

**NOODLE-SOUP WASTEWATER TREATMENT AND BIOGAS
PRODUCTION BY A CONVENTIONAL ANAEROBIC DIGESTER**



**A THESIS SUBMITTED IN PARTIAL FULFILLMENT
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Thesis
Entitled

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PRODUCTION BY A CONVENTIONAL ANAEROBIC DIGESTER**



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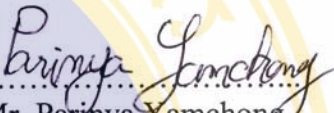
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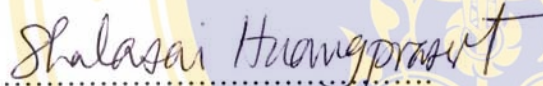
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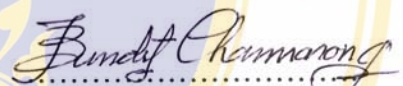
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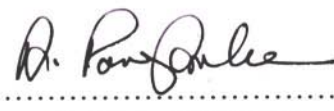
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**NOODLE-SOUP WASTEWATER TREATMENT AND BIOGAS PRODUCTION
BY A CONVENTIONAL ANAEROBIC DIGESTER**

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SCIENCE), KRAICHAT TANTRAKARNAPA, Ph.D.(ENVIRONMENTAL
ENGINEERING)**ABSTRACT**

The objective of this research was to determine the efficiency in Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Volatile Solids (TVS) and Total Solid (TS) removal as well as biogas production from noodle-soup wastewater by a conventional anaerobic digester at hydraulic retention time of 20, 25, 30 and 35 days.

The results showed that the efficiency in COD removal at the hydraulic retention times of 20, 25, 30 and 35 days were 83.01%, 87.17%, 89.72% and 88.91%, respectively, whereas, BOD removal was 89.36%, 90.40%, 92.28% and 91.41%, at the same respective retention times. Regarding TVS removal, the efficiency measure were 76.35%, 79.02%, 83.34% and 82.35%, respectively, while for TS removal they were 58.54%, 61.88%, 65.13% and 63.36%, respectively. The amount of biogas production at the hydraulic retention times of 20, 25, 30 and 35 days were 0.118, 0.102, 0.127 and 0.103 m³/kgCOD_{removed} or the equivalent of 1.531, 1.750, 2.684 and 2.498 m³ biogas/m³ feeding wastewater, respectively. Furthermore, the methane contents of biogas were respectively 36.43%, 43.50%, 46.64% and 35.92% at the same respective retention times. In all cases, the digester could be operated without addition of nutrients and base for pH adjustment

These results clearly demonstrated that the most suitable condition for operating the system was a 30-day hydraulic retention time as this condition obtained the highest efficiency in COD, BOD, TVS and TS removal, which was 89.72%, 92.28%, 83.34% and 65.13% respectively, and produced the largest amount of biogas production of around 2.684 m³ biogas/m³ feeding wastewater with a methane content of 46.64 %.

**KEY WORDS: ANAEROBIC PROCESS / BIOGAS/ NOODLE-SOUP
WASTEWATER/CONVENTIONAL ANAEROBIC DIGESTER**

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การผลิตก๊าซชีวภาพและการบำบัดน้ำเสียจากหม้อต้มน้ำก๋วยเตี๋ยวโดยถังย่อยสลายแบบไม่ใช้อากาศ
(NOODLE-SOUP WASTEWATER TREATMENT AND BIOGAS PRODUCTION
BY A CONVENTIONAL ANAEROBIC DIGESTER)

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บทคัดย่อ

งานวิจัยนี้ เป็นการศึกษาประสิทธิภาพในการผลิตก๊าซชีวภาพและการบำบัดน้ำเสีย จากหม้อต้มน้ำก๋วยเตี๋ยว โดยใช้ถังย่อยสลายแบบไม่ใช้อากาศ โดยใช้ระยะเวลาเก็บน้ำที่ 20, 25, 30 และ 35 วัน

ผลการศึกษาพบว่า ถังย่อยสลายสามารถทำงานได้โดยไม่ต้องเติมสารอาหารใดๆแก่ระบบ และยังไม่ต้องเติมต่างเพื่อปรับสภาพอีกด้วย ซึ่งประสิทธิภาพเฉลี่ยในการบำบัดน้ำเสียของถังย่อยสลายแบบไม่ใช้อากาศ โดยควบคุมระยะเวลาเก็บน้ำที่ 20, 25, 30 และ 35 วัน สามารถกำจัด COD ได้เท่ากับร้อยละ 83.01, 87.17, 89.72 และ 88.91 โดยที่ประสิทธิภาพในการกำจัด BOD ได้เท่ากับร้อยละ 89.36, 90.40, 92.28 และ 91.41 ตามลำดับ ถังย่อยสลายดังกล่าวสามารถกำจัด TVS ได้เท่ากับร้อยละ 76.35, 79.02, 83.34 และ 82.35 นอกจากนี้ยังสามารถลด TS ได้เท่ากับร้อยละ 58.54, 61.88, 65.13 และ 63.36 ตามลำดับ จากการศึกษาเปรียบเทียบประสิทธิภาพในการผลิตก๊าซชีวภาพ เมื่อควบคุมระยะเวลาเก็บน้ำที่ 20, 25, 30 และ 35 วัน พบว่า สามารถผลิตก๊าซชีวภาพได้ 0.118, 0.102, 0.127 และ 0.103 ลูกบาศก์เมตรต่อกิโลกรัมชีโอดีที่ถูกกำจัด หรือ เทียบเท่าความสามารถในการผลิตก๊าซชีวภาพที่ 1.531, 1.750, 2.684 และ 2.498 ลูกบาศก์เมตรของก๊าซชีวภาพต่อลูกบาศก์เมตรของน้ำเสียที่เข้าสู่ระบบตามลำดับ โดยองค์ประกอบของก๊าซมีเทนในแต่ละระยะเวลากักเก็บน้ำเท่ากับ ร้อยละ 36.43, 43.50, 46.64 และ 35.92 ตามลำดับ

ดังนั้น ถังย่อยสลายที่ควบคุมระยะเวลาเก็บน้ำ 30 วัน จึงมีประสิทธิภาพสูงสุดในการผลิตก๊าซชีวภาพและการบำบัดน้ำเสียจากหม้อต้มน้ำก๋วยเตี๋ยว โดยสามารถกำจัด COD, BOD, TVS และ TS ได้เท่ากับร้อยละ 89.72, 92.28, 83.34 และ 65.13 ตามลำดับ และสามารถผลิตก๊าซชีวภาพได้เท่ากับ 2.684 ลูกบาศก์เมตรของก๊าซชีวภาพต่อลูกบาศก์เมตรของน้ำเสียที่เข้าสู่ระบบ โดยมีองค์ประกอบของก๊าซมีเทนร้อยละ 46.64

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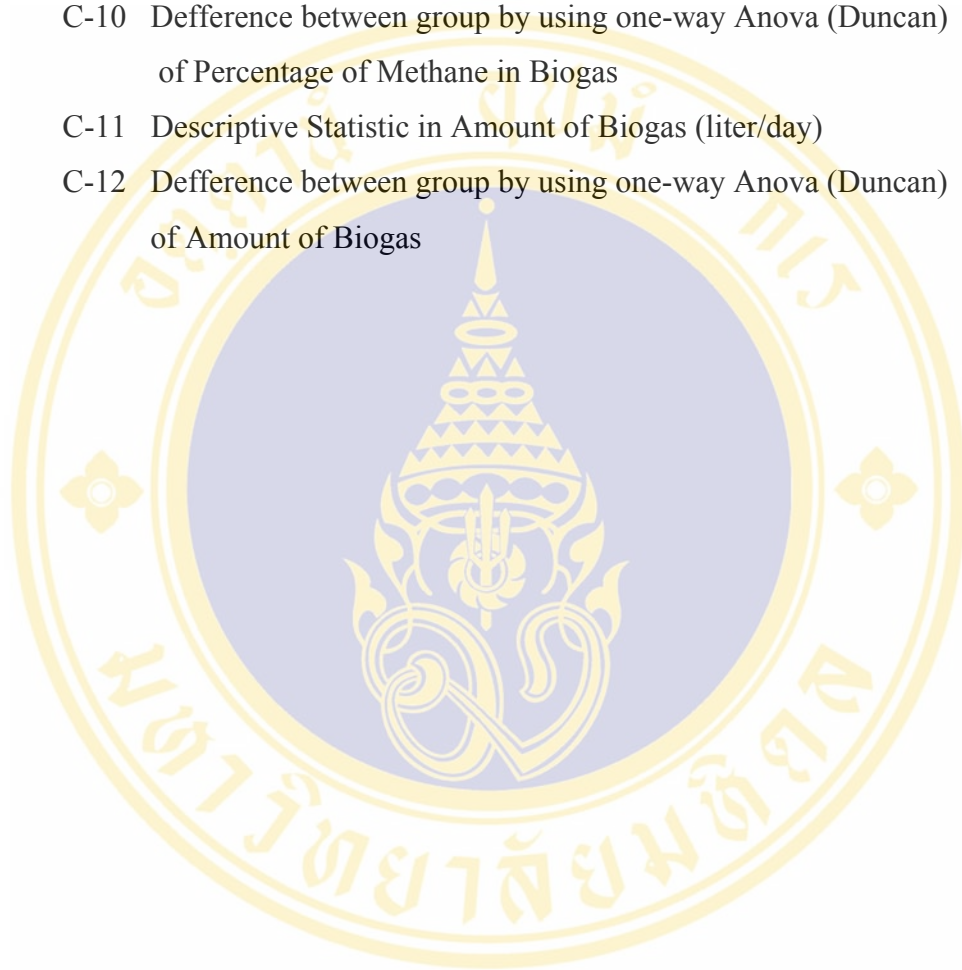
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CHAPTER I INTRODUCTION

1.1 Background

Water pollution has been a major environmental problem in Thailand for a long time, thus, the policies of Thailand to solve this problems still focused on the construction of wastewater treatment facilities, approximately 82 % of capital was invested to solve the mentioned problem (Sukarn, 2003). The success was not much to solve the wastewater problem because of high cost in wastewater treatment plant construction.

The one important source of water pollution in the river was community wastewater. Community wastewater was defined as the generated wastewater from human activities discharged to the receiving water body such as drainage system and natural water sources without treatment (Department of industries, 2002). Sources of wastewater from community are hotel, market, hospital, factories, restaurants, and etc. Wastewater community was generated from several sources with a huge volume and it was not easy to treat.

The process of wastewater treatment could be concluded as followed (Suree, 2001)

- 1) Wastewater collection
- 2) Wastewater Treatment
- 3) Sludge disposal
- 4) Discharge of treated water
- 5) Re-use and Reclamation
- 6) Energy recovery from wastewater

From these processes mentioned above, the re-use and reclamation process was the reduction process prior to discharge from the treatment system. If this process was employed, a huge and complex treatment system was not necessary to construct.

Moreover if any wastewater treatment system could generate the biogas with the high content of methane, it could be used as energy. It would be “win-win” situation that meant not only treating wastewater, but energy was also recovered and could be used for other purposes such as fuel. Energy recovery could be obtained from anaerobic wastewater treatment process as so called anaerobic digestion by microorganisms .The advantage of anaerobic digestion process was concluded in Table1-1

Table 1-1 Advantages of Anaerobic Digestion Process

Source: (Ron , 1991)	Source: (Kriengsak , 2001)
<ul style="list-style-type: none"> - High moisture feed can be processed - Product gas is easily separated from the medium, and contains primarily methane and CO₂ with trances of H₂S - Product gas is useful at various level of purification 	<ul style="list-style-type: none"> - less of sludge to dispose - easy to conduct a dewatering of sludge - not required nutrient too much - given methane - can receive high organic loading - Sludge can be kept for long times - not required electric energy in small-scale digester

From the advantage of anaerobic digestion, methane was the end product that 1 m³ of CH₄ can generate 35,000 kJ or 9.7 kw/hr (Kriengsak, 2001). Trend of energy uses in Thailand in term of natural gas was increased 15.9 % in 2000 (Department of development and policy, 2000).

Wastewater from community that can produce a large of biogas must have high organic material contents without toxic substrates; thus, this type of wastewater generated from some kinds of wastewater such as food industries, food-shop could be Noodle-soup wastewater, water from cooking, oil from cooking and etc. The problems of wastewater treatment from community wastewater were the high cost to construct wastewater treatment facilities.

This research has the purpose to study the potential of using the conventional anaerobic digester in small-scale to treat some of wastewater from community. Therefore, Noodle-soup wastewater was used in this research to be treated by anaerobic process.

1.2 Objectives

1) To determine the efficiency of the conventional anaerobic digester in COD, BOD, TS and TVS removal from noodle-soup wastewater with 4 different HRTs (20,25,30 and 35 days).

2) To determine the quantity of biogas production including the percentage of methane generated from noodle-soup wastewater by a conventional anaerobic digester with 4 different HRTs (20, 25, 30 and 35days).

1.3 Conceptual Framework

This research emphasized on removal efficiency of COD, BOD, TS, TVS and biogas production from noodle-soup wastewater by using conventional anaerobic digester. In all case, the digester could be operated without addition of chemical substances or nutrient into the system for each digester.

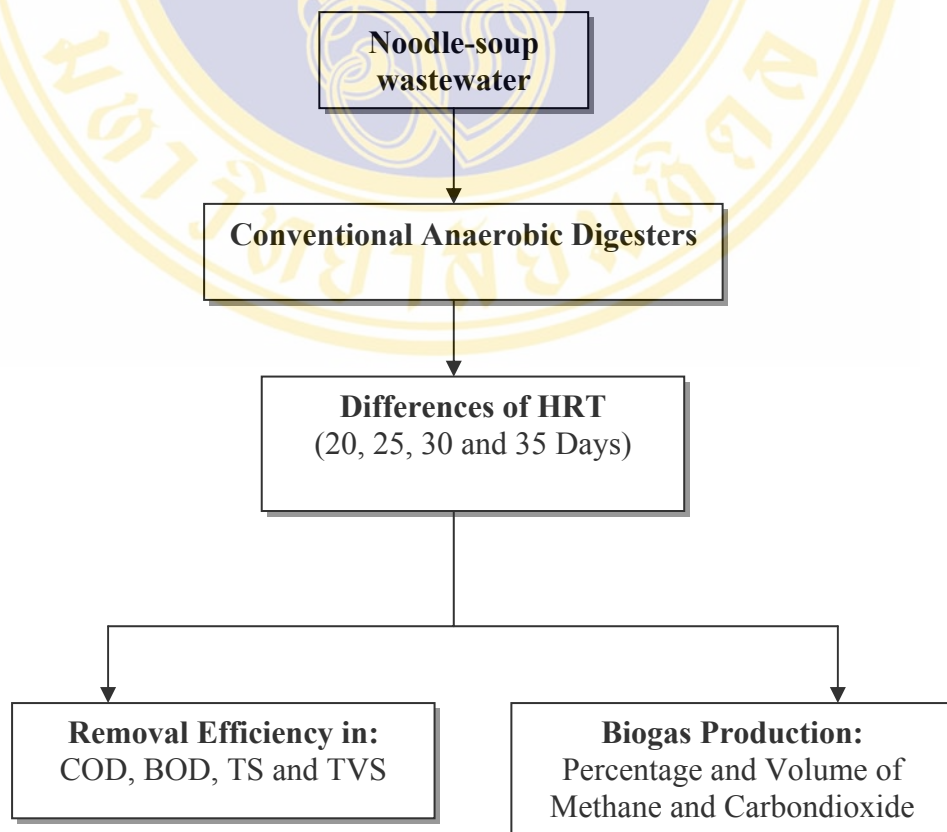


Figure 1-1 Conceptual framework

1.4 Hypothesis

The efficiency in COD, BOD TS and TVS removal and percentage of methane production in the different HRTs is different.

1.5 Scope of the research

- 1) Noodle-soup wastewater from the central canteen of Mahidol University, Salaya Campus, Nakornpathom province was used for this study.
- 2) A lab-scale conventional anaerobic digester was employed for this study.

1.6 Variables

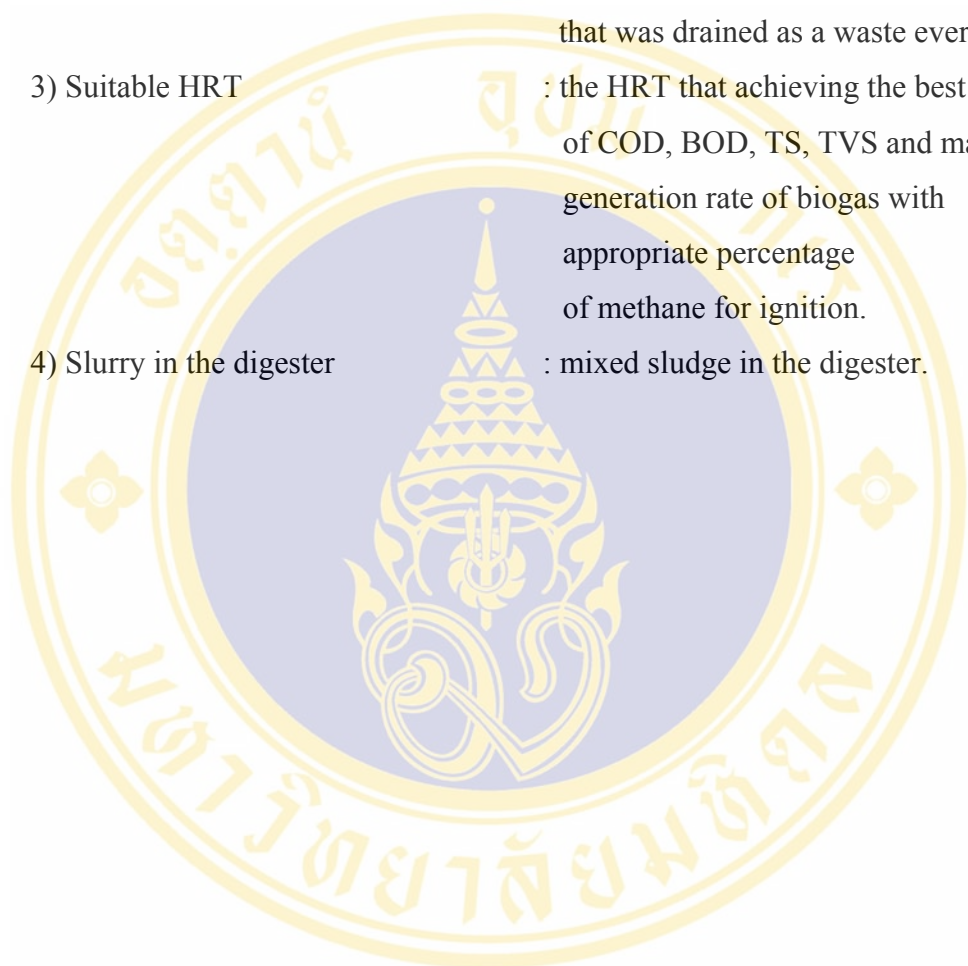
- 1) Independent Variables
 - The difference of HRT
- 2) Dependent Variables
 - Removal Efficiency of COD, BOD, TS and TVS
 - Quality and Quantity of biogas in term of methane and carbondioxide
 - pH, Alkalinity, Volatile Fatty Acid and Ammonia Nitrogen of the slurry in the digester
- 3) Control Variables
 - Effective volume of digester
 - Volume of wastewater feeding in each digester

1.7 Excepted Outcome

- 1) To obtain the suitable HRT in COD, BOD, TS and TVS removal of noodle-soup wastewater from conventional anaerobic digester.
- 2) To obtain the suitable HRT in quantity of biogas and percentage of methane generated from conventional anaerobic digester using noodle-soup as feed.

