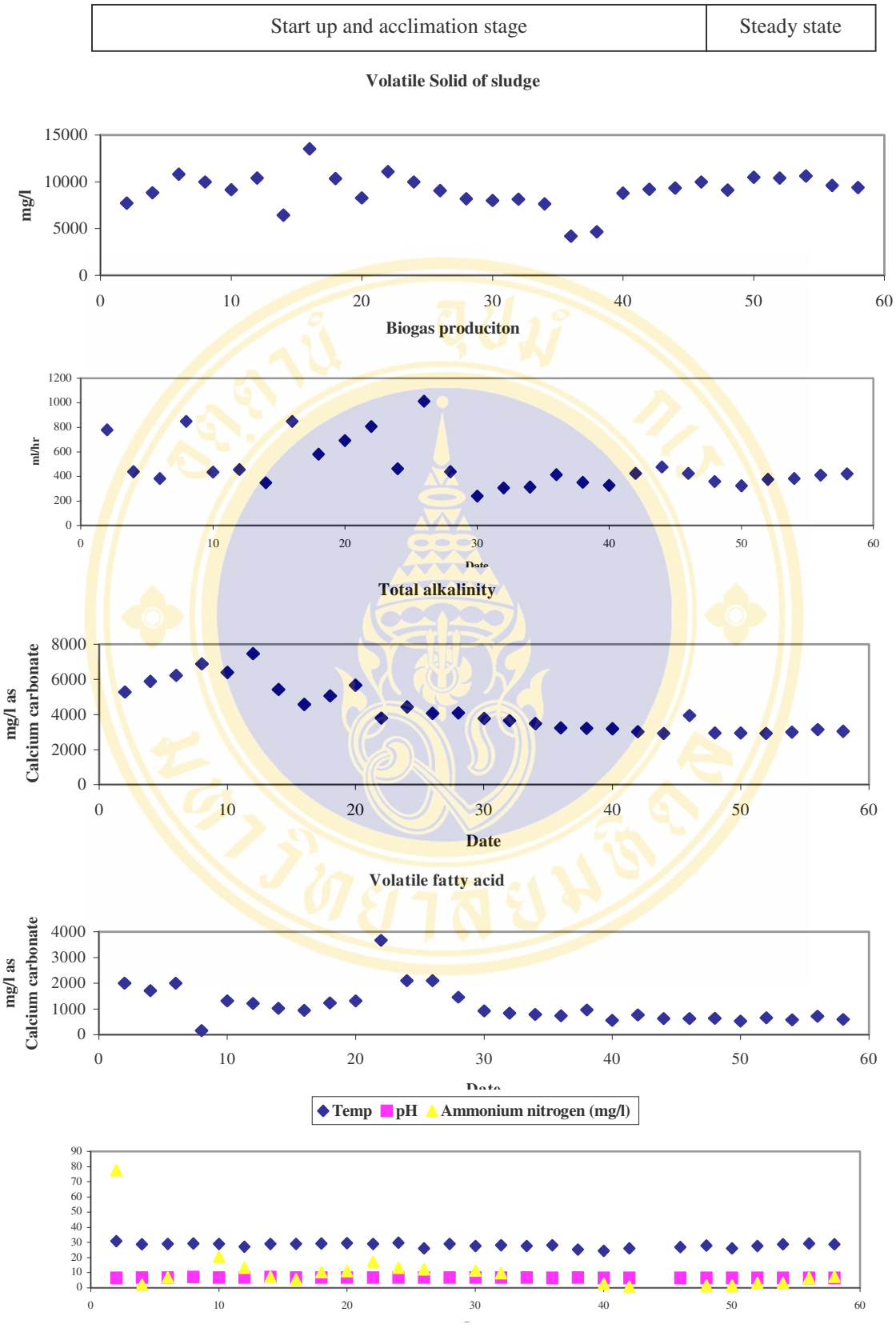

Figure A-4 The change of gas production, volatile solid of slurry and environmental factors in digester 2(FVW:CM 80: 20)

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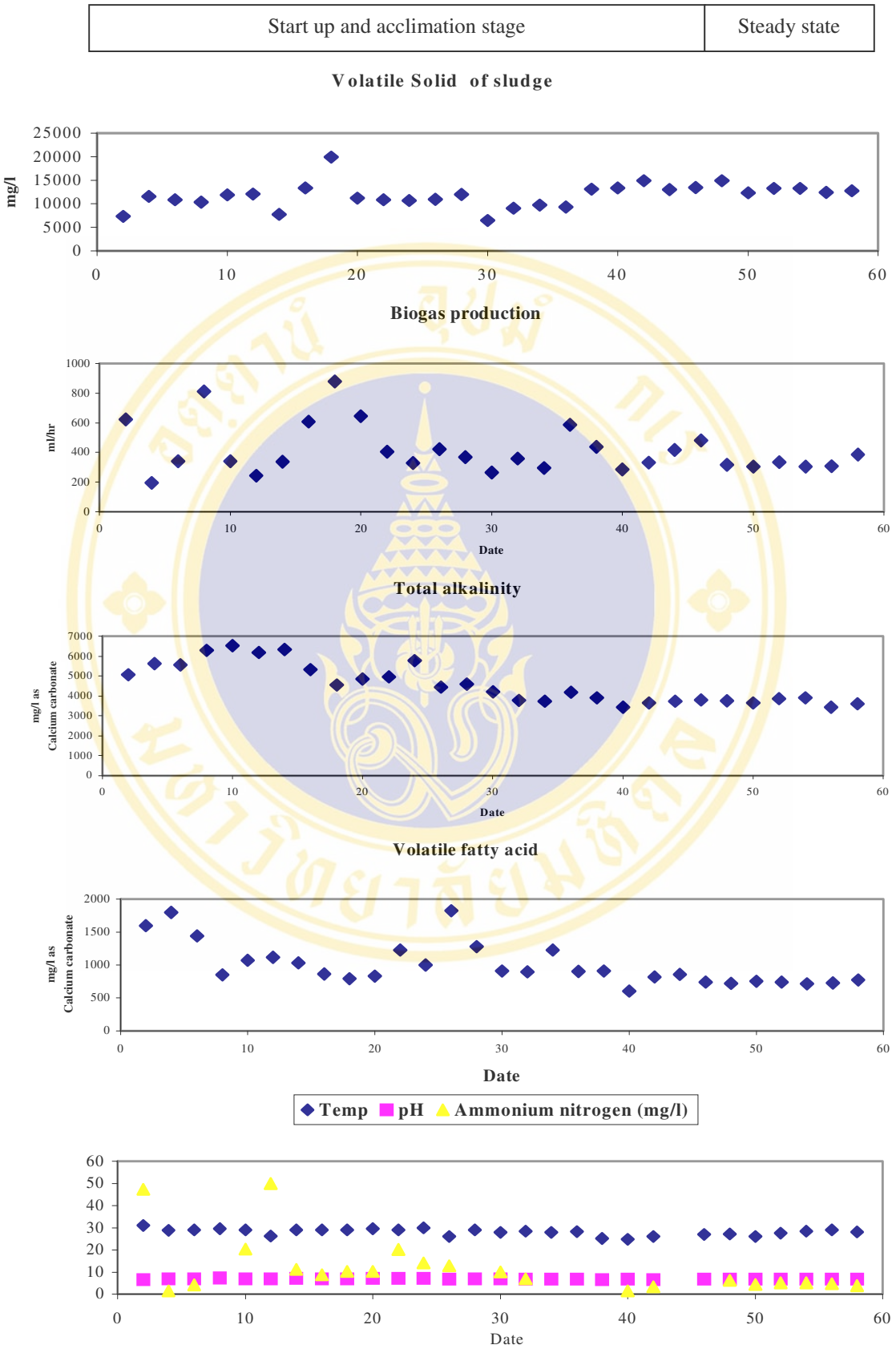

Figure A-5 The change of gas production, volatile solid of slurry and environmental factors in digester 3 (FVW:CM = 60: 40)

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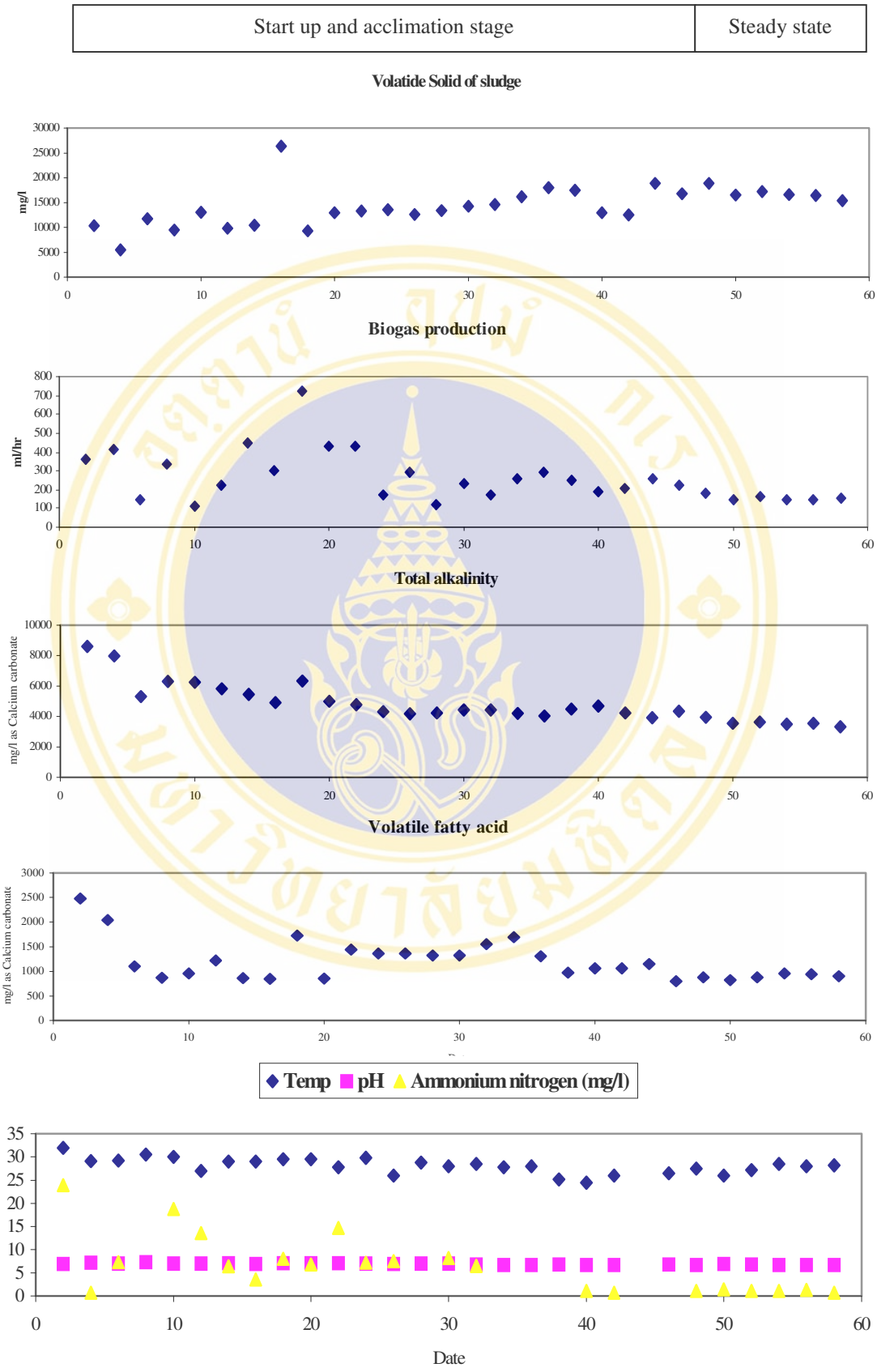