1.8 Definitions

- 1) HRT (Hydraulic Retention Time) : the period that wastewater is retaining in the digester.
- 2) Noodle-soup wastewater : the wastewater of the noodle-soup that was drained as a waste everyday.
- 3) Suitable HRT : the HRT that achieving the best removal of COD, BOD, TS, TVS and maximum generation rate of biogas with appropriate percentage of methane for ignition.
- 4) Slurry in the digester : mixed sludge in the digester.



CHAPTER II LITERATURE REVIEW

2.1 Biogas

Biogas is an end product of anaerobic digestion from microorganisms in the absence of oxygen. The composition of biogas depends on many factors such as the characteristics of wastewater, the environmental condition in digester, organic loading applied into digester and technology in each digester.

Biogas is a mixture of gases containing of 55-65 % of CH₄ by volume, 35-45 % of CO₂ by volume, and small amount of N₂, H₂ and H₂S (Polprasert, 1989), However CH₄ and CO₂ are the dominant composition of biogas.

The property of methane and carbon dioxide were shown in Table 2-1 and 2-2, respectively.

Table 2-1 Physical Constants of Methane Gas

Physical Constants	Methane Gas
Molecular Weight	16.04
Specific Volume at 70 °F, 1 atm	23.7 cu ft/lb
Boiling Point at 1 atm	-258.9 °F (-161.61 °C)
Freezing Point at 1 atm	-296.5 °F (-182.5 °C)
Specific gravity, Gas 60 °F, 1 atm, Air =1	0.5549
Density, Gas at 32 °F, 1 atm	0.04475 lb/cu ft
Critical Temperature	-115.8 °F (-82.1 °C)
Critical Pressure	673.3 psia (45.8 atm)
Critical Density	0.162 g/cc
Latent Heat of Vaporization at bp	121.87 cal/g
Latent Heat of Fusion at mp	14.03 cal/g
Specific Heat, Gas at 60 °F	
C _p	0.5271 Btu/(lb) (°F)
C _v	0.4032 Btu/(lb) (°F)
Ratio, C _p /C _v	1.307
Flammable Limited in air	5.3-14 % (by volume)
Heat of Combustion at 25 °C	97.8 Btu/cu ft
Gross Heat of Combustion; 60 °F, 1 atm	1011.6 Btu/cu ft
Viscosity at 60 °F	0.012 centipoise
Viscosity, Gas, 32 °F, 1 atm	0.0109 centipoise

Source: Jewell, 1975

Table 2-2 Physical Constants of Carbon dioxide Gas

Physical constants	Carbon dioxide
Molecular Weight	44.01
Vapor Pressure at 70 °F	830 psig
Specific Volume at °F, 1 atm	8.76 cu ft/lb
Sublimation Point at 1 atm	-109.3 °F
Triple Point at 5.11 atm	-69.9 °F
Density, Gas at 70 °F, 1 atm	0.1146 lb/cu ft
Specific gravity, Gas (Air=1)	1.5239
Critical Temperature	87.8 °F (31.0 °C)
Critical Pressure	1071.6 psia (72.9 atm)
Critical Density	0.468 g/ml
Latent Heat of Vaporization	
At tp	149.6 Btu/lb
At 0 °C	101.03 Btu/lb
Specific Heat, Gas at 60 °F	
Cp	0.1988 Btu/(lb) (°F)
Cv	0.1525 Btu/(lb) (°F)
Ratio, Cp/Cv	1.303
Viscosity, Gas, 70 °F, 1 atm	0.0148 centipoise

Source: Jewell, 1975

Methane gas is most desirable gas from biogas because 1 m³ of CH₄ can generate 35,000 kJ or 9.7 KW/hr, respectively (Kriengsak, 2000). The percent of carbon dioxide in biogas involved the capable of ignition. If the biogas composes of CO₂ higher than 50 %, biogas will not ignite (Pollution control department, 1995).

2.2 Anaerobic Digestion Fundamental

In the past anaerobic digestion used to dispose the sludge from wastewater treatment plants, especially sludge from sedimentation tank that passed another wastewater treatment technology by microorganism. From energy crisis in the present, anaerobic digestion was used to treatment wastewater, that the advantage and disadvantage of anaerobic digestion was concluded as Table 2-3

Table 2-3 Advantage and disadvantage of Anaerobic Stabilization Process

Advantages	Disadvantages
<ul style="list-style-type: none"> - High degree of stabilization - Low production of waste biological sludge - Low nutrient requirements - Low energy requirements - Methane gas is useful end product 	<ul style="list-style-type: none"> - Slow growth rate of methanogens - Requires long solid retention time - Methanogen sensitivity - May require auxiliary heating

Source: Owen, 1982

From advantages and disadvantages of anaerobic digestion above, thus, this process require less of energy and methane is the end product of this process.

2.2.1 Biochemical Reactions and Microbiology

There are two major groups of bacteria that cooperated in anaerobic digestion process, first, call “Acid forming bacteria” that can lived in both of dissolved oxygen or in the absence of dissolved oxygen. The second group called “Methane forming bacteria” that can live only in the absence of oxygen. Anaerobic digestion depended on two groups of these bacteria.

Anaerobic digestion is generally considered to process in three stages as followed (Polprasert, 1989).

- 1) liquefaction or polymer breakdown
- 2) Acid formation
- 3) Methane formation

Stage 1: Liquefaction or polymer breakdown

Many organic wastes consist of complex organic polymers such as proteins, fats, Cabohydrates, cellulose, lignin, etc., some of which are in the form of insoluble solids. In this stage these organic polymers are broken down by extracellular enzymes produced by hydrolytic bacteria, and dissolved in water. The simple, soluble, organic components (or monomers) which are formed are easily available to any acid-producing bacteria. It is difficult to distinguish this stage from what is known as stage 2 (acid-formation stage), because some molecules will be absorbed without further breakdown and can be degraded internally.

Stage 2: Acid formation

The monomeric components released by the hydrolytic breakdown due to bacteria action in stage 1, are further converted to acetic acid (acetates) and H₂ and CO₂ by the acetogenic bacteria. Volatile fatty acids are produced as the end-products of bacterial metabolism of protein, fat, and carbohydrate; in which acetic, propionic, and lactic acids are the major products. Carbon dioxide and hydrogen gas are also liberated during carbohydrate catabolism, which methanol, and other simple alcohols, being other possible by-products of carbohydrate breakdown. The proportion of these different substrates produced depends on the flora present, as well as on the environmental conditions.

Stage 3: Methane formation

The products of stage 2 are finally converted to CH₄ and other end-products by a group of bacteria called methanogens. Methanogenic bacteria are obligate anaerobes whose growth rate is generally slower than the bacteria in stage 1 and 2.

The methanogenic bacteria use acetic acid, methanol, or carbon dioxide and hydrogen gas to produce methane. Acetic acid or acetate is the single most important substrate for methane formation, which approximately 70% of methane produced from acetic acid. The remaining methane come from carbon dioxide and hydrogen. A few other substrates can also be used, such as formic acid, but these are not important, since they are not usually present in anaerobic fermentation.

The energy flow of anaerobic digestion was shown in Figure 2-1

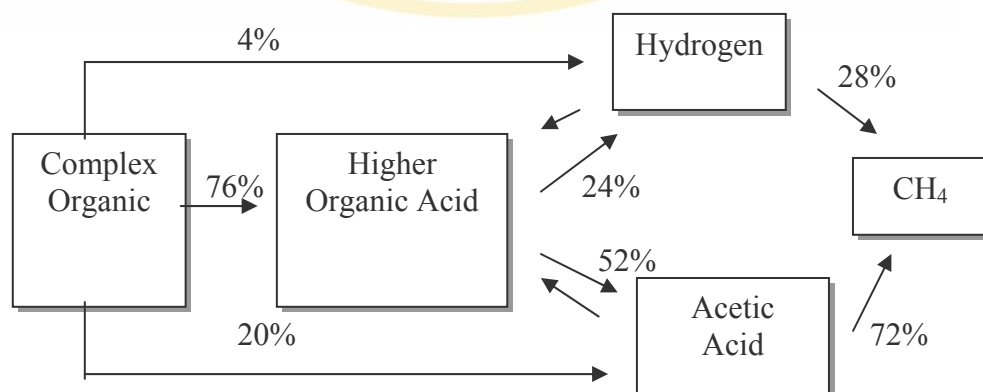


Figure 2-1 Step in the anaerobic digestion process with energy flow (Metcraft and Eddy, 1991)

The methane formation reaction in stage 3 is very important in anaerobic digestion. Besides producing CH₄ gas, the methanogen also regulate and neutralize the pH of the digester slurry by converting the volatile fatty acids into CH₄ and other gases. The conversion of H₂ into CH₄ by the methanogen helps reduce the partial pressure of H₂ in the digester slurry, which is beneficial to the activity of acetogenic bacteria. If the methanogenic bacteria fail to function effectively there will be little or no CH₄ production from the digester, and so waste stabilization is not achieved because the organic compounds will be converted only to volatile fatty acids, which can cause further pollution if discharged into the environment. Some of methanogenic bacteria were shown in Table 2-4.

Table 2-4 Methanogenic bacteria and their substrates

Organism	Substrates
<i>Methanobacterium formicicum</i>	H ₂ , CO ₂ and HCOOH
<i>M. bryantii</i>	H ₂ and CO ₂
<i>M. thermoautotrophicum</i>	H ₂ and CO ₂
<i>M. ruminantium</i>	H ₂ and CO ₂
<i>M. arboriphilus</i>	H ₂ and CO ₂
<i>M. hungatei</i>	H ₂ , CO ₂ and HCOOH
<i>Methanobacterium soehngenii</i> , (Methanotrix)	CH ₃ COOH
<i>Methanoplasma elizabethii</i>	H ₂ and CO ₂

Sources: Balch, 1979 and Water Environment Federation of USA, 1996.

For more understanding of anaerobic digestion was concluded in Figure 2-3

2.2.2 Factors Affecting Anaerobic Digestion

The environmental and operational factors that influence system performance are as follow:

1) Temperature

Anaerobic process are typically operated in the mesophilic range (90-105 ° F), although higher temperature in the thermophilic range (49-57 ° C) are commonly used, and lower temperature are possible at long HRT. In general, within the mesophilic temperature range, higher temperature result in more rapid decomposition of organics, thus decreasing the reactor volume required to achieve a specific degree of

stabilization. Although the rates of reaction are much greater in the thermophilic range, the maintenance of higher temperature is usually not economically justifiable (Eckenfelder, 1989).

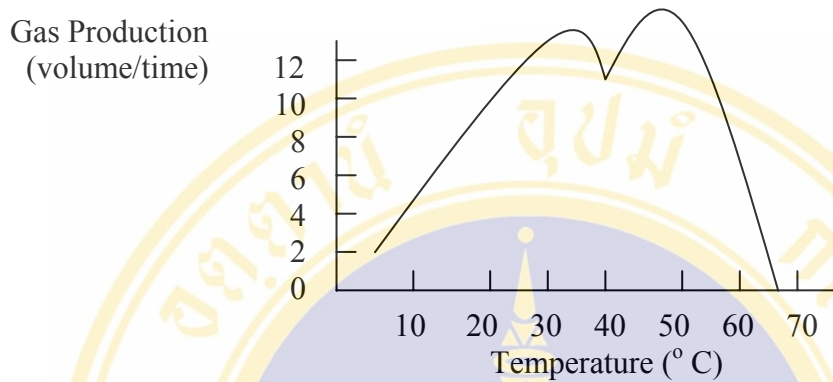


Figure 2-2 Effect of temperature on Gas production (Gray, 1989)

2) pH and Alkalinity

The operational range of pH in anaerobic digester should be between 6.6 and 7.6, with the optimum range being 7 to 7.2. Although acid-forming bacteria can tolerate a pH as low as 5.5, the methanogenic bacteria are inhibited at such low pH values. The pH of a digester may drop to below 6.6 if there is an excessive accumulation of volatile fatty acids. Such an accumulation may occur when the organic loading rates are excessively high and/or when toxic materials are present in the digester, all producing inhibitory effects to the methanogenic bacteria.

Appropriate measures should be taken promptly when there is a lowering of pH in an anaerobic digester, due to accumulation of volatile fatty acids, or increase in H₂ partial pressure, and the rate of CH₄ production decrease. In general, the feeding of the digester should be stopped to allow the methanogens to utilize the accumulated volatile fatty acids and H₂ at their own place. When the optimum gas production rates are re-established the normal loading of the digester can be resumed. In addition of lime or other basic material. The alkalinity of the digester slurry is maintained within the range 2,500-5,000 mg/l, a good buffering capacity is normally obtained in the digester.

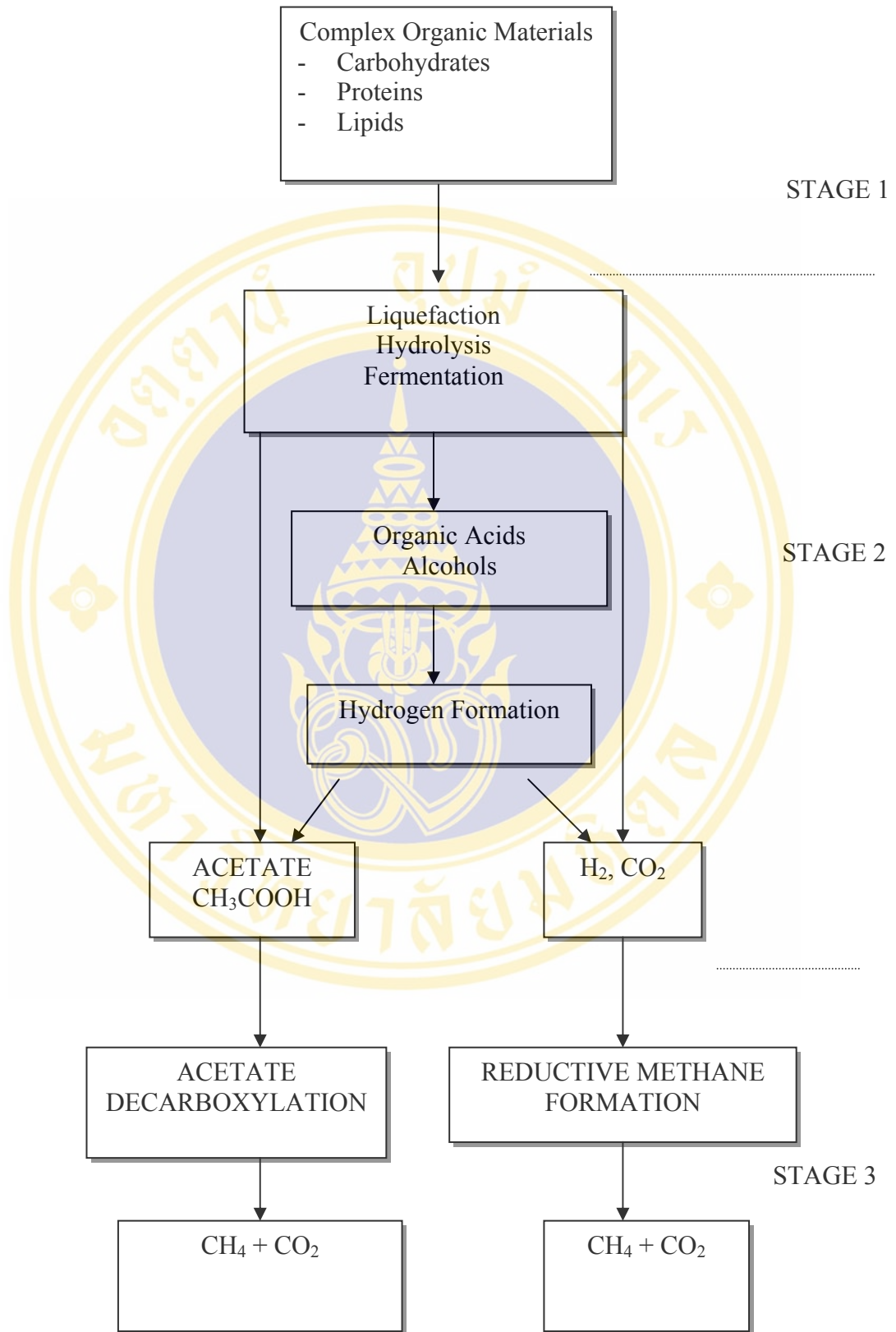


Figure 2-3 Multistep methanogenesis in anaerobic digestion (Prince, 1981)

The effect of pH on biogas production is shown in Figure 2-4

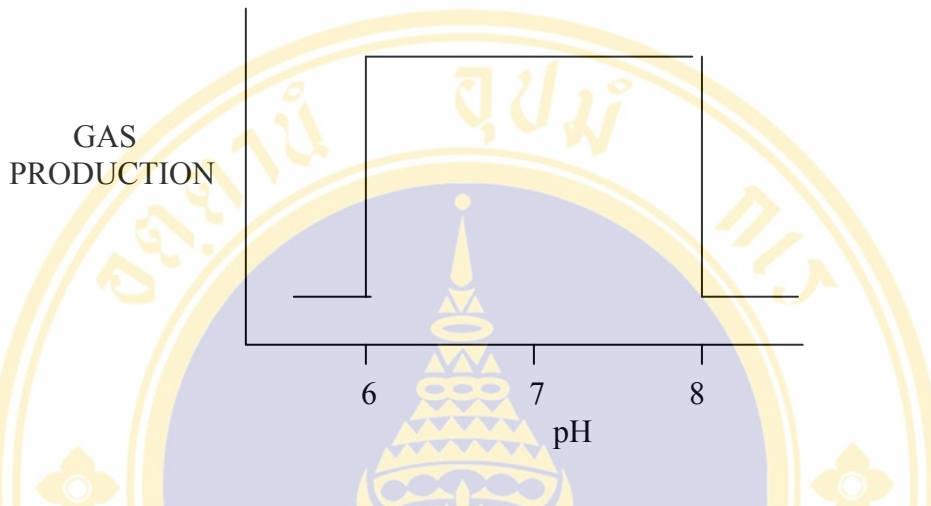


Figure 2-4 The effect of pH on biogas production (Gray, 1989)

Although total alkalinity is a non-specific measure of the carbonate, bicarbonate, and hydroxide content of a culture, but at pH levels ranging from 6 to 8, bicarbonate alkalinity is dominance (David, 1987). In addition, the bicarbonate alkalinity can find out from the following equation (McCarty, 1964).

$$BA = TA - (0.85) (0.833) (TVA)$$

Where BA = Bicarbonate Alkalinity (mg/l as CaCO₃)
 TA = Total Alkalinity (mg/l as CaCO₃)
 TVA = Total Volatile Acid Concentration (mg/l as CaCO₃)

3) Volatile Acids

Volatile acids are intermediate digestion products. Although typical volatile acid concentrations range from 50 to 300 mg/l (Water Environment Federation of USA., 1996), higher levels are possible if sufficient alkalinity exists to buffer the acid level.