Figure A-6 The change of gas production, volatile solid of slurry and environmental factors in digester 4 (FVW :CM =40:60)

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Start up and acclimation stage	Steady state

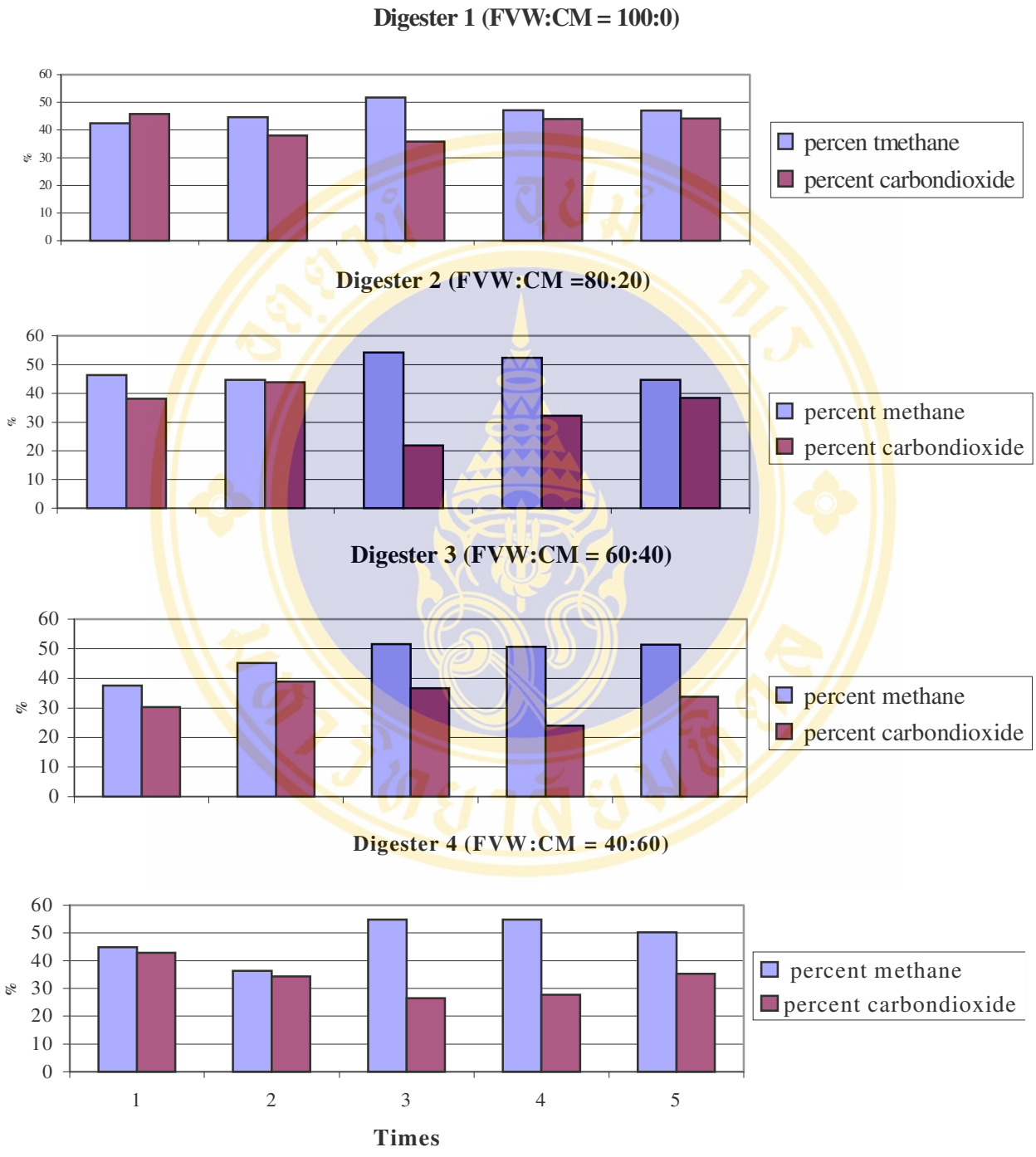

Figure A-7 Percent methane and carbon dioxide of biogas from digesters under start-up stage, acclimation stage and steady state

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Table A-2. Solid reduction efficiency of a low-solids anaerobic digester under steady state

Digester 1(FVW:CM=100:0)						
Day	TS feeding (mg/l)	TS slurry (mg/l)	% TS Reduction	VS feeding (mg/l)	VS slurry (mg/l)	% VS Reduction
48	32185.79	9152	71.57	30196.90	6532	78.37
50	32060.59	8375	73.88	29902.91	5771	80.70
52	32060.59	9121	71.55	29902.91	5905	80.25
54	32044.94	8520	73.41	29888.32	5879	80.33
56	32073.11	7092	77.89	29914.59	4813	83.91
58	32048.07	9487	70.43	29891.23	5908	80.23
Min	32044.94	7092.00	70.43	29888.32	4813	78.37
Max	32185.79	9478.00	77.89	30196.9	6532	83.91
Mean	32078.85	8623	73.12	29949.48	5801.33	80.63
SD	53.35	857.31	2.67	121.577	554.933	1.80
Digester 2(FVW:CM= 80:20)						
Day	TS feeding (mg/l)	TS slurry (mg/l)	% TS Reduction	VS feeding (mg/l)	VS slurry (mg/l)	% VS Reduction
48	33068.01	12244.00	62.97	29979.41	9128.00	69.35
50	33227.3933	13869.33	58.26	29926.34	10489.33	64.95
52	244.93	13653.33	58.93	29942.44	10405.00	65.25
54	33263.81	13404.00	59.70	29957.41	10608.00	64.59
56	33309.07	12865.00	61.38	29994.60	9636.00	67.87
58	33218.2	12490.00	62.40	29920.81	9385.33	68.63
Min	33068.01	12244.00	58.26	29779.40	9128.00	64.59
Max	33309.07	13869.33	62.97	2994.60	10608.00	69.35
Mean	33221.90	13087.61	60.61	29920.17	9941.94	66.77
SD	81.99	655.68	1.93	73.86	636.18	2.08
Digester 3(FVW:CM=60:40)						
Day	TS feeding (mg/l)	TS slurry (mg/l)	% TS Reduction	VS feeding (mg/l)	VS slurry (mg/l)	% VS Reduction
48	34640.43	19745.33	42.99	30140.62	14886.67	50.61
50	34650.17	16794.67	51.53	30148.77	12285.33	59.25
52	34647.04	18358.67	47.01	30145.85	13306.67	55.86
54	34675.36	17753.33	48.80	30168.30	13238.67	56.12
56	34719.23	16853.33	51.46	30207.90	12453.33	58.77
58	34684.60	17006.67	50.97	30180.88	12728	57.83
Min	34640.43	16794.67	43.00	30140.61	12285.33	50.61
Max	34719.23	19745.33	51.53	14886.67	14886.67	59.25
Mean	34669.47	17752.00	48.79	30165.39	13149.78	56.41
SD	29.86	1150.74	3.35	25.80	944.41	3.15
Digester 4(FVW:CM=40:60)						
Day	TS feeding (mg/l)	TS slurry (mg/l)	% TS Reduction	VS feeding (mg/l)	VS slurry (mg/l)	% VS Reduction
48	35550.31	25170.67	29.19	29980.94	18897.33	36.97
50	35599.15	22148.00	37.79	30017.91	16518.00	44.97
52	35550.36	22874.67	35.66	29979.66	17230.67	42.53
54	35567.65	22176.00	37.65	29993.81	16613.33	44.61
56	3560.97	22006.67	38.19	30026.64	16472.00	45.14
58	35578.63	20430.67	42.57	3003.39	15372.00	48.77
Min	35550.31	20430.67	29.20	29979.66	15372.00	36.97
Max	35604.97	25170.67	42.58	30026.67	18897.33	48.77
Mean	35575.18	22467.78	36.84	3000.39	16850.56	43.83
SD	23.52	1550.55	4.38	19.27	1168.77	3.92

Remark: TS = Total solid
VS =Total volatile solid

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Table A-3 Biogas production, methane production and carbon dioxide production of a low -solids anaerobic digester under steady state