Because of the required balance between volatile acids and alkalinity, the volatile acid: alkalinity ratio provides an excellent indicator of the digester's health. Careful monitoring of the rate of change of that ratio can indicate a depression and inhibition

of methane production occurs. Increases above ratios of 0.3 to 0.4 indicate upset and the need for corrective action.

4) Nutrient Availability

Nitrogen and Phosphorus are major elements, which most often limit in nutrient-deficient wastes. The nitrogen requirement is approximately 11% of the cell volatile solids, and phosphorus requirement are approximately one-fifth of that for nitrogen, or 2% of cell volatile solids weight (McCarty, 1964). For every 1000 lb of BOD loading stabilized by anaerobic treatment, the nitrogen requirement are approximately 6 to 10 lb of nitrogen and 1 to 2 lb of phosphorus.

Trace elements such as Ca Mg Co and Fe are also important for bacterial growth but they are needed in small amount. As such, most wastewater has enough trace elements for anaerobic treatment (Krengsak, 2543), (Sub, 2528).

5) Toxicity

Toxic substrates are known to influence anaerobic fermentation systems; however, there has been a great deal of misunderstanding of this topic. The term "Toxic" is relative. The concentration at which a material becomes inhibitory may vary from fraction of mg/l to several thousand. In fact, at very low concentration, many so-called toxic substrates will stimulate biological activity.

Inhibition caused by excess concentrations of certain ions can be counter balanced by some other ions (antagonistic ions), while it can also be exacerbated by others (synergistic ions). Ions that are known to produce such interactions are list in Table 2-5.

The toxicant level can be accomplished by (OWEN, 1982)

- Removal of the toxicant prior to biological treatment
- Dilution of the waste
- Precipitation
- Addition of an "antagonistic" material

Table 2-5 Synergistic and Antagonistic cation combination

Toxic cations	Synergistic cations	Antagonistic cations
Ammonium	Calcium, Magnesium, Potassium	Sodium
Calcium	Ammonium, Magnesium	Potassium, Sodium
Magnesium	Ammonium, Calcium	
Potassium	-	Ammonium, Calcium, Magnesium
Sodium	Ammonium, Calcium, Magnesium	Potassium

Source: Water Environment Federation of USA, 1996

Table 2-6 Concentration of toxicant inhibitory to anaerobic treatment*

Element	Metabolic effect			
	Stimulatory	No effect	Moderate Inhibitory	Strongly
	Inhibitory			
Cation				
Sodium	100-200	-	3,500-5,500	8,000
Potassium	200-400	-	2,500-4,500	12,000
Calcium	100-200	-	2,500-4,500	8,000
Magnesium	75-150	-	1,000-1,500	3,000
Ammonia nitrogen	50-200	200-1,000	1,500-3,000	>3,000
			(Inhibitory at higher pH values)	
	-	<200	200-350	>370
Sulfide (soluble)				
Heavy metals (step fed)				
Chromium (VI)	-	-	130	260
Chromium (III)	-	-	110	420
Copper	-	-	40	70
Nickle	-	-	10	30
Heavy metal (pulse fed)				
Chromium (VI)	-	-	-	<200
Chromium (III)	-	-	-	<180
Copper	-	-	-	<50
Nickle	-	-	-	>30

Remark * all concentration in mg/l

Source: OWEN, 1982

6) Solids Retention time and/or Hydraulic Retention time and Organic loading

The period that solids are retained in the digester is a crucial factor affecting performance. In flow-through systems the residence time of waste (HRT) and of the microbial biomass (MCRT) will be the same. The design of the digesters normally aims at a minimum retention period of 25-30 days, allowing for some loss in digester capacity due to accumulated non-biodegradable solids within reactor. Clearly, any increase in the water content of raw sludge will increase the HRT, and in flow-through systems this will cause an increased washout rate of the microbial biomass and an associated reduction in performance.

HRT is determined by calculating the number of days required for displacement of the fluid volume of the culture as following equation (David, 1987).

$$\text{HRT} = V/Q$$

Where

V = Effective volume of digester

Q = Fluid volume per day

The relationship between HRT and Organic loading rate (OLR) is present as following equation (Malee, 2531).

$$\text{OLR} = \text{Substrate concentration (VS or BOD or COD)} / \text{HRT}$$

7) Internal mixing

The purpose of mixing and circulation within the digester is

- To promote close contact between the raw and digesting sludge.
- To maintain a uniform temperature and solids mixture throughout the tank.
- Prevent localized accumulation of inhibitory substances.
- To discourage scum formation and settlement of grit and dense solids.
- To encourage the release of gas from the sludge in the lower regions of the digester.

Poor mixing will lead to stratification within the digester and will result in partially digested sludge being withdrawn (Gray, 1989).

2.2.3 Mode of Operations

There are the different types of anaerobic digesters for experimental purposes, pilot plant investigations and actual field use. Major modes of digester operation can be classified into three groups as follows (Polprasert, 1989).

1) *Batch operation*

In this mode of operation the digester is filled completely with organic matter and seed inoculum, sealed, and the process of decomposition is allowed to proceed for a long time until gas production is decreased to a low rate (duration of process varies based on regional variation of temperature, type of substrate, etc.). Then it is unloaded, leaving 10-20 percent as seed, and then reloaded and the operation continues. In this type of operation the gas production is expected to be unsteady and the production rate is expected to vary from high to low. Digestion failures due to shock load are not uncommon. This mode of operation, however, is suitable for handling large quantities of organic matter in remote areas. It may need separate gas-holders if a steady supply of gas is desired.

2) *Semi-Continuous Operation*

This involves feeding the digester on a more regular basis. Feeding is done usually once or twice a day. The digested organic matter is also removed at the same time intervals. This type of operation is suitable when there is a steady flow of organic matter. The digester volume will have to be large enough to serve both as a reactor and a gas storage tank. Total gas production per unit organic weight of organic matter loaded is usually high. Most of the operational biogas plants in the field are of this type.

3) *Continuous Operation*

In this mode of operation the feeding and removal of organic matter take place continuously. The amount of material to be digested is kept constant in the digester by overflow or pumping. The process has been used in treatment of liquid wastes or organic wastes with low solid concentrations. Continuous operation relies heavily on external energy inputs for pumping and mixing, and therefore has limited application in areas where energy resources are limited.

2.2.4 Conventional Anaerobic Digester

Conventional (Standard rate) digesters are single-stage reactors that are not mixed by supplemental means. Some degree of agitation is provided by natural gas evolution during digestion convection currents caused by temperature gradients, and pumped recirculation for digester heating (OWEN, 1982).

Conventional (Standard rate) digesters are typically designed for HRT (SRT) in excess of 30 days (30 to 60 days) and corresponding organic loading up to 0.1 lb VS/day/cubic ft (Sawyer, 1960).

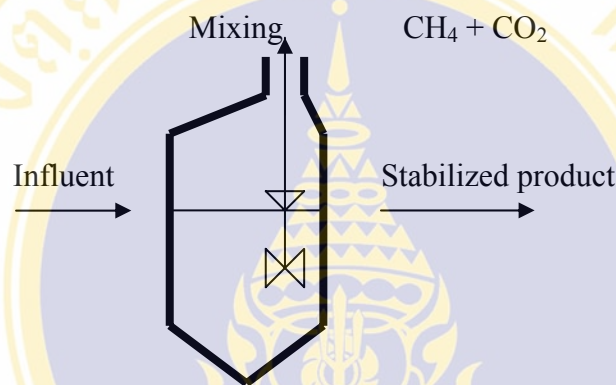


Figure 2-5 Conventional Single-stage Digester (OWEN,1982)

Table 2-7 Design criteria for standard-rate conventional digester

Sources	OLR (Kg VS/m ³ .day)	HRT (Days)	VS Reduction	GAS Production	% CH ₄
Price and Cheremisinoff (1981)	0.5-1.6	30-60	-	-	-
Metcalf and Eddy (1991)	0.5-1.6	30-90	-	-	-
McGhee and Steel (1979)	2.4-6.4	30-60	50%	0.65 m ³ /kg VSS added	65
George <i>et al</i> (1993)	0.6-1.6	10-20	60-80%	0.5-0.7 m ³ /kg VS destroyed	55
Nounpan and Mongkhol (1999)	1.5-2.0	40	-	-	-
Mark and Mark Jr (2001)	0.32-0.8	30-90	50-70%	0.45-0.51 m ³ /kg VS destroyed	65-69

2.2.5 Start-up of Digester

Anaerobic digestion is a difficult process to start because of the slow growth rate and sensitivity of acid-splitting methane-forming bacteria. Furthermore, the number of these microorganisms is very low in raw sludge compared with acid-forming bacteria.

The normal procedure for start-up is to fill the tank with wastewater and to apply raw sludges feed at about one-tenth of the design rate. If several thousand gallons of digesting of sludge from an operating digester are used as seed, the new process can be operational in a few weeks. However, if only raw sludge available, developing the biological process may take months. Careful additions of lime added with raw sludge are helpful in maintaining the pH near 7.0, but erratic dosage can result in sharp pH changes detrimental to the bacteria. After gas production and volatile acids concentration have stabilized, the feed rate is gradually increased by small increments to full loading. Daily monitoring of this process involves plotting the daily gas production per unit of raw sludge feed, percentage of carbon dioxide in the head gases, and concentration of volatile acids in the digesting sludge (Mark and Mark Jr, 2001).

2.2.6 Causes of Failure

The four basic causes of digester instability or failure are hydraulic over load, organic over load, temperature stress, and toxic over load (Graef and Andrews, 1974). A brief description of each situation is given below.

1) Hydraulic Overload

Hydraulic over load of a digester occurs when the effective retention time is reduced to a point where the organisms cannot reproduce fast enough to avoid washout. Hydraulic overload can result from overpumping a dilute feed sludge; sludge production exceeding digester capacity; or from the reduction of effective digester volume by grit deposition, scum formation, or poor mixing. Hydraulic overload can also cause alkalinity washout, resulting in a poorly buffered system.

2) Organic Overload

Organic overload occurs when the organic feed rate exceeds the rate at which the process microorganisms can consume the organics under balanced conditions. Organic overload results from a sudden increase in solids feed rate, a sudden increase in feed solids concentration, too rapid digester start-up, excessive loading on an infrequent basis, or a feed sludge that is too high in carbohydrates.

3) Temperature Stress

Temperature-related stress occurs when the digester temperature changes rapidly (less than 10 days) by more than 1 or 2 ° C. Then, the temperature sensitive methane-

forming microorganisms are shocked, but can be revived if the proper temperature is restored soon enough. If the methane formers are not quickly revived, the acid formers, unaffected by the temperature change, continue to produce volatile acids. The volatile acids eventually consume the available alkalinity, resulting in a fatal drop in pH.

4) Toxic Overload

The anaerobic treatment process is sensitive to certain compounds including sulfides, volatile acids, heavy metals, calcium, sodium, potassium, dissolved oxygen, ammonia, and chlorinated organic compound. The inhibitory concentration of a substance depends on many variables including pH, organic loading, temperature, hydraulic loading, the presence of other materials, and the ration of the toxic substance concentration to the biomass concentration (Kugelman, 1965).

Table 2-8 Summary of process failure

Indicators	Typical causes of process failure	Solutions
<ul style="list-style-type: none"> - Volatile acids concentration increases - Bicarbonate alkalinity drops - pH falls - Gas production rate drops - Percentage of carbon dioxide in gas increase 	<ol style="list-style-type: none"> 1. Hydraulic overload <ul style="list-style-type: none"> - Dilute feed sludge - Excessive sludge production - Grit and scum accumulation - Alkalinity washout 2. Organic overload <ul style="list-style-type: none"> - Increase in sludge production - Increase in sludge concentration - Change in sludge characteristics - Too rapid startup - Infrequent feeding 3. Toxic overload <ul style="list-style-type: none"> - Heavy metal - Etc. 	<ul style="list-style-type: none"> - Adjust alkalinity using a supplement - Adjust feed schedule - Prethicken - Industrial pretreatment - Clean digester - Restart Digester

Source: Water Environment Federation of USA, 1996.

2.3 Municipal Wastewater and Noodle-soup Wastewater

Wastewater can generate from many of activities that each activities can generated the wastewater that have the differences of quantity and characteristics. The major activities that generated wastewater were wastewater from community, wastewater from industry, and wastewater from agriculture.

Noodle-soup wastewater is only one kind of wastewater from restaurant that is a subset of wastewater from community.

And the characteristics of wastewater from community was shown in Table 2-9 as followed:

Table 2-9 Characteristics of Wastewater from Community

Activities	Quantities of Wastewater	BOD loading	Wastewater characteristics (mg/l)			
			BOD	TSS	Oil & Grease	TKN
Condominium and Guesthouse	520 litter/day-room, unit	48 g/day-room, unit	151*	63*	473*	33*
Hotel	1061 litter/day-room	123 g/day-room	190	84	563	23
Students' hostel	78 litter/day-room	76 g/day-room	723**	660**	377**	329**
Hospital	800 litter/day-bed	94 g/day-bed	238	87	631	15
Restaurant	25 litter/day-m ²	53 g/day-m ²	1759	913	1570	63
Market	69 litter/day-m ²	21 g/day-m ²	1172	660	897	76
Department store	4.6 litter/day-m ²	0.27 g/day-m ²	81	61	577	66
Office	2.54 litter/day-m ²	0.09 g/day-m ²	180	158	450	44

Source: Thongchai, 1987.

Note: * mean some of treatment, ** mean wastewater from toilet

Restaurant wastewater (wastewater from cooking process) consists of highly proteins, oil & grease, nutrients, etc., that could make noodle-soup wastewater suitable for produce biogas and if we don't treat noodle-soup wastewater before discharge into the river that make the problem with water pollution.

2.4 Research Relevant

Atcharaporn (2002) studied the efficiency in COD, BOD, TVS and TS removal as well as biogas production from the tuna-processing wastewater by using a conventional anaerobic digester. The results clearly demonstrated that the suitable condition for operating the system was a 30-day hydraulic retention time obtained the highest efficiency in COD, BOD, TVS and TS removal which were 81.33%, 90.57%, 68.25% and 35.79%, respectively, and produced the largest amount of biogas production of around $0.49 \text{ m}^3 \text{ biogas} / \text{m}^3 \text{ feeding wastewater}$ with a methane content of 44.84%.

Warut (1987) studied biogas production from liquid squeezed from solid pineapple waste in fixed film reactor by using downflow stationary fixed film reactor. The result suggested that digester at organic loading rate of $0.5 \text{ kgCOD/m}^3\text{day}$; the operation was possible at HRT not shorter than 19.9 days. Gas production was $0.4 \text{ m}^3 \text{ kg COD added/day}$, COD removal was 79.91%. Increasing organic loading rate to $1.0 \text{ kgCOD/m}^3\text{day}$, increase HRT to 21.1 days. Gas production was $0.37 \text{ m}^3 \text{ kg COD added/day}$, COD removal was 78.21%. When HRT was shorter than 19.9 days causing the reactor was failure.

Chulaporn (1991) studied the effect of feeding modes on the developments of biofilm in anaerobic filter reactor. The research aimed to study the effect of feeding modes on the development of biofilm in an anaerobic filter reactor treating tapioca wastewater. The rate of biogas production per kg COD used with different feed flow was determined. The production were 0.42, 0.45 and $0.38 \text{ m}^3/\text{kg COD}$ from the reactor with downflow, up and sideflow. The biogas production per VSS in the 3 reactors is the same in range of $0.05\text{-}0.06 \text{ m}^3 \text{ gas/g of VSS}$. The production of biogas per reactor was 0.82, 0.86 and $0.79 \text{ m}^3/\text{m}^3 \text{ reactor}$ from up, side and down flow.

Sumet (1987) studied the efficiency of the two-stage digester to treat the starch wastewater and compare with the 1-stage digester. The results were found the 2-stage digester at the HRT of 1 day of stage 2 (acid formation) and HRT of 5 days for methane formation that have OLR = 3.63 kg COD/m³.day (1 and 2 stage) and the efficiency to treat COD = 92.1% and gas production rate were 0.256 m³/kg COD destroyed. The 1-stage digester that need the efficiency to treat COD in the vicinity with 2-stage digester must have HRT = 13 days and OLR = 1.642 kg COD/m³.day.

Chaiyuth and Preecha (2000) studied the biogas generation from UASB pilot plant reactor of starch wastewater treatment. The results from 1-year operation period indicated that at a steady state condition, the UASB reactor required pretreatment by a solubilization reactor in order to reduce SS concentration in wastewater to be not more than 500 mg/l before feeding into the reactor, otherwise it will cause wash-out of granular bacteria. The maximum organic loading rate when operated at HRT 10 hr was 4.8 kg COD/m³.day. The COD removal was in the range of 85-90% while the BOD removal was not lower than 90%. The gas production rate was 0.35 m³CH₄/kg COD removed.

CHAPTER III MATERIALS AND METHODS

The Lab-scale of conventional anaerobic digester was conducted to determine the suitable retention time (HRT) for treatment and biogas production from noodle-soup wastewater. The research was carried out at Faculty of Environment and Resource Studies, Mahidol University, Salaya Campus, Nakornpathom province during July 2004 to October 2004.

3.1 Lab-scale of Conventional Anaerobic Digester

Four experimental models were used in this study. Each set as was consisted of

- 1) Conventional anaerobic digester
- 2) Biogas measurement unit

3.1.1 Conventional Anaerobic digester

This digester consists of 3 major parts as followed

- 1) A digester

The digester was modified from a polyethylene bucket having a bottom diameter of 26.0 cm. and a top diameter of 35.5 cm. with 34.0 cm. height. The total volume and effective volume that used in this research were 18 and 15 liters, respectively (Figure 3-1).

- 2) A cover of digester

A cover that made of 0.6 cm. thickness of PVC sheet was sealed at the top of bucket by rubber gasket to prevent air leakage. The cover plastic sheet was installed with a sleeve pipe for insert a mixing shaft, a wastewater feeding pipe (or slurry drained pipe) and biogas pipe with valve. The sleeve pipe was a 1.0 inch diameter PVC pipe which extended 10.0 cm. below the surface of the slurry in the digester for biogas sealing (Figure 3-2).