Digester 1(FVW:CM=100:0)									
Day	Biogas production			Methane production			Carbon digestion		
	ml /hr	l / l vol-d	l / g feed	%	l / l vol-d	l / g feed	%	l / l vol-d	l / g feed
48	314.61	0.6040	0.2500	51.09	0.2938	0.1216	35.77	0.2494	0.1032
50	299.03	0.5741	0.2400	-	0.2793	0.1167	-	0.2370	0.0991
52	328.35	0.6304	0.2635	47.24	0.3066	0.1282	44.01	0.2603	0.1088
54	390.82	0.7503	0.3138	-	0.3649	0.1526	-	0.3098	0.1295
56	354.82	0.6812	0.2847	46.99	0.3313	0.1385	44.07	0.2812	0.1175
58	391.5	0.7516	0.3143	-	0.3656	0.1529	-	0.3103	0.1298
Min	299.03	0.5741	0.2400	46.99	0.2792	0.1167	35.77	0.2370	0.0991
Max	391.5	0.7516	0.3143	51.69	0.3649	0.1526	44.07	0.3096	0.1295
Mean	346.52	0.6653	0.2777	48.64	0.3236	0.1351	41.28	0.2746	0.1147
SD	39.13	0.0751	0.0318	2.64	0.0365	0.0155	4.77	0.0310	0.0131
Digester 2(FVW:CM= 80:20)									
Day	Biogas production			Methane production			Carbon digestion		
	Ml /hr	l / l vol-d	l / g feed	%	l / l vol-d	l / g feed	%	l / l vol-d	l / g feed
48	357.14	0.6857	0.2878	54.29	0.3461	0.1453	21.81	0.2088	0.0877
50	324.53	0.6231	0.2603	-	0.3145	0.1313	-	0.1898	0.0793
52	376.90	0.7237	0.3021	52.45	0.3653	0.1525	32.15	0.2204	0.0920
54	383.43	0.7362	0.3072	-	0.3716	0.1551	-	0.2242	0.0935
56	409.71	0.7866	0.3278	44.69	0.3971	0.1655	38.39	0.2396	0.0998
58	420.40	0.8071	0.3372	-	0.4074	0.1702	-	0.2458	0.10269
Min	354.53	0.6231	0.2602	44.69	0.3145	0.1314	21.81	0.1897	0.0793
Max	420.40	0.8071	0.3372	54.29	0.3970	0.1655	38.39	0.2397	0.10269
Mean	378.69	0.7271	0.3037	50.47	0.3670	0.1533	30.78	0.2214	0.0925
SD	35.00	0.0672	0.0278	5.09	0.0339	0.0140	8.37	0.021	0.0085
Digester 3(FVW:CM=60:40)									
Day	Biogas production			Methane production			Carbon digestion		
	Ml /hr	l / l vol-d	l / g feed	%	l / l vol-d	l / g feed	%	l / l vol-d	l / g feed
48	315.48	0.6057	0.2512	51.47	0.3099	0.1285	36.57	0.1904	0.0789
50	302.66	0.5811	0.2409	-	0.2973	0.1233	-	0.1826	0.0757
52	334.77	0.6428	0.2665	50.59	0.3289	0.1364	23.95	0.2020	0.0838
54	305.12	0.5858	0.2427	-	0.2997	0.1242	-	0.1841	0.0763
56	307.51	0.5904	0.2443	51.42	0.3021	0.1249	33.77	0.1856	0.0768
58	385.17	0.7395	0.3063	-	0.3783	0.1567	-	0.2324	0.0963
Min	302.66	0.5811	0.2409	50.59	0.2973	0.1233	23.95	0.1826	0.757
Max	385.17	0.7395	0.3063	51.47	0.3289	0.1364	36.57	0.2324	0.0963
Mean	325.11	0.6242	0.2587	51.16	0.3194	0.1323	31.43	0.1962	0.0813
SD	31.65	0.0608	0.0251	0.49	0.0311	0.0129	6.63	0.0191	0.0079
Digester 4(FVW:CM=40:60)									
Day	Biogas production			Methane production			Carbon digestion		
	Ml /hr	l / l vol-d	l / g feed	%	l / l vol-d	l / g feed	%	l / l vol-d	l / g feed
48	176.41	0.3387	0.1412	54.79	0.1838	0.0766	26.46	0.1011	0.0421
50	144.89	0.2782	0.1158	-	0.1509	0.0629	-	0.0830	0.0346
52	167.29	0.3212	0.1339	57.75	0.1743	0.0727	27.78	0.0959	0.0399
54	144.59	0.2776	0.1157	-	0.1506	0.0628	-	0.0828	0.0345
56	145.08	0.2786	0.1157	50.23	0.1511	0.0629	35.29	0.0831	0.0346
58	154.22	0.2961	0.1234	-	0.1607	0.0669	-	0.0884	0.0368
Min	144.59	0.2776	0.1157		0.1506	0.0628	26.46	0.0828	0.0421
Max	176.41	0.3387	0.1412		0.1838	0.0766	35.29	0.1010	0.0345
Mean	155.41	0.2984	0.1243		0.1619	0.0675	29.84	0.0890	0.0371
SD	13.55	0.0260	0.0109		0.0141	0.0059	4.77	0.0078	0.0033

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Table A-4 Environmental factors of a low -solids anaerobic digester under steady state

Digester 1(FVW:CM=100:0)							
Day	pH	Temp	VFA	ALK	VFA/ALK	NH_3-N	CONDUCT
48	6.74	27.8	1141.46	3370.00	0.34	12.12	3900
50	6.66	25.8	1024.38	3290.00	0.31	14.14	3800
52	6.71	27.8	1287.79	3400.00	0.38	16.16	4000
54	6.67	28.8	1199.98	3140.00	0.38	16.16	4050
56	6.7	29.0	1350.00	3080.00	0.44	15.97	4100
58	6.74	29.0	1275.00	3310.00	0.38	17.26	4100
Min	6.66	25.8	1024.38	3080.00	0.311	12.12	3800
Max	6.74	29.0	1350.00	3400.00	0.44	17.26	4100
Mean	6.70	28.0	1213.10	3265.00	0.37	15.30	3991.67
SD	0.03	1.2	117.53	128.87	0.04	1.86	120.07
Digester 2(FVW:CM=80:20)							
Day	pH	Temp	VFA	ALK	VFA/ALK	NH_3-N	CONDUCT
48	6.67	28.0	965.85	2940.00	0.33	1.47	3300
50	6.78	26.0	790.23	2950.00	0.27	1.66	3150
52	6.68	27.8	995.12	2920.00	0.34	3.31	3100
54	6.73	28.8	863.40	2980.00	0.29	3.3	3300
56	6.70	29.2	1080.00	3140.00	0.34	6.61	3400
58	6.76	28.8	900.00	3030.00	0.29	7.34	3450
						1.47	3400
Min	6.67	26.0	790.23	2920.00	0.27	7.34	3100
Max	6.72	29.2	1080	3140.00	0.34	7.34	3400
Mean	6.72	28.1	932.43	2993.33	0.31	3.95	3283.33
SD	0.04	1.2	102.82	81.40	0.03	2.48	136.63
Digester 3(FVW:CM=60:40)							
Day	pH	Temp	VFA	ALK	VFA/ALK	NH_3-N	CONDUCT
48	6.79	27.2	1082.91	3760.00	0.29	6.24	3600
50	6.81	26.0	1126.82	3660.00	0.31	4.41	3450
52	6.8	27.5	1112.19	3860.00	0.29	5.14	3500
54	6.75	28.5	1068.28	3900.00	0.27	5.14	3600
56	6.76	29.0	1095.00	3440.00	0.32	4.77	3600
58	6.78	28.0	1155.00	3600.00	0.32	3.86	3500
Min	6.75	26.0	1068.29	3440.00	0.27	3.86	3450
Max	6.81	29.0	1155.00	3900.00	0.32	6.24	3600
Mean	6.78	27.7	1106.7	3703.33	0.29	4.93	3541.67
SD	0.02	1.05	31.45	172.24	0.02	0.80	66.46
Digester 4(FVW:CM=40:60)							
Day	pH	Temp	VFA	ALK	VFA/ALK	NH_3-N	CONDUCT
48	6.73	27.5	1317.06	3940.00	0.33	1.10	3400
50	6.88	26	1229.25	3550.00	0.35	1.47	3150
52	6.76	27.2	1317.06	3625.00	0.36	1.10	3200
54	6.69	28.5	1434.14	3500.00	0.41	1.10	3300
56	6.66	28	1410.00	3560.00	0.39	1.29	3300
58	6.73	28.2	1350.00	3330.00	0.41	0.73	3100
Min	6.66	26	1229.25	3330	0.33	0.73	3150
Max	6.88	28.5	1434.14	3940	0.41	1.47	3400
Mean	6.74	27.57	1342.92	3584.17	0.38	1.13	3241.67
SD	0.07	0.90	73.66	200.86	0.03	0.24	111.67

Remarks: Temp = Temperature of digester (C)
VFA = Volatile fatty acid (mg/l as CH3COOH)
ALK = Total alkalinity (mg/l as CaCO3)
NH_3-N= Ammonium nitrogen (mg/l)
CONDUCT= Conductivity (mhos/M)