The mixing shaft was designed by using 70.0 cm. length of PVC pipe (3/4 in diameter) joined with a circular PVC sheet (0.6 cm. thickness) as a horizontal, circular

mixing paddle(25 cm. in diameter). The paddle was stroked 10 times before collecting the slurry and 10 times after feeding wastewater. The wastewater-feeding pipe (or slurry-drained pipe) was made of 1.0 inch in diameter of PVC pipe and also extended 10.0 cm. below the surface of slurry in the digester. After used in each day, the pipe was plugged with rubber stopper (Figure 3-3).

3.1.2 Biogas collecting unit

The gas was measured by using water displacement method (David, 1980). When the biogas from the digester flowed through a silicone tube into a tightly sealed bottle, the filled water was flowed out through the glass tube, of the collecting bottle, into a beaker in order to measure the gas volume by volumetric cylinder again (Figure 3-4).

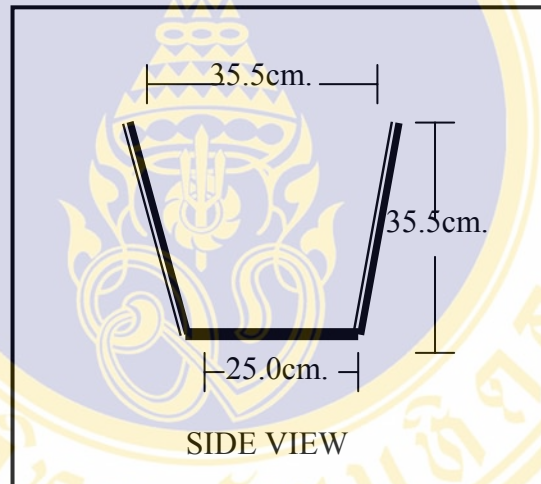


Figure 3-1 Bucket

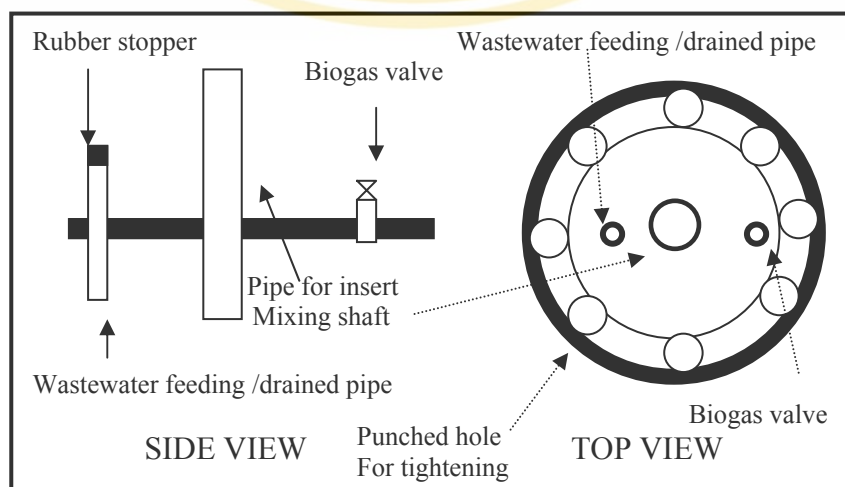


Figure 3-2 Covered sheet

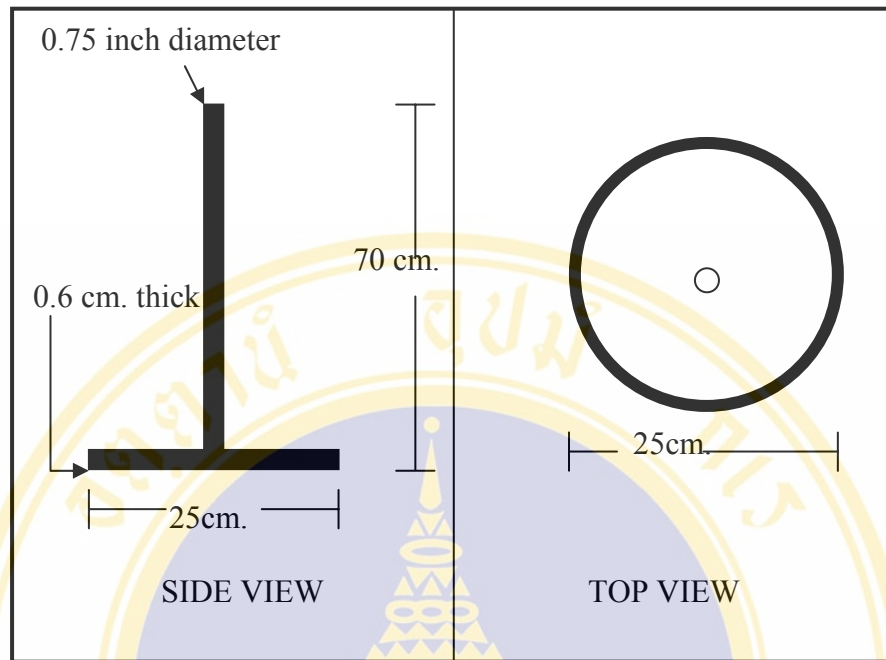


Figure 3-3 Mixing shaft

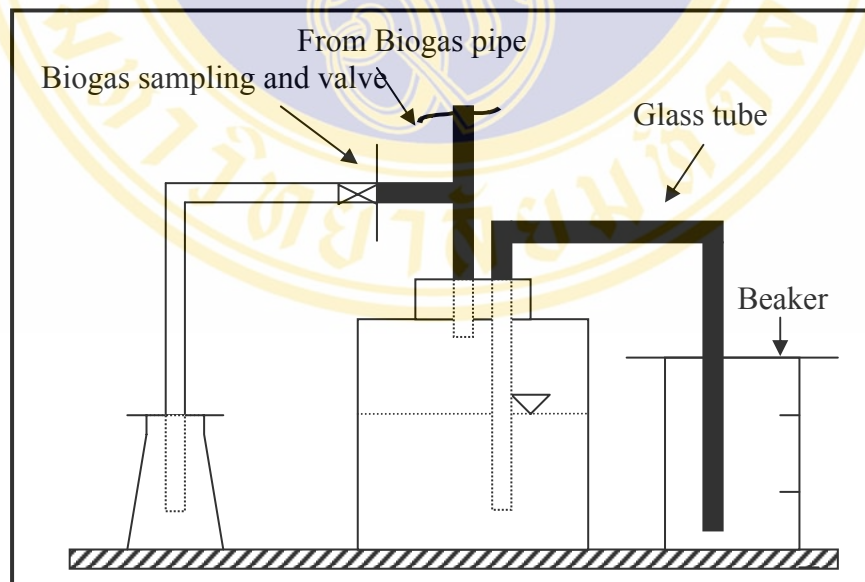


Figure 3-4 Biogas Measurement Unit

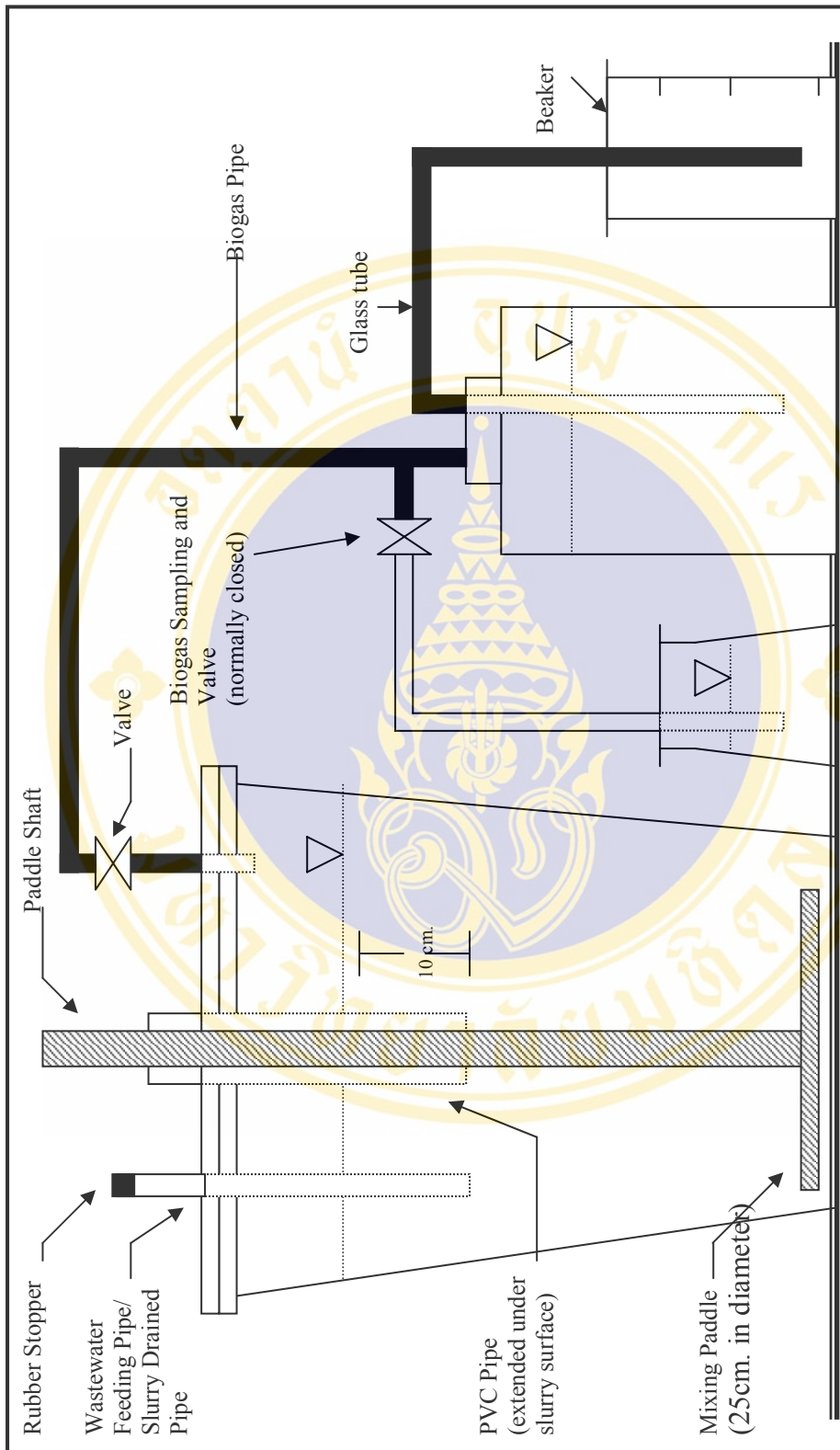


Figure 3-5 Experimental Apparatus

3.2 Sampling and Preservation

Noodle-soup wastewater, Treated water, supernatant of 5 minutes settled slurry (from digester) and biogas was collected and preserved as followed:

3.2.1 Noodle-soup Wastewater Sampling and Preservation

Noodle-soup wastewater was collected from central canteen of Mahidol University, Salaya Campus, Nakornpathom province during July 2004 to October 2004. The wastewater was collected by using grab-sampling method, and settled for 12 hour in a glass container for removal some of oil & grease. The wastewater was collected only supernatant layer then preserved followed Table 3-1, after that was preserved in refrigerator at 4 ° C. Before feeding the wastewater was warmed by hotplate until the temperature of wastewater reached to ambient temperature.

Table 3-1 Wastewater preservation of wastewater

Parameters	Preservation	Duration Keeping
BOD	Preserved at 4 ° C	6 Hours.
TS	Preserved at 4 ° C	7 days
pH	On field	-
TKN	Preserved at 4 ° C and fixed with H ₂ SO ₄ , pH < 2	7 days
COD	Preserved at 4 ° C and fixed with H ₂ SO ₄ , pH < 2	7 days
TVS	Preserved at 4 ° C	7 days
Temperature	On field	-
TDS	Preserved at 4 ° C	7 days
Oil & Grease	Filled HCl, pH =2 and Preserved at 4 ° C	28 days
TP	To filter and Preserved at 4 ° C	2 days
Alkalinity	Preserved at 4 ° C	24 hours

Sources: Munsin,1998

The noodle-soup wastewater was sampled for analysis of physical and chemical characteristics. These characteristics were pH, COD, BOD, TS, TDS, TVS, Oil & Grease. TKN (Total Kjeldahl Nitrogen), NH₃-N (Ammonia Nitrogen) and Total Phosphorous followed the Standard Method (APHA, 1999). The wastewater was also determined for Alkalinity and VFA (Volatile Fatty Acid) by conforming to Direct Titration Methods (Dial, 1961).

3.2.2 Sampling of Treated Water

The mixed slurry from each digester was settled in a 1-liter beaker for 1 hour. Then, the supernatant of the settled slurry was sampled for analysis of COD, BOD, TS and TVS by conforming to Standard Methods (AWWA, 1999).

3.2.3 Sampling of Supernatant of 5 minutes settled Slurry

After mixed by stroking the paddle up and down for 10 times, the slurry from each digester was withdrawn by using a syringe under surface of slurry. Then, it was settled in a 1-liter beaker for 5 minutes before analyzed pH and ammonia nitrogen followed the standard Method and Alkalinity and VFA by conforming to Direct Titration Methods (AWWA, 1999).

3.2.4 Biogas Sampling and Preservation

Quantity of Biogas was measured by water displacement method (David, 1980).

Biogas was kept by using glass-tube under surface of clean water and tightly sealed by using rubber plug and sealing with silicone and Para-film, after that it was preserved at 4 °C. The percentage of methane (CH₄) and carbondioxide (CO₂) of the biogas were determined by gas chromatography. Measuring of methane and carbondioxide, by using gas chromatography with a thermoconductivity detector and helium as the carrier, at a flow rate of 33 ml/min. For isothermal separation of gases at 50 °C, a WG-100 SS column was used.

The methods for analyzing of each parameter were summarized in Table 3-2.

Table 3-2 Analytical parameters and methods

Parameters	Methods/Equipment	Sources
1. BOD	Azide Modification	(AWWA., 1999)
2. COD	Open Reflux, Titration Method	(AWWA., 1999)
3. TS	Dried at 103 °C	(AWWA., 1999)
4. TVS	Ignited at 550 °C	(AWWA., 1999)
5. TDS	Filter and dried at 103 °C	(AWWA., 1999)
6. pH	pH meter	(AWWA., 1999)
7. Alkalinity	Direct Titration Method	(Diallo, 1961).
8. VFA	Direct Titration Method	(Diallo, 1961).
9. Ammonia Nitrogen	Distilled and Titration Method	(AWWA., 1999)

Table 3-2 (Continued) Analytical parameters and methods

Parameters	Methods/Equipment	Sources
10. TKN	Kjeldahl Digestion	(AWWA., 1999)
11. TP	H ₂ SO ₄ ,HNO ₃ Acid Digestion/ Ascorbic Acid Method	(AWWA., 1999)
12. Oil & Grease	Soxhlet Extraction Method	(AWWA., 1999)
13. CH ₄ and CO ₂	Gas Chromatography	-

3.3 Starting up and Operating Procedure

The lab-scale of conventional anaerobic digester was conducted to determine the suitable hydraulic retention time (HRT) of noodle- soup wastewater by using 4 lab-scales digester. The step for starting up and operating the lab-scales were presented as followed:

3.3.1 Starting up

The lab-scale of conventional anaerobic digester was started up by adding fresh pig manure and water for ration that make TS around 30,000 mg/l in each digester. The seed was kept in each digester for 5 days until each digester have slightly gas production, then calculation for feeding control was calculated as shown in Table 3-3.

Table 3-3: The operation procedure of digester

Digester No.	HRT (days)	Slurry Drained Volume (liter/day)	Wastewater Feed Volume (liter/day)
1	20	0.75	0.75
2	25	0.60	0.60
3	30	0.50	0.50
4	35	0.43	0.43

After the calculation of wastewater feeding controlled, then the fed and drained volume started at 1/10 of Total feed volume from each digester. After the wastewater was feed and drained for 6 days, then the volume was increase gradually for 1/10 of totally feed volume everyday until every digester have reached the maximum feeding volume within 10 days.

3.3.2 Operating procedure after starting up until steady stage

After maximum feeding for 16 days some characteristic of wastewater were analyzed for control anaerobic process. The parameters to be determined were (pH, Alkalinity, Volatile fatty acid and Ammonia Nitrogen in mixed slurry) and COD, BOD, TS and TVS in supernatant until reaching steady stage.

3.4 Data Interpretation

The following statistics were used to analyze data (Chusri, 2001)

- 1) Mean
- 2) Range (Maximum-Minimum)
- 3) Standard deviation
- 4) One-way Anova

During Steady stage 45 days period (day 58-103) was used to monitoring the stabilized of anaerobic process in each digester. The 100 samples were collected for each parameter such as pH, Alkalinity, VFA, Ammonia nitrogen, TS, TVS, COD, temperature, conductivity and total gas. And 40 samples of BOD were collected for analysis in this research. For analysis of methane and carbon dioxide concentration, The biogas were collected for 20 samples.