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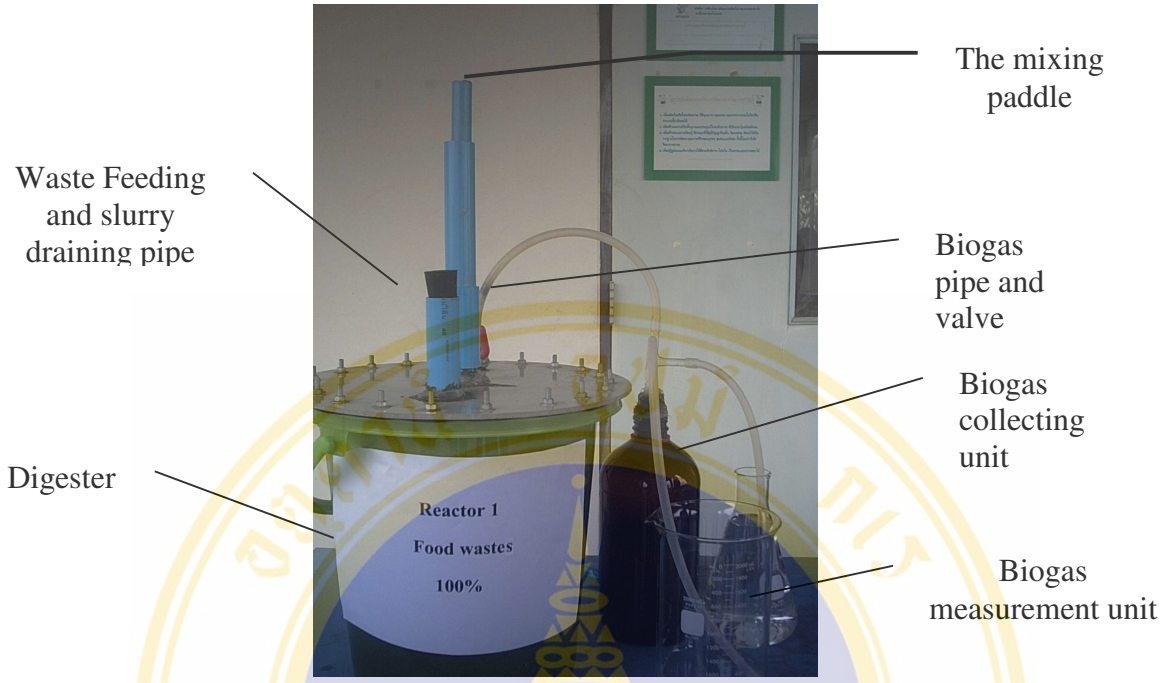

Figure A-8 Digester, Gas collection and measurement unit

a

b

c

d

Figure A-9 The mixing paddle (a),the cover (b), the trapezoid plastic bucket(c) and gas collecting and measurement unit(d)

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APPENDIX B
Nitrogen Determination by Kjeldahl (Rack)
Method of calculation of percent carbon and C/N ration

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Nitrogen determination by Kjeldahl(Rack)

1.Basic principle

The Kjeldahl method consists of three basic steps

1.1 Digestion of the sample in sulfuric acid with a catalyst, which results in conversion of nitrogen to ammonia

1.2 Distillation of the ammonia into a trapping solution

1.3 Quantification of the ammonia by titration

2.Equipment

2.1 Kjeldahl flask

2.2 Kjeldahl digestion unit with fume removal manifold

2.3 Kjeldahl distillation apparatus–Kjeldahl flask connected to distillation trap by rubber stopper.

2.4 Erlenmeyer flask 250 ml

2.5 Analytical balance, sensitive to 0.1 mg

3.Reagents

3.1 Sulfuric acid, concentrated, 95-98 % reagent grade

3.2 Sodium hydroxide, pellets, flakes, or 45 % solution with specific gravity 1.36 (low M) dissolve 450 g in cool water and dilute to 1l

3.3 Potassium sulfate (K_2SO_4)

3.4 Anhydrous Copper sulfate ($CuSO_4$)

Methy red indicator: dissolve 1 g Methy red (sodium salt) in 100 ml methanol or ethanol

3.5 Hydrochloric acid standard solution, 0.5 N.

Prepare by diluting 430.1 ml 36.5 to 38% HCl to 10l with distilled water and standardize by method

3.6 Sodium hydroxide standard solution.

Prepare 0.1 N sodium hydroxide (NaOH) solution and standardize

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3.7 Trapping solution (with indicator)/ titrant

Boric acid solution 4% dissolve 400 g boric acid (H_3BO_3) in distilled water containing 70 ml 0.1 % alcohol solution of methyl red and 100 ml 0.1% alcohol solution of bromocresol green and dilute to 10 l with distilled water.

4.Procedure:

4.1 Digestion

Weigh approximately 1g ground sample into digestion flask, recording weight (W) to nearest 0.1 mg.

Add 15g potassium sulfate (K_2SO_4), 0.04 g anhydrous sludge. Then add 20 ml sulfuric acid.(Add additional 1.0 ml sulfuric acid for each 0.1 g fat or 0.2 g other organic matter if sample weight is greater than 1 g)

Place flask on preheated burner (adjusted to bring 250 ml water at 25°C to rolling boil in 5 min)

Heat until white fumes clear bulb of flask, swirl gently and continue heating for 90 min

Cool, cautiously add 50 ml distilled water and cool to room temperature (25°C) Note: add water as soon as possible to reduce amount of caking

4.2 Distillation

Place 250 ml titrating flask containing 25 ml boric acid solution with indicator so that tube of condenser is immersed below surface of absorbing solution

Add 2 to 3 drops of tributyl citrate or other antifoam agent to digestion flask to reduce foamimg

Add another 0.5 to 1.0 g alundum granules

Slowly down side of flask, add sufficient 45 % sodium hydroxide solution (approximately 80 ml) to make mixture strongly alkali (Do not mix until after flask is connected to distillation apparatus of ammonia will be lost.)

Immediately connect flask to distillation apparatus, swirl to mix contents and distill at about 7.5 boil rate (Temperature set to bring 250 ml water at 25 °C to boil in 7.5 min) until at least 150 ml distillate is collected in titrating flask.

Remove digestion flask and titrating flask from unit, rinsing the condenser tube with distilled water as the flask is being removed.

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4.3 Titration

Titrate with 0.2 N HCL to neutral gray endpoint and record volumn to nearest 0.1 ml (VA).Titrate reagent blank (VB) similarly(Color change is green to gray to purple)

5. Calculation: percent nitrogen (%N)

%N (DM basic) = [(VA-VB)x NaHCLx1.4007] / W

VA = Volume, in ml, of standard HCL required for sample

VB = Volume, in ml, of standard HCL required for blank

NHCl = Normality of standard HCL

1.4007 = miliequivalent weight of N x100

W= Sample weight in grams

Reference :

Protein(Crude)Determination in Animal Feed: Copper Catalyst Kjeldahl Method. (984.13)Official Methods of Analysis.1990.Association of Official Analytical Chemists.15th Edition.

Protein(Crude)in Animal Feed: CuSO4/TiO2 Mixed Catalyst Kjeldahl Method (988.05)Official Methods of Analysis.1990.Association of Official Analytical Chemists.15th Edition.

Nitrogen (Total) in Fertilization: Official. Method (Mercury).(955.04).Official Methods of Analysis.1990.Association of official Analytical Chemists.15 Edition.

Nitrogen (Total) in milk.(991.20) Official Methods of Analysis. 2nd supplement.1991 Association of Official Analytical Chemists.15th Edition

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Method of calculation of percent carbon and C/N ration

(Chongrak,1989)

1.Percent carbon

Gray et al (1971) comment that, in practice, accurate calculations and adjustments of optimum C/N ratios are made difficult by the following factors

1. Parts of the C substrate, such as cellulose and lignin, are highly resistant to biological breakdown, and are only decomposed over a long period of time
2. Some of the nutrient such as keratin-type proteins, are in anadaccessibly difficult form, and are not easily available during much of accessibly difficult form
3. Analysis of C concentration may be difficult and inaccurate.

The following relationship, providing an accuracy of with 2-10 percent is proposed (Gotaas, 1956):

$$\text{Percentage Carbon (\% C)} = \frac{100 - \text{percentage ash}}{1.8}$$

Percent ash refers to materials remaining after being burnt at 550°C for 1 hours: however; some types of wastes that c contain a large portion of plastics (which disappear at 550°C) value of percentage C, which is largely non-biodegradable

2. Calculation of C/N ration

The example a-1 showing a method of calculation of appropriate mixing ratio of some raw material, is given below

Examples a-1 Sludge from a septic tank has the following has the following characteristic

C/N ratio = 15/1 (dry weight basis)

Total solids =10 percent

Volatile solids = 90 percent of total solids

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Determine the quantity of rice straw needed to be mixed with this septic tank sludge to raise the C/N ratio of the mixture to 30/1. Rice straw has a C/N ratio of 80/1,moisture content 50 percent, bulk density = 100 kg/m3, and N =0.2 percent of dry weight
For the sludge

$$\text{Percentage Carbon (\% C)} = \frac{100-10}{1.8} = 50 \text{ percent of total solids}$$

Let x be kg dry weight of rice straw needed to be mixed with 1 kg dry weight of septic tank sludge

For1 kg dry weight of septic tank sludge, C content =1(0.5) kg; N content =1 (0.5)(1/15) kg

For x kg dry weight of rice straw ,N content = x (0.2/100) kg, C content = x (0.2/100)(80/1) kg. Therefore C/N of the mixture is

$$\frac{1(0.5)+ x(0.2/100)(80/1)}{1(0.5)(1/15)+x(0.2/100)} = \frac{30}{1}$$

$$x = 5 \text{ kg}$$

$$\text{Volumn of rice straw required} = \frac{5}{0.5(100 \text{ kg}/100\text{l})} = 100 \text{ L}$$

$$\text{1 kg dry weight of septic tank sludge} = \frac{1}{0.1(1.1)} = 9.09 \text{ L}$$

Therefore 9.09 L septic tank tank sludge requires 100 L of rice straw to be mixed to rise straw to be mixed to raise the C/N ratio to 30/1

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References

Gotaas,H.B. (1956). Composting: Sanitary Disposal and Reclamation of Organic wastes.World Gealth Organization Monograph Series No.31,Geneva.

Gray,K.R., Sherman,K.' and Biddlestone,AJ.(1971).A review of composting Past 1, Process Biochem.,6,32-6.

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BIOGRAPHY

NAME Miss Jarassri Rungvichaniwat

DATE OF BIRTH 21 October 1977

PLACE OF BIRTH Yala, Thailand

INSTITUTIONS ATTENDED Thammasat University, 2000

Bachelor of Science and Technology (Environmental Science)

Mahidol University, 2003

Master of Science (Appropriate Technology for Resource and Environmental Development)

Home Address 25 Chatarothai Road

Betong Yala,Thailand

Tel 073230518

E-mail Jara_r@hotmail.com

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