The steps of this research was illustrated in Figure 3-6 as followed:

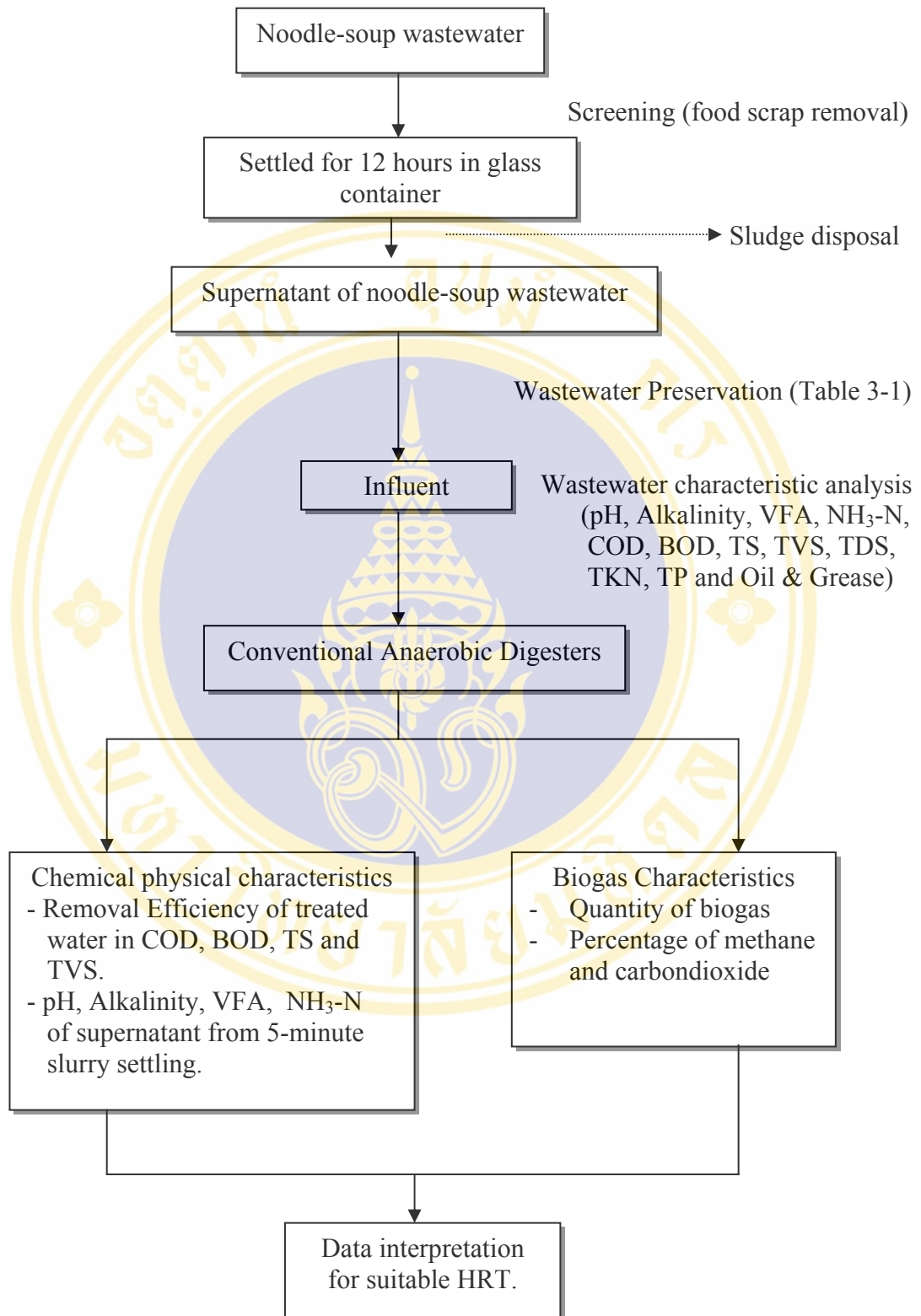


Figure 3-6 Experimental flow chart of this research

CHAPTER IV RESULTS AND DISCUSSION

During the steady-state of this research between 58-103 experimental day .The chemical and physical characteristics, and the removal efficiency were presented as followed:

4.1 Noodle-Soup Wastewater Characteristics

The noodle-soup wastewater was collected from the central canteen of Mahidol University, Salaya Campus, Nakornpathom province during July 2004 to October 2004 by using randomly grab-sampling method. The noodle-soup wastewater was a result of the supernatant of wastewater after settled in glass container for 12 hours. The characteristics of wastewater were summarized in Table 4-1.

Table 4-1 The characteristics of wastewater used in this research under steady stage

Parameters	Mean	Range	SD.
pH	4.94	4.64-5.19	0.17
TS (mg/l)	13,973	12,171-16,110	1,019
TDS (mg/l)	10,532	9,463-12,478	1,053
TVS (mg/l)	8,399	7,958-9,017	316.2
COD (mg/l)	11,740	9,826-13,842	1,244
BOD (mg/l)	5,533	5,012-5,839	235
TKN (mg/l)	624	506-714	73.4
NH ₃ -N (mg/l)	3.97	2.72-5.79	0.86
TP (mg/l)	1,178	976-1,487	183.3
Oil & Grease (mg/l)	1,361	1,156-15,740	146.4
Alkalinity (mg/l as CaCO ₃)	177.8	147.6-201.5	13.25
Volatile Fatty Acid (mg/l as CH ₃ COOH)	731.2	654.7-803.4	755.9

The characteristics of wastewater of the soup that made by boiled the chicken skeleton mixed with various ingredients was investigated. The BOD:N:P ratio was 100:11.3:21.3 and COD:N:P was 150:7.9:15.1, respectively. From the ratio above expressed that it was sufficient nutrients for anaerobic biological treatment. The value of Phosphorus and Nitrogen in wastewater rather high that make the problem in water pollution. Oil and Grease was trap and removal by pretreatment using settled noodle-

soup wastewater in the glass container for 12 hours. The anaerobic digester can operate efficiently without pH adjustment.

It can be observed that the alkalinity, Volatile fatty acid and pH of the influent was rather lower than the alkalinity, volatile fatty acid and pH at steady stage this may be caused by the organic-acid that was produced by acid forming bacteria.

Organic loading rate (OLR) depended on influent TVS or COD concentration and the flow rate, which was controlled by HRT. From the data of Table 4-1, the calculated OLR of the digesters performance with the HRT of 20, 25, 30 and 35 days were 0.420, 0.336, 0.280 and 0.240 kg TVS m⁻³ d⁻¹ (or 0.587, 0.470, 0.391 and 0.335 kg COD m⁻³ d⁻¹), respectively.

4.2 The Performance of Noodle-soup Wastewater Treatment Process

The efficiency in COD, BOD, TVS and TS removal of the digesters performed with the HRT of 20, 25, 30 and 35 days from the details in Figure 4-1 to 4-4 were summarized in Table 4-2.

4.2.1 COD Removal Efficiency

The concentration of COD in the wastewater was around 11,740 mg/l, whereas, that in the effluent of the digester performed with the HRT of 20, 25, 30 and 35 days were 1,973, 1,489, 1,194 and 1,287 mg/l, respectively. Then the efficiency in COD removal of the digester performed with the HRT of 20, 25, 30 and 35 days were 83.01%, 87.17%, 89.72% and 88.91%, respectively, as present in Table 4-2 and Figure 4-1. The results showed that the operation at the HRT of 30 days was the suitable condition for COD removal. From one-way Anova testing (Duncan) the efficiency in COD removal between HRT 30 and HRT 35 day was not differenced ($\alpha = 0.05$, $N=16$). However, the HRT of 30 day provided the best efficiency in COD removal (89.72% removal, respectively). All of COD removal in this research was higher than the efficiency of anaerobic treatment by conventional anaerobic digester of tuna-processing wastewater (81.33%) reported by Atcharaporn (2002).

4.2.2 BOD Removal Efficiency

The BOD concentration in the wastewater was around 5,533 mg/l, whereas, BOD in the effluent of the digester performed with the HRT of 20, 25, 30 and 35 days were 588, 530, 426 and 474 mg/l, respectively. Then the efficiency of conventional anaerobic digester in BOD removal of the digester performed with the HRT of 20, 25, 30 and 35 days were 89.36%, 90.40%, 92.28% and 91.41%, respectively, as presented in Table 4-2 and Figure 4-2. The results were clearly showed that the operation at the HRT of 30 days was the suitable condition for BOD removal. From one-way Anova testing (Duncan) the efficiency in BOD removal was differenced in all HRT conditions ($\alpha = 0.05$, $N=8$). However, the HRT of 30 day provided the best efficiency in BOD removal (92.28% removal, respectively). The result in this research was comparable to the efficiency of anaerobic treatment by conventional anaerobic digester of tuna-processing wastewater (90.57%) reported by Atcharaporn (2002).

4.2.3 TVS Removal Efficiency

The concentration of TVS in the noodle-soup wastewater was around 8,399 mg/l, whereas, that in the effluent of the digester performed with the HRT of 20, 25, 30 and 35 days were 1,984, 1,760, 1,399 and 1,480 mg/l, respectively. Then the efficiency in TVS removal of the digester performed with the HRT of 20, 25, 30 and 35 days were 76.35%, 79.02%, 83.34% and 82.35%, respectively, as present in Table 4-2 and Figure 4-3. From one-way ANOVA testing (Duncan) the efficiency in TVS removal was differenced in all the HRT conditions ($\alpha = 0.05$, $N=16$). However, the HRT of 30 day provided the best in TVS removal (83.34% removal, respectively). From the results of this research was showed that TVS removal was higher than the performance of anaerobic treatment by conventional anaerobic digester of tuna-processing wastewater (68.25%) that reported by Atcharaporn (2002). The efficiency in TVS removal of noodle-soup wastewater better than tuna-processing wastewater because noodle-soup wastewater have more volatile solids that also having more in organic content than tuna-processing wastewater. Therefore, it could mean noodle-soup wastewater easily to digest by anaerobic bacteria than tuna-processing wastewater.

4.2.4 TS Removal Efficiency

The concentration of TS in the wastewater was around 13,973 mg/l, whereas, that in the effluent of the digester performed with the HRT of 20, 25, 30 and 35 days were 5,764, 5,299, 4,849 and 5,093 mg/l, respectively. Then the efficiency in TS removal of the digester performed with the HRT of 20, 25, 30 and 35 days were 58.54%, 61.88%, 65.13% and 63.36%, respectively, as present in Table 4-2 and Figure 4-4. The results showed that the operation at the HRT of 30 days was the suitable condition for TS removal (65.13%). From one-way Anova testing (Duncan) the efficiency in TS removal between HRT 25 and HRT 35 day, HRT 30 and HRT 35 days was not differenced ($\alpha = 0.05$, N=16). However, the HRT of 30 day provided the best in TS removal (65.13%).

Table 4-2 The average efficiency in COD, BOD, TVS and TS removal by the digesters performed with the HRT of 20, 25, 30 and 35 days under steady stage (Date 58-103).

Parameters	Influent (mg/l)	HRT = 20 days		HRT = 25 days		HRT = 30 days		HRT = 35 days	
		Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)
COD	Min.	1,856	79.39	1,405	85.02	1,109	87.77	1,219	86.56
	Max.	2,103	85.81	1,531	89.24	1,248	91.62	1,367	90.77
	Mean	1,973	83.01	1,489	87.17	1,194	89.72	1,287	88.91
	SD.	56.36	1.75	30.52	1.32	38.57	1.14	40.40	1.19
BOD	Min.	577	88.49	520	89.55	414	91.48	462	90.50
	Max.	598	89.93	544	91.01	439	92.76	488	91.78
	Mean	588	89.36	530	90.40	426	92.28	474	91.41
	SD.	6.78	0.41	7.90	0.45	7.43	0.37	8.72	0.40
TVS	Min.	1,879	74.86	1,688	77.62	1,324	82.64	1,397	81.67
	Max.	2,105	78.18	1,846	80.74	1,489	84.64	1,524	83.69
	Mean	1,984	76.35	1,760	79.02	1,399	83.34	1,480	82.35
	SD.	58.78	0.83	52.63	0.83	39.76	0.57	37.54	0.55
TS	Min.	5,533	51.58	5,189	56.48	4,632	59.63	4,913	57.39
	Max.	5,985	61.35	5,414	67.05	4,987	69.53	5,221	69.35
	Mean	5,764	58.54	5,299	61.88	4,849	65.13	5,093	63.36
	SD.	122.50	3.02	81.10	2.74	90.78	2.38	98.49	2.72

As can be seen obviously in Figure 4-1, the HRT of 30 days provided the best condition for removing COD, BOD, TVS and TS and seem that the HRT of 30 days was the optimum condition for treating the noodle-soup wastewater. In addition, the removal efficiency of any waste by anaerobic treatment depends on their nature and process technology (John MS, 1987).

Nevertheless, BOD of treated effluent of this research did not meet the effluent standard of Ministry of Science, Technology and Energy, B.E. 2528. Therefore, the effluent from the digester should be further treated before discharged into the river.

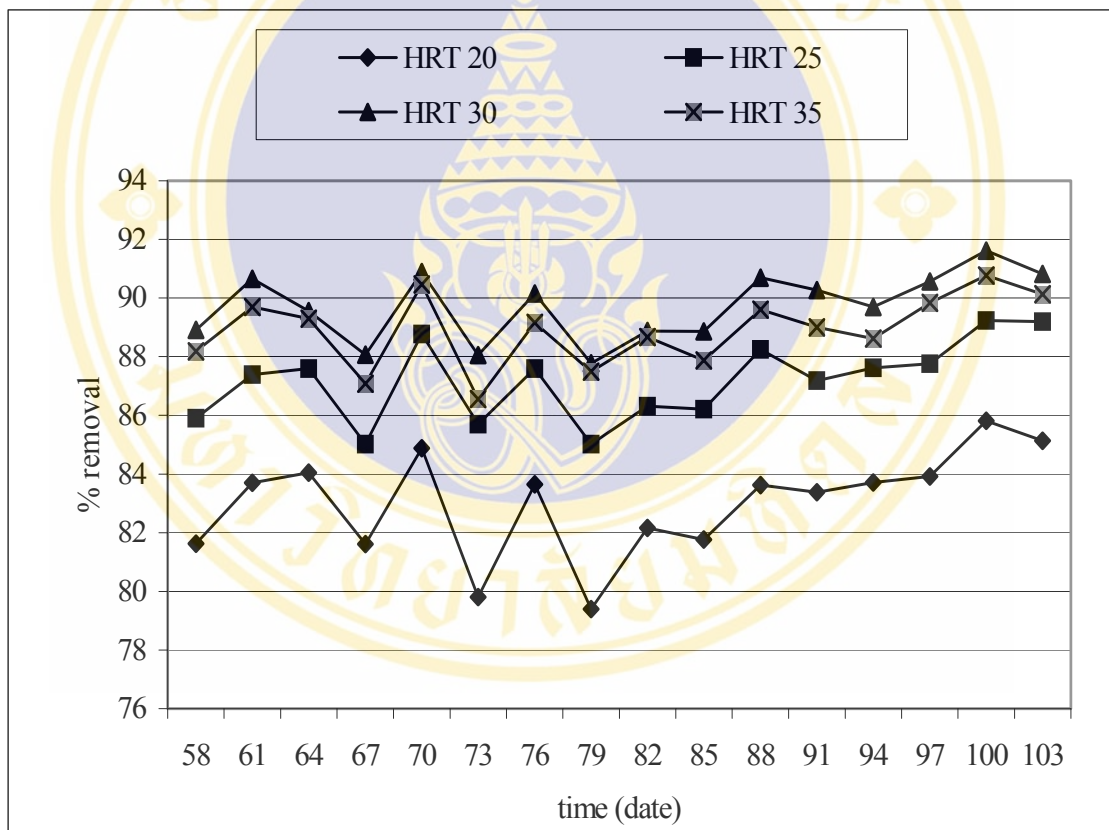


Figure 4-1 The efficiency in COD removal by the digesters performed with the HRT of 20, 25, 30 and 35 days under steady stage

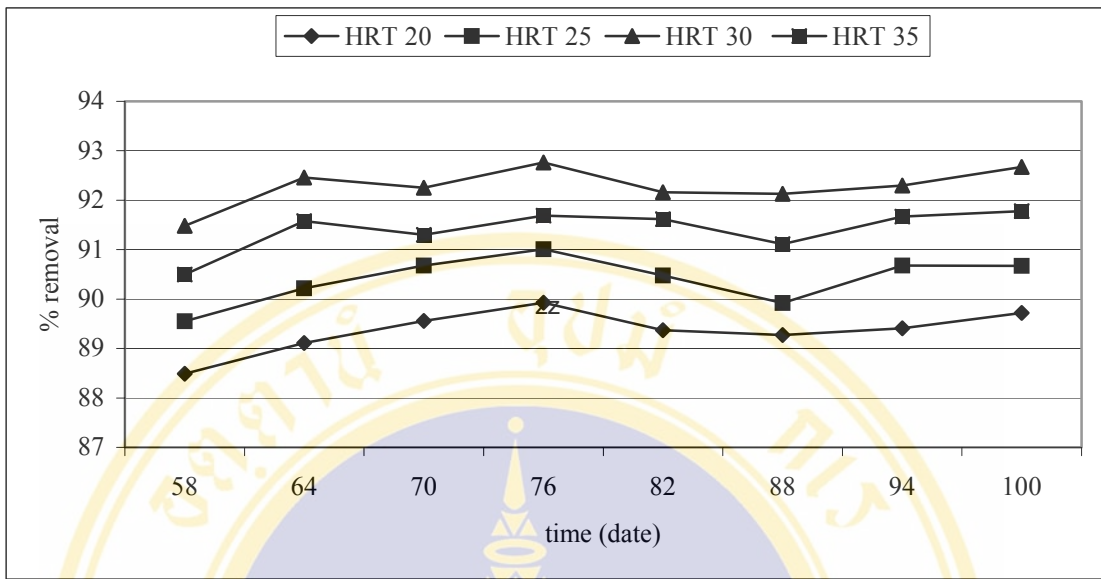


Figure 4-2 The efficiency in BOD removal by the digesters performed with the HRT of 20, 25, 30 and 35 days under steady stage

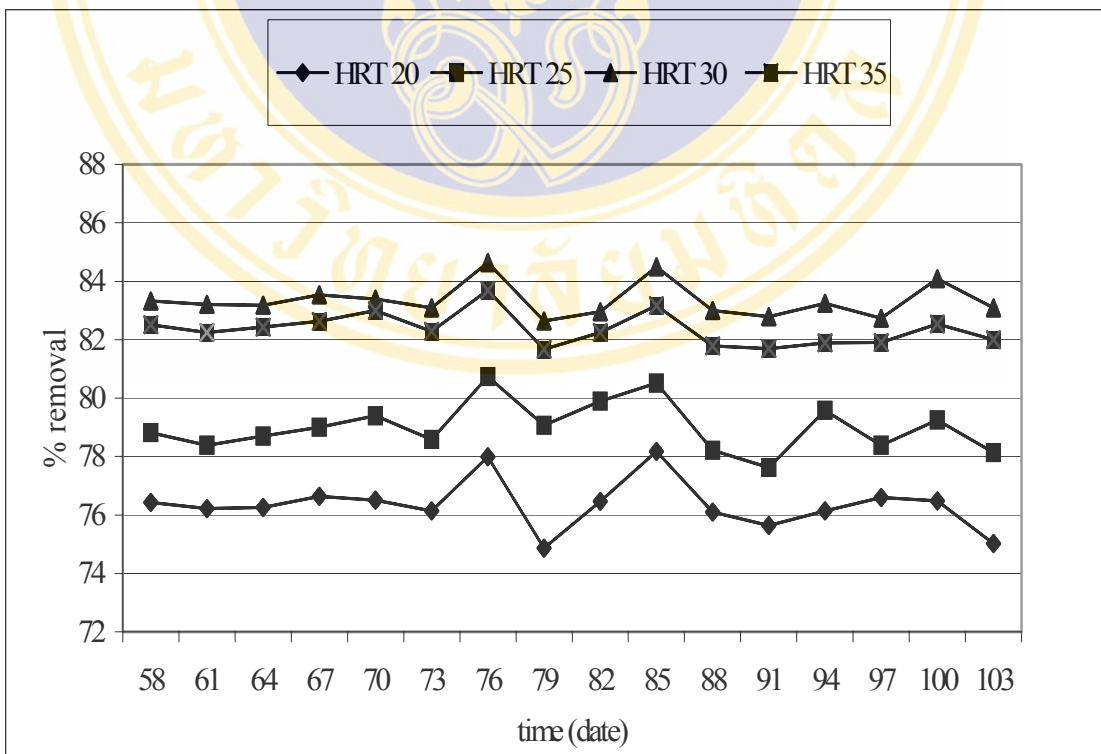


Figure 4-3 The efficiency in TVS removal by the digesters performed with the HRT of 20, 25, 30 and 35 days under steady stage

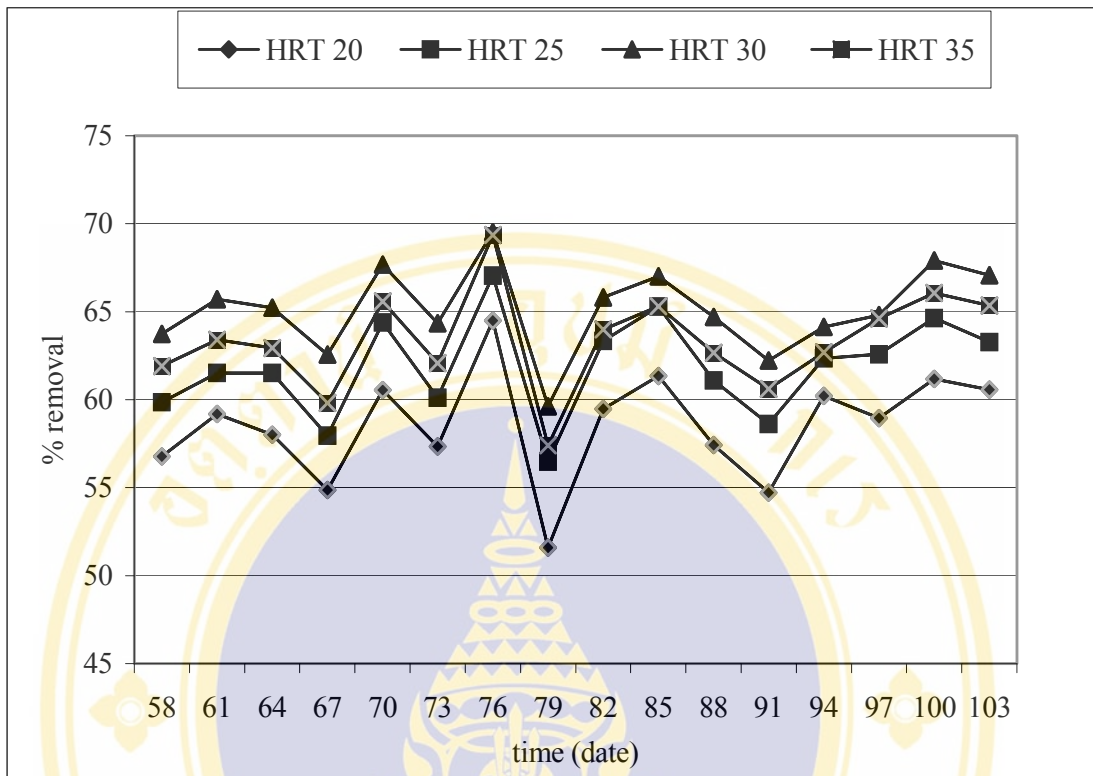


Figure 4-4 The efficiency in TS removal by the digesters performed with the HRT of 20, 25, 30 and 35 days under steady stage

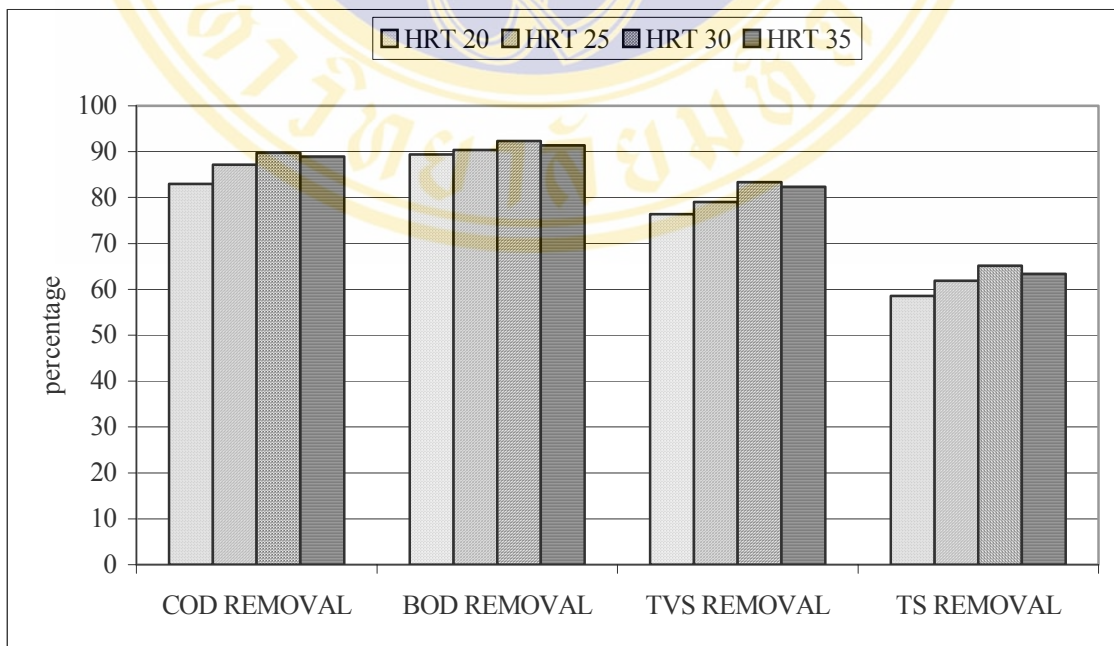


Figure 4-5 The average efficiency in COD, BOD, TVS and TS removal by the digesters performed with the HRT of 20, 25, 30 and 35 days under steady stage

4.3 Characteristic of the supernatant from 5-minute slurry settling

The results of pH, alkalinity and VFA of the supernatant from 5-minute slurry settling for evaluating of digesters performed with the HRT of 20, 25, 30 and 35 days under steady stage were summarized in Table 4-3 and Figure 4-6, 4-7, 4-8, 4-9, 4-10, 4-11, 4-12 and 4-13. Ammonia nitrogen of the supernatant from 5-minute slurry settling were summarized in Figure 4-14, 4-45 4-16 and 4-17.

Table 4-3 The pH, Alkalinity, VFA and ammonia nitrogen of the supernatant from 5-minute slurry settling performed with the HRT of 20, 25, 30 and 35 days under steady stage

Parameters		HRT (days)			
		20	25	30	35
pH	Min.	7.00	7.01	7.04	7.07
	Max.	7.07	7.09	7.09	7.12
	Mean.	7.03	7.04	7.07	7.09
	SD.	0.02	0.02	0.02	0.01
Alkalinity (mg/l as CaCO₃)	Min.	1,532.7	1,597.3	1,621.5	1,669.6
	Max.	1,596.4	1,698.5	1,690.1	1,701.6
	Mean.	1,559.8	1,629.8	1,660.9	1,686.2
	SD	20.13	26.61	21.94	8.72
Volatile Fatty Acid (mg/l as CH₃COOH)	Min.	317.8	344.3	262.3	266.5
	Max.	388.1	299.5	295.8	301.4
	Mean.	364.1	279.7	281.6	282.9
	SD	20.93	13.67	9.90	11.17
NH₃-N (mg/l)	Min.	51.34	50.68	48.44	50.15
	Max.	55.47	54.92	52.71	53.21
	Mean.	53.60	52.56	50.64	52.14
	SD	1.43	1.11	1.33	0.84

Although the average of pH value of influent is 4.96 that is a problem in aerobic digestion. However, the average pH of the supernatant from 5-minute slurry settling performed with the HRT of 20, 25, 30 and 35 days were 7.03, 7.04, 7.07 and 7.09, respectively. All these values were in optimum range for anaerobic digestion that reported by Polprasert and the system can operate without pH adjustment that probably because organic acid was almost completely digested by acid forming

bacteria. In addition, it was indicated that equilibrium with in these digesters was maintained by buffering action of ammonium bicarbonate. The bicarbonate ions are derived from carbon dioxide in the digester gas and ammonium ions are delivered from the degradation of proteins in the raw wastewater (Gray, 1989).

The average alkalinity of the supernatant from 5-minute slurry settling performed with the HRT of 20, 25, 30 and 35 days were 1,559.8, 1,629.8, 1,660.9 and 1,686.2 mg/l as calcium carbonate, respectively. These values were regularly found in anaerobic operation (1,000-5,000 mg/l as CaCO_3) (Kriengsuk, 2000). It was very interesting on alkalinity because alkalinity value of influent wastewater rather low (about 177.8 mg/l) when compare with the alkalinity in steady stage (about 1,500-1,600 mg/l) that probably because acid-forming bacteria can neutralize organic-acid almost completely that make carbonate and bicarbonate alkalinity increase in anaerobic digester.

The average VFA of the supernatant from 5-minute slurry settling performed with the HRT of 20, 25, 30 and 35 days were 364.1, 279.7, 281.6 and 282.9 mg/l as CH_3COOH , respectively. Volatile acid concentrations should have a range from 50 to 300 mg/l in anaerobic digestion (Water Environment Federation of USA., 1996). It was interesting on VFA concentration of influent wastewater rather high (about 731.2 mg/l) but in steady stage VFA concentration is lower than influent wastewater that probably because VFA was used by acid-forming bacteria. Therefore, those under HRT 25, 30 and 35 days were in the optimum range. However, the operation under HRT of 20 days provided in higher VFA concentration than recommended value but it was not a problem for anaerobic operation.

The average ammonia nitrogen of the supernatant from 5-minute slurry settling performed with the HRT of 20, 25, 30 and 35 days were 53.60, 52.56, 50.64 and 52.14 mg/l were quite similar. It was interesting on ammonia concentration of influent wastewater is lower than in steady stage that probably because the degradation of proteins in the raw wastewater make the concentration of ammonia nitrogen increase. These concentrations were in the range that did not an effect to anaerobic operation (>1,500 mg/l) as reported by OWEN (1982).

The average pH, alkalinity, VFA and ammonia nitrogen were in the suitable range for operation of the digester.

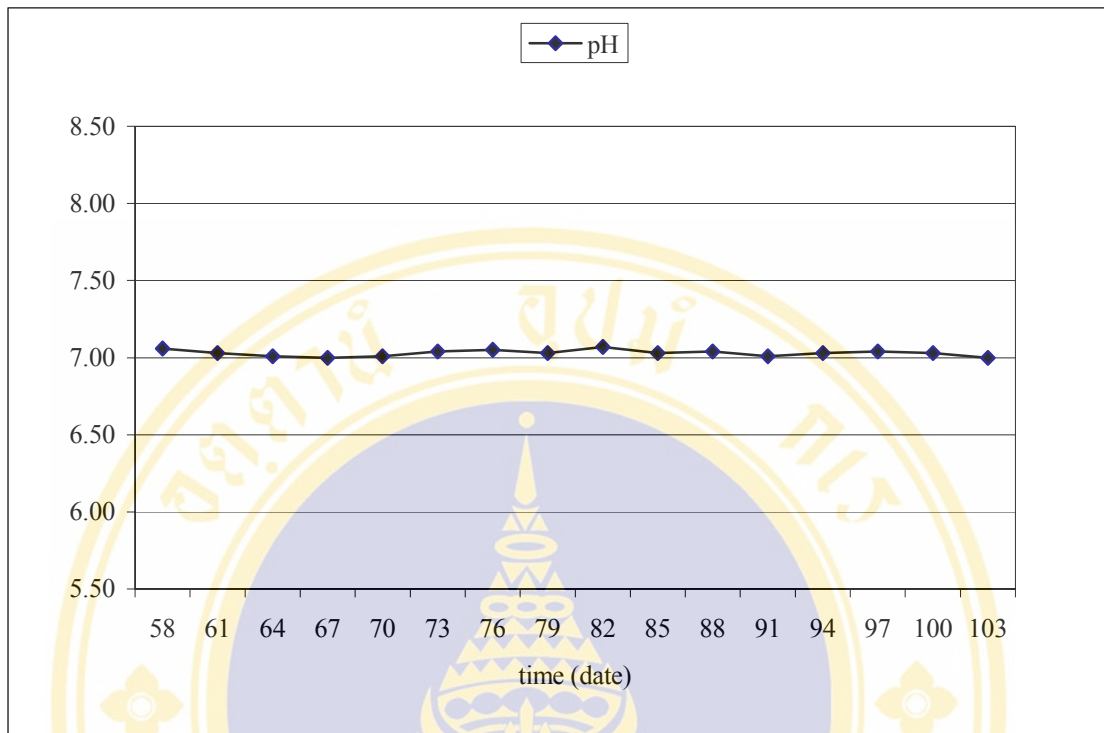


Figure 4-6 pH of the supernatant from 5-minute slurry settling performed with the HRT of 20 days under steady stage

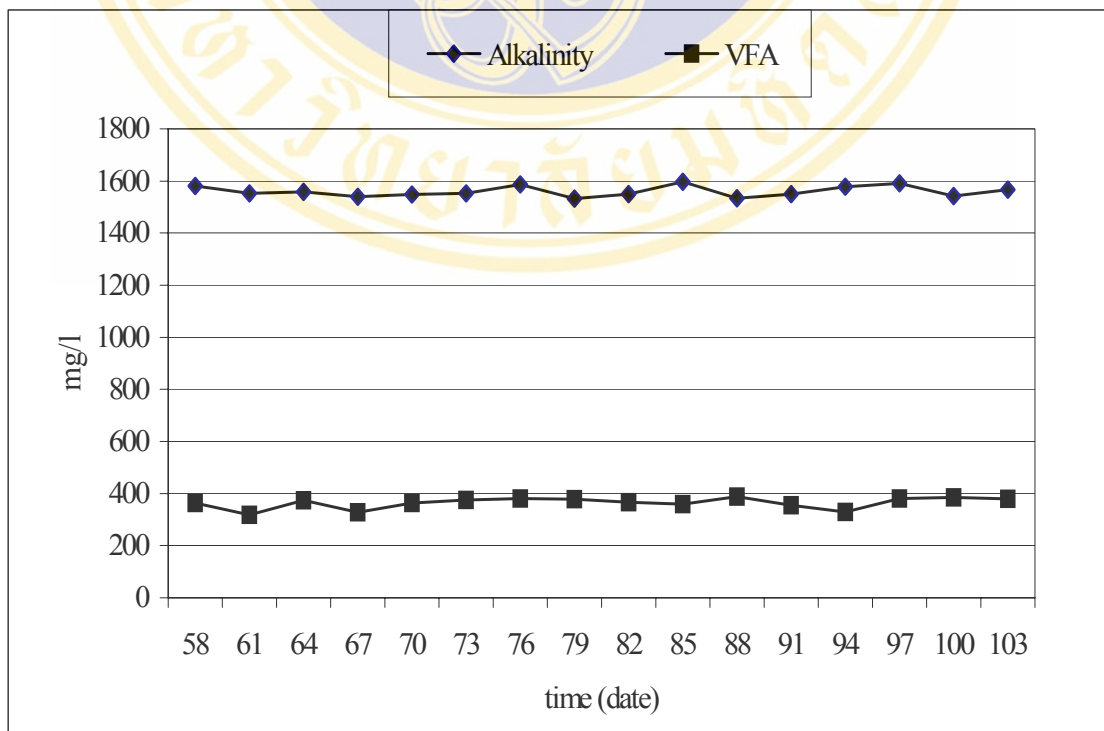


Figure 4-7 Alkalinity and VFA of supernatant from 5-minute slurry settling performed with the HRT of 20 days under steady stage

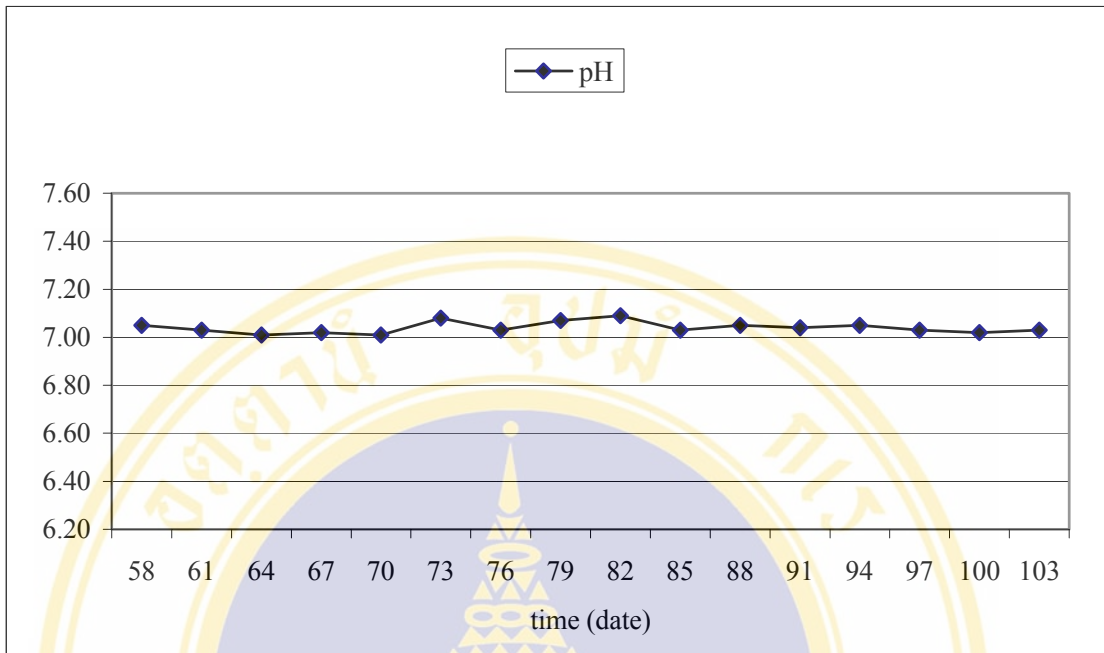


Figure 4-8 pH of the supernatant from 5-minute slurry settling performed with the HRT of 25 days under steady stage

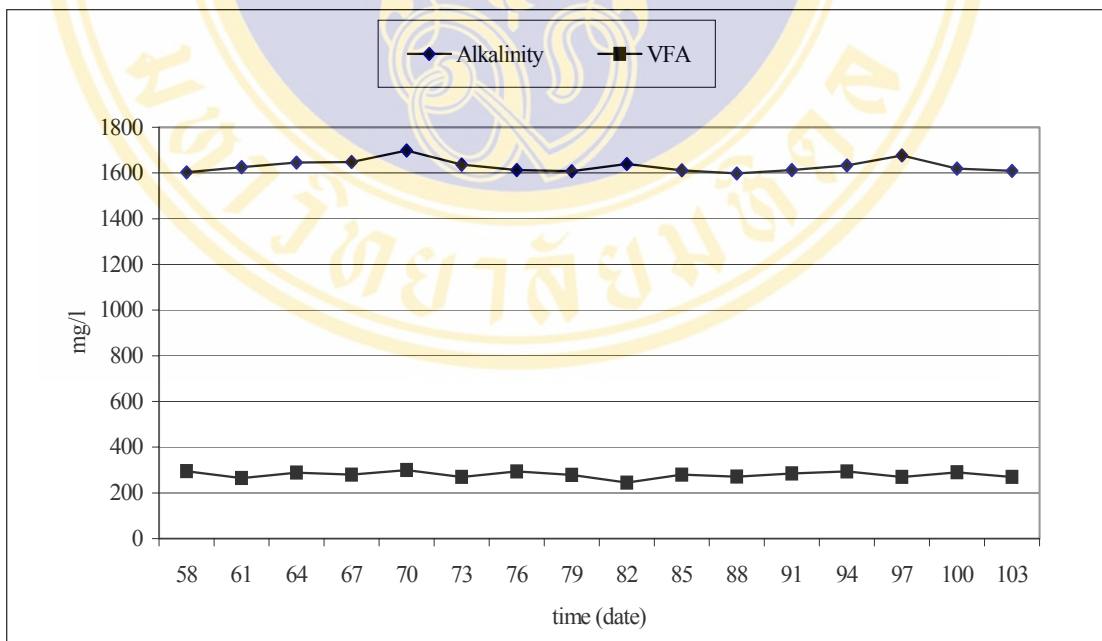


Figure 4-9 Alkalinity and VFA of the supernatant from 5-minute slurry settling performed with the HRT of 25 days under steady stage

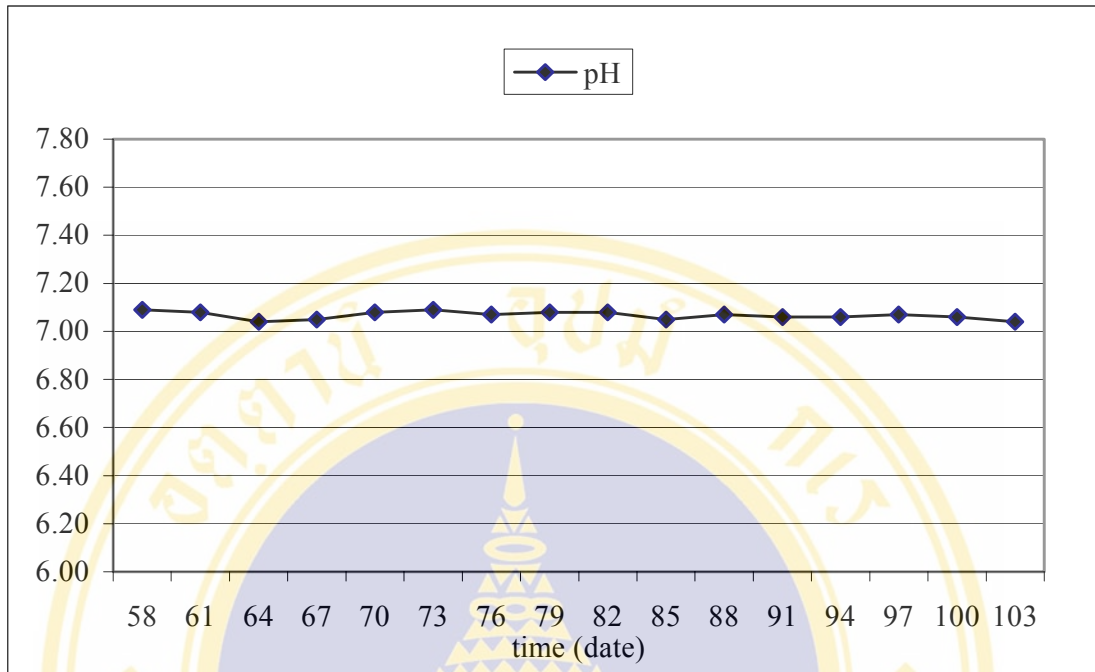


Figure 4-10 pH of the supernatant from 5-minute slurry settling performed with the HRT of 30 days under steady stage

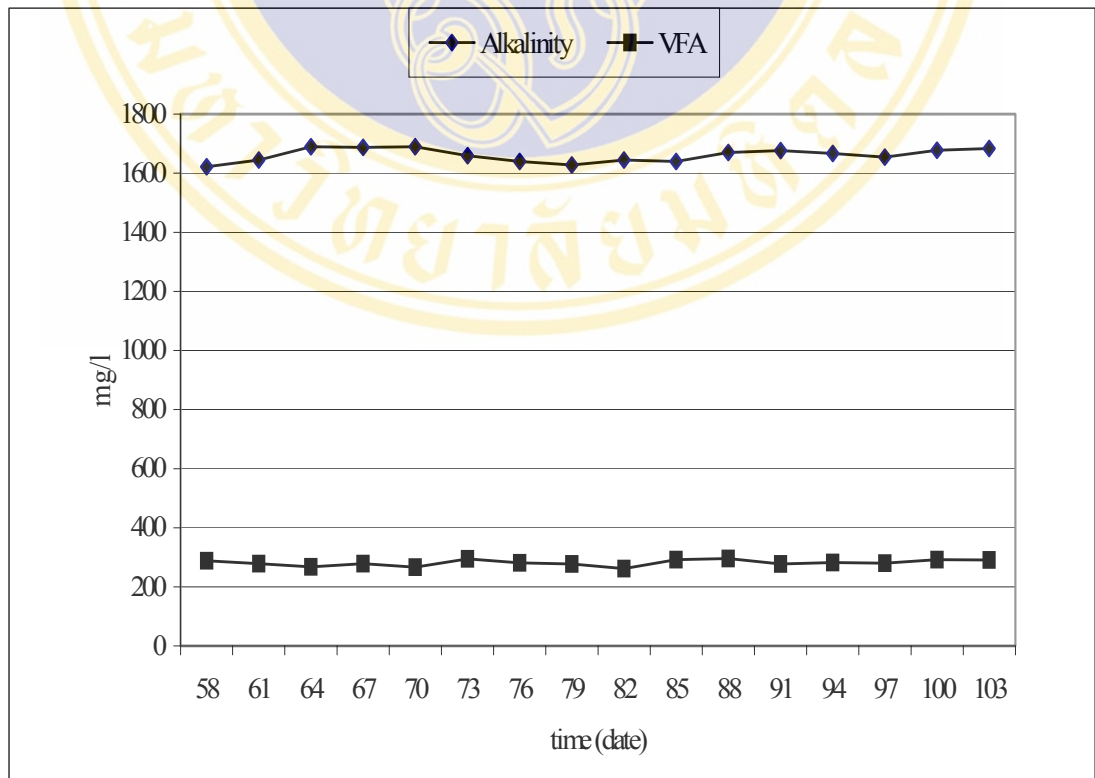


Figure 4-11 Alkalinity and VFA of the supernatant from 5-minute slurry settling performed with the HRT of 30 days under steady stage

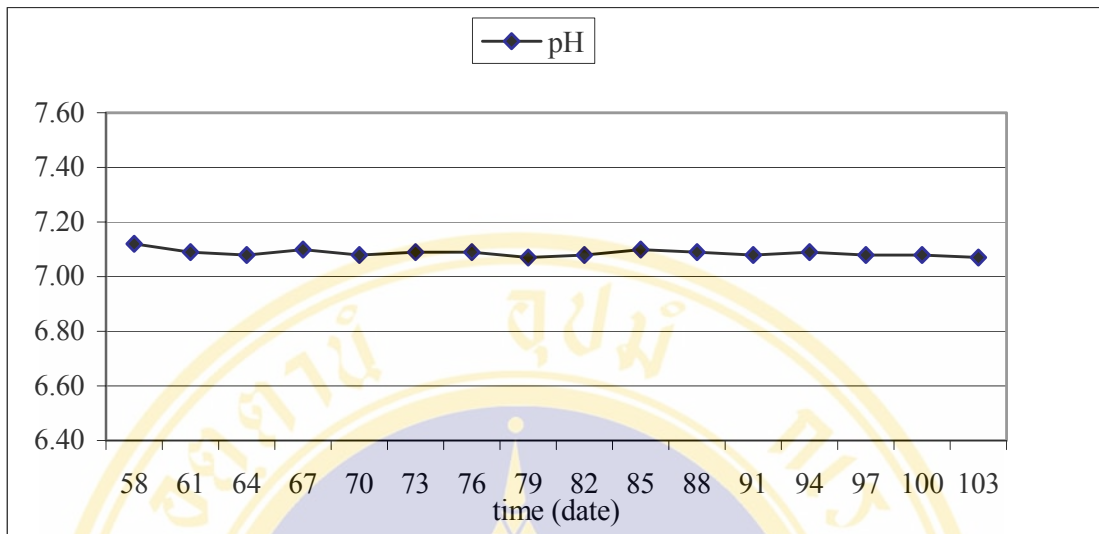


Figure 4-12 pH of the supernatant from 5-minute slurry settling performed with the HRT of 35 days under steady stage

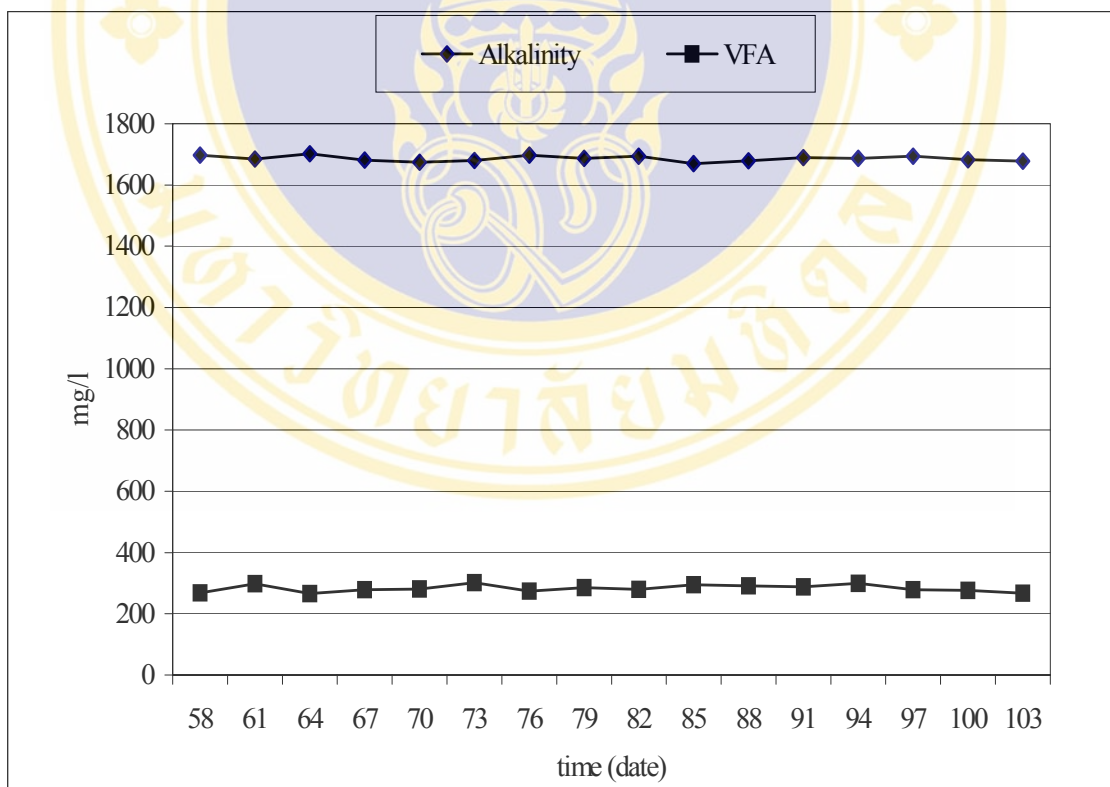


Figure 4-13 Alkalinity and VFA of the supernatant from 5-minute slurry settling performed with the HRT of 35 days under steady stage

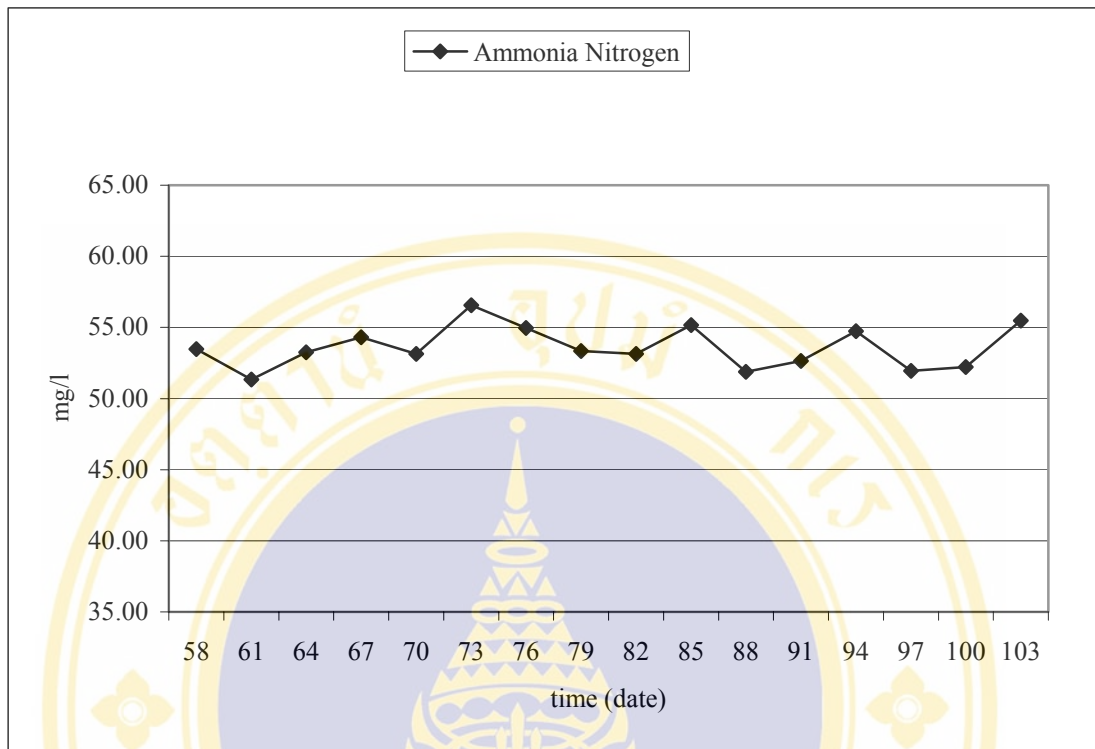


Figure 4-14 Ammonia Nitrogen of the supernatant from 5-minute slurry settling performed with the HRT of 20 days under steady stage

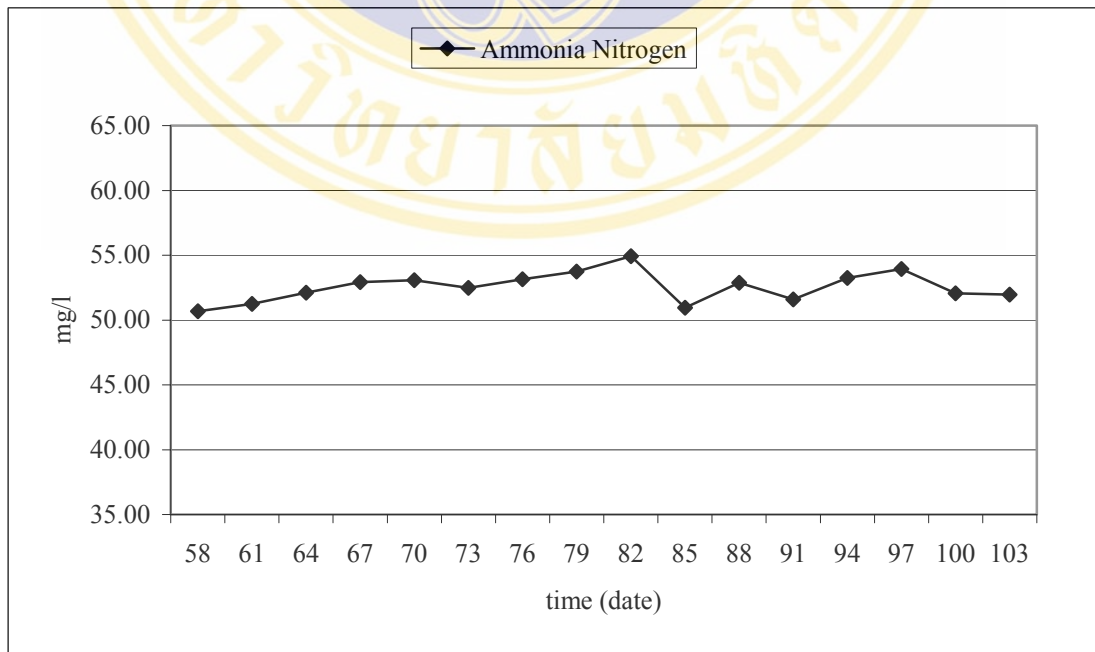


Figure 4-15 Ammonia Nitrogen of the supernatant from 5-minute slurry settling performed with the HRT of 25 days under steady stage

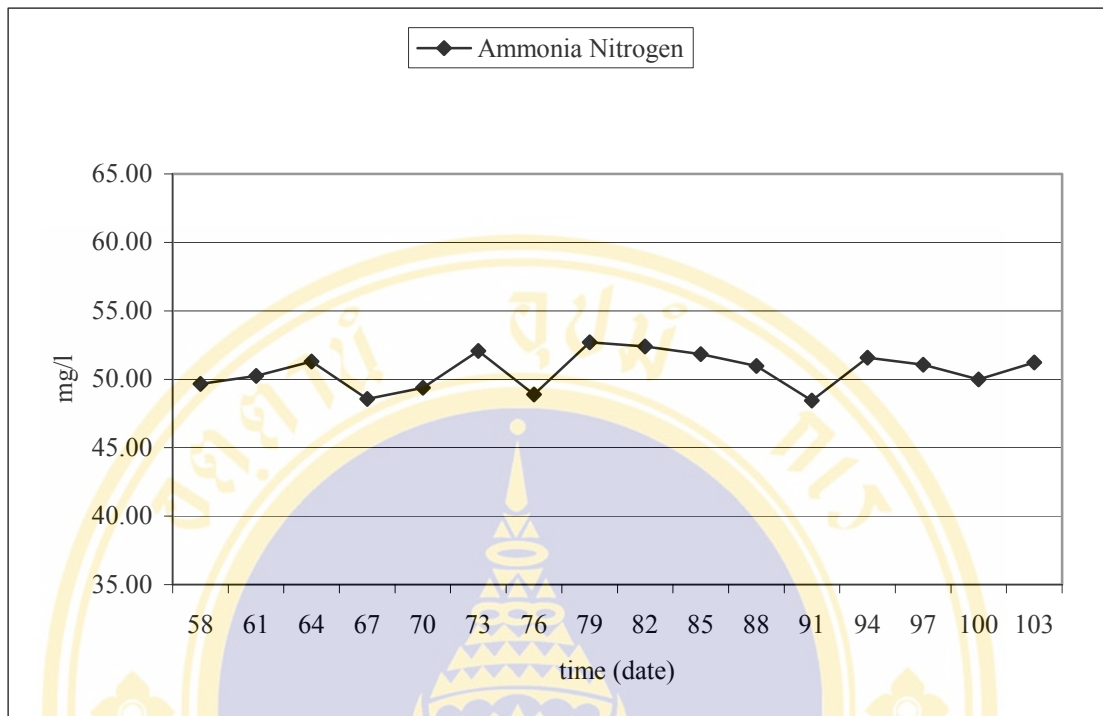


Figure 4-16 Ammonia Nitrogen of the supernatant from 5-minute slurry settling performed with the HRT of 30 days under steady stage

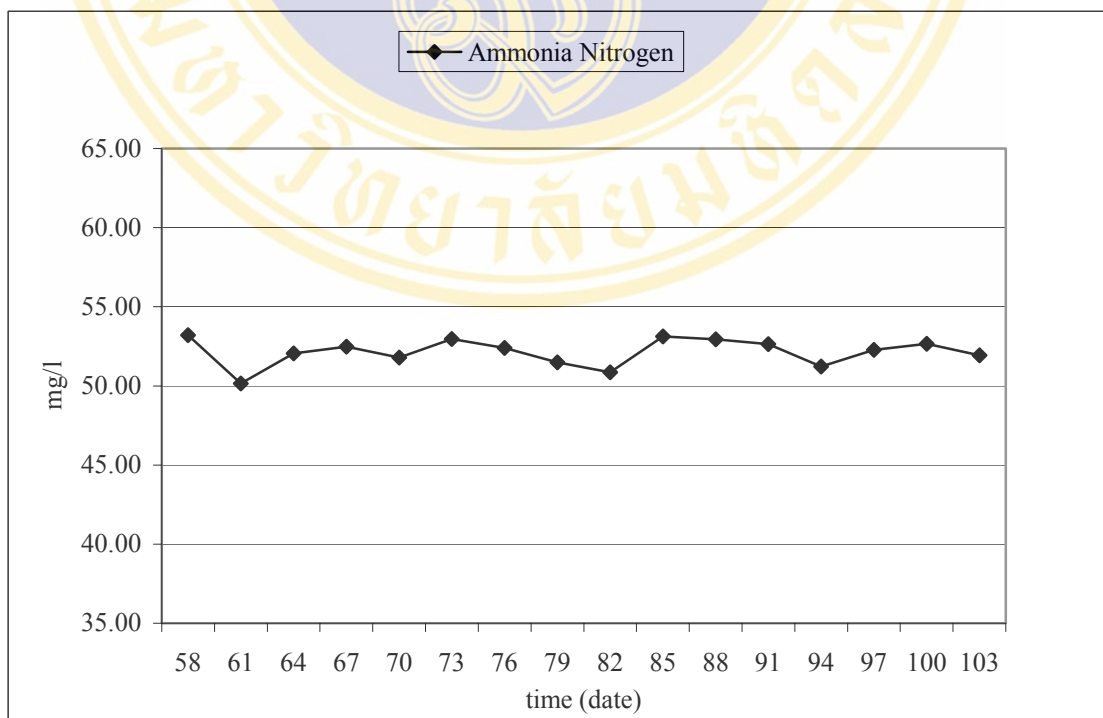


Figure 4-17 Ammonia Nitrogen of the supernatant from 5-minute slurry settling performed with the HRT of 35 days under steady stage

4.4 Biogas Production and Composition

The biogas production and composition of the digester performed with the HRT of 20, 25, 30 and 35 days were summarized in Table 4-4 and Figure 4-18 and 4-19.

4.4.1 Biogas Production

Biogas production was presented in the volume of biogas produced per weight of TVS_{removed} or COD_{removed}. The biogas productions of the digesters performed with the HRT of 20, 25, 30 and 35 days were 0.179, 0.158, 0.192 and 0.189 m³/kg TVS_{removed}, respectively. And also by means of 0.118, 0.102, 0.127 and 0.103 m³/kg COD_{removed}, respectively, as presented in Table 4-4. These biogas producing rate could not be comparable to the producing rate that reported by George *et al* (1993) and Mark and Mark Jr. (2001) that probably because the OLR used in this research was rather low and slightly varying in the characteristics of noodle soup wastewater in each days.

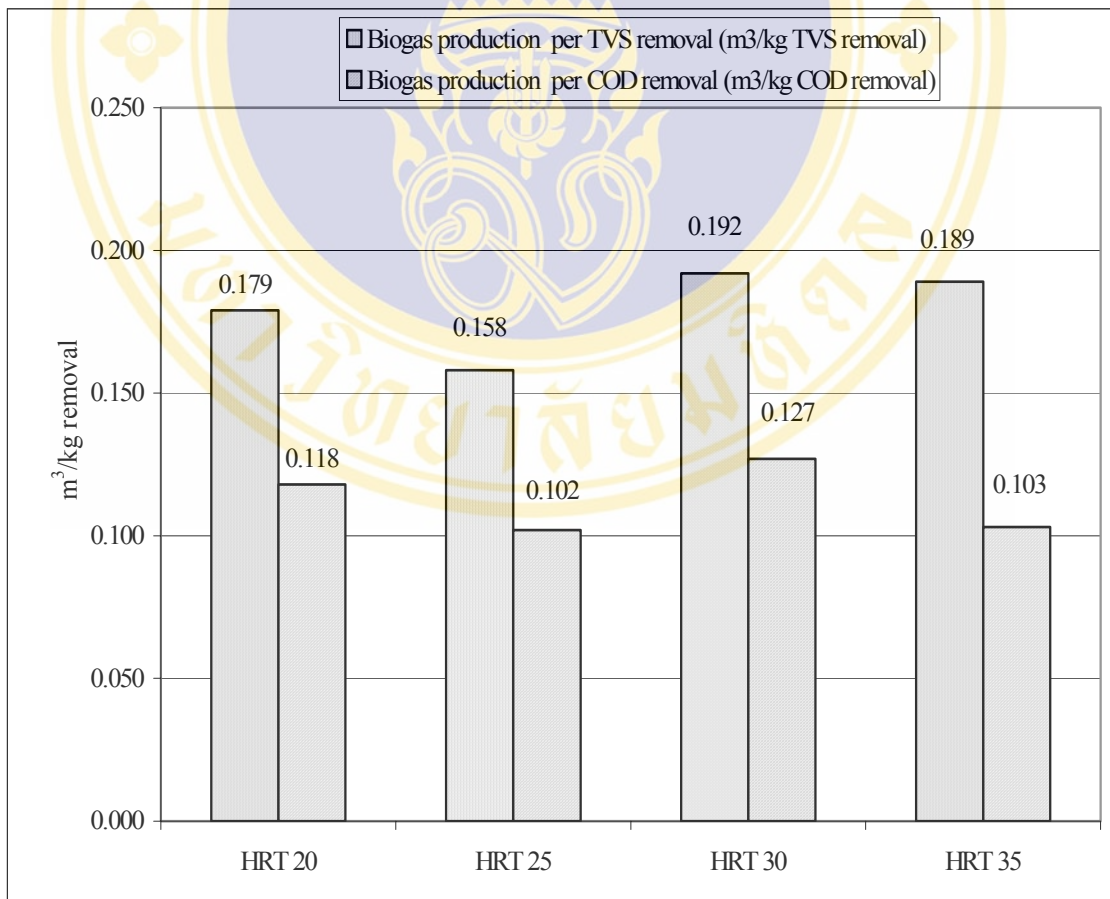
In addition, the biogas production was also presented in the amount of biogas produced per feeding volume of wastewater. The biogas production performed with 20, 25, 30 and 35 days of HRT were 1.531, 1.750, 2.684 and 2.498 m³/m³_{feeding wastewater}, respectively, if the noodle-soup wastewater was fed around 15 liters (the average of noodle-soup wastewater per day per 1 shop in this research), the gas yield would be around 80.52 m³/m³_{feeding wastewater}. That was quite interesting to use as a waste-to-energy process. The digester with the 30-day HRT provide the highest average amount of biogas (1.342 liters or 2.684 m³/m³_{feeding wastewater}).

Table 4-4 Comparison of biogas production of the digesters at various HRT

Parameters	HRT (days)			
	20	25	30	35
Q, m ³ /day, (l/day)	0.75x10 ⁻³ (0.75)	0.60x10 ⁻³ (0.60)	0.50x10 ⁻³ (0.50)	0.43x10 ⁻³ (0.43)
Organic loading rate, kg TVS/m ³ .d kg COD/m ³ .d	0.420 0.587	0.336 0.470	0.280 0.391	0.240 0.335

Table 4-4 (Continued) Comparison of biogas production of the digesters at various HRT

Parameters	HRT (days)			
	20	25	30	35
Gas production,				
liter/d	1.148	1.050	1.342	1.074
m^3 / m^3 of effective volume	0.077	0.070	0.0895	0.0716
m^3 / kg TVS removed	0.179	0.158	0.192	0.189
m^3 / kg COD removed	0.118	0.102	0.127	0.103
m^3 / m^3 feeding wastewater	1.531	1.750	2.684	2.498
Gas composition,				
%CH ₄	36.43	43.50	46.64	35.92
%CO ₂	10.55	14.12	17.04	6.71

**Figure 4-18** The average biogas production of the digesters performed with the HRT of 20, 25, 30 and 35 days

4.4.2 Biogas composition

The composition of produced biogas was shown in a percentage of methane (CH_4) and carbon dioxide (CO_2) as presented in Table 4-4 and Figure 4-15. The methane content of biogas produced from the digesters performed with the HRT of 20, 25, 30 and 35 days were 36.43%, 43.50%, 46.64% and 35.92%, respectively. Whereas the carbon dioxide content of those digesters were 10.55%, 14.12%, 17.04% and 6.71%, respectively.

The methane content of this research was in the vicinity of tuna-processing wastewater that reported by Atcharaporn (44.84%) but less than that reported by Polprasert (55-65%). The factor that may affect to this study was the low pH value of wastewater and operation without pH adjustment or varying in characteristics of noodle soup wastewater in each days.

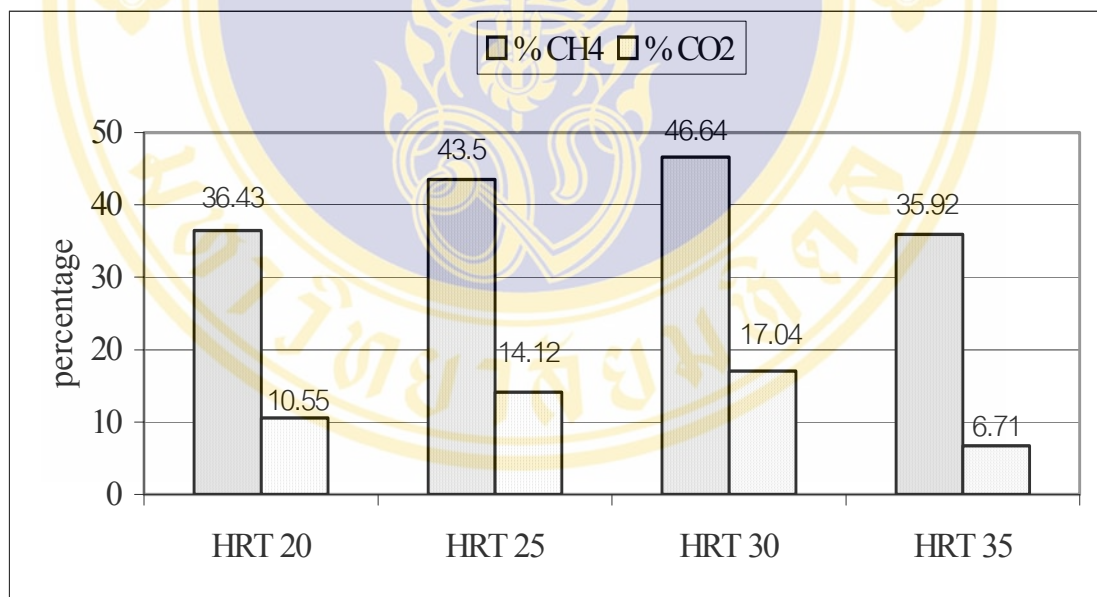


Figure 4-19 The average methane and carbon dioxide contents of the biogas from the digesters performed with the HRT of 20, 25, 30 and 35 days.

As can be seen in the figure 4-18 and 4-19, the HRT of 30 days provided the highest gas production and methane content, likely as the highest removal efficiency because the process of removal relatively occurred when organic matter was digested anaerobically and converted to the biogas.

From above information seem that the HRT of 30 days was the optimum in biogas production. Because it could produced the highest amount of biogas with the same methane concentration.

Biogas from every digester can ignite at ambient temperature because these biogas compose of carbondioxide lower than 50 %.



CHAPTER V CONCLUSION AND RECOMMENDATION

5.1 Conclusions

Temperature, Ammonia-nitrogen, pH and Alkalinity from every digester have optimum range for anaerobic treatment process. And the results were concluded as followed:

5.1.1 The Efficiency of wastewater treatment

The efficiency in COD removal at the HRT 20, 25, 30 and 35 days was 83.01 %, 87.17%, 89.72% and 88.91%, respectively, whereas, that in BOD removal was 89.36%, 90.40%, 92.28% and 91.41%, at the same respective hydraulic retention times. As for TS removal, the efficiency was 58.54%, 61.88%, 65.13% and 63.36%, while for TVS removal, it was 76.35%, 79.02%, 83.34% and 82.35%. In all cases, the digester could be operated without addition of any nutrient and alkali addition.

From the one-way anova (Duncan) was found as followed:

- 1) COD Removal Efficiency of HRT 30 days and HRT 35 days were not difference ($\alpha=0.05$, N=16).
- 2) TS Removal Efficiency of HRT 25 days and HRT 35 days were not difference ($\alpha=0.05$, N=16).
- 3) TS Removal Efficiency of HRT 30 days and HRT 35 days were not difference ($\alpha=0.05$, N=16).
- 4) The digester with the 30-day HRT provided the best efficiency in COD (89.72%), BOD (92.28%), TS (65.13%) and TVS (83.34%) reduction.

5.1.2 Biogas Production and Composition

The amount of biogas production at the HRT of 20, 25, 30 and 35 days was 0.118, 0.102, 0.127 and 0.103 $\text{m}^3/\text{kgCOD}_{\text{removed}}$ or the equivalent of 1.531, 1.750, 2.684 and 2.498 $\text{m}^3 \text{ biogas}/\text{m}^3 \text{ feeding wastewater}$, respectively. Furthermore, the concentration of methane gas of the biogas were respectively 36.43%, 43.50%, 46.64% and 35.92% at the same hydraulic retention time. From these results the best

of the digester that given the concentration of methane gas was the digester with the HRT30days.

From the one-way anova (Duncan) was found as followed:

- 1) The concentration of methane gas of the digester with the HRT 20 days and the digester with the HRT 35 days were not difference ($\alpha=0.05$, $N=5$).
- 2) The concentration of methane gas of the digester with the HRT 25 days and the digester with the HRT 30 days were not difference ($\alpha=0.05$, $df = 4$).
- 3) The digester with the HRT 30 days provide the highest average percentage of methane (46.64%).
- 4) The amount of biogas of HRT 25 days and HRT 35 days were not difference.
- 5) The digester with the HRT 30 days provide the highest average amount of biogas (1.342 liters or $2.684 \text{ m}^3/\text{m}^3$ feeding wastewater).

However, The results from this research were concluded the digester with the HRT 30 days given the highest concentration of methane gas was 46.64%, respectively and highest amount of biogas (1.342 liters or $2.684 \text{ m}^3/\text{m}^3$ feeding wastewater).

5.1.3 Suitable HRT

The above results almost clearly demonstrated that the suitable condition for operating the system was the HRT 30 days as this obtained the highest efficiency in COD, BOD, TS, and TVS removal which was 89.72%, 92.28%, 65.13% and 82.35%, respectively, and produced the largest amount of biogas production of around $2.684 \text{ m}^3 \text{ biogas}/\text{m}^3 \text{ feeding wastewater}$ with a methane content of 46.64%.

5.2 Recommendations

1) The efficiency of the conventional anaerobic digester in treatment and biogas production of the other food-processing wastewater should be further studied.

2) The efficiency of wastewater treatment and biogas production from noodle-soup wastewater by the other types of digester or the other anaerobic process should be further studied.



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Table A-1 The characteristics of wastewater using for the experiment under steady state

Date	pH	Alkalinity (mg/l)	VFA (mg/l)	NH ₃ -N (mg/l)	TS (mg/l)	TVS (mg/l)	COD (mg/l)	BOD (mg/l)	Temp. (°C)	Conductivity (µMHOS)
1	4.85	174.8	759.6	2.72	13178	8164	10311	5012	30.1	11500
3	4.97	179.3	712.4	3.78	13996	8262	11879	-	30.0	11200
6	4.89	165.7	758.2	3.36	14026	8476	11947	5489	30.1	10800
9	5.11	184.2	695.2	3.98	12373	8042	10092	-	29.9	11500
12	4.93	165.2	718.4	5.79	15170	8963	13156	5612	30.2	10500
15	5.14	189.6	654.7	3.81	13148	7958	9826	-	30.0	10800
18	4.64	172.8	732.1	4.17	16110	9017	12160	5839	30.1	11100
21	5.07	181.1	716.7	5.58	12171	8112	9876	-	31.0	10500
24	5.18	201.5	803.4	3.29	14154	8397	11181	5597	30.2	11000
27	4.79	192.6	683.7	3.87	14987	8955	10839	-	30.5	11200
30	5.03	170.4	739.6	4.33	13871	8297	12836	5397	30.0	11500
34	4.86	175.3	745.1	3.64	12975	8104	11856	-	30.0	11200
36	4.69	147.6	694.6	2.81	13904	8388	12016	5581	31.0	10500
38	5.19	198.4	788.7	3.70	13888	8377	12487	-	30.0	11500
40	4.74	167.9	741.5	5.21	14893	8490	13842	5742	30.0	12500
42	4.92	177.8	755.9	3.44	14738	8391	13545	-	29.5	11000
Min.	4.64	147.6	654.7	2.72	12171	7958	9826	5012	29.5	10500
Max.	5.19	201.5	803.4	5.79	16110	9017	13842	5839	31.0	12500
Mean	4.94	177.8	731.2	3.97	13973	8399	11740	5533	30.2	11143
SD.	0.17	13.25	37.51	0.86	1019	316.20	1244	235.01	0.37	492.4

Table A-2 Performance data of the conventional digester performed with the HRT 20 days under steady state

Date	pH	Alkalinity (mg/l)	VFA (mg/l)	NH ₃ -N (mg/l)	TS (mg/l)	TVS (mg/l)	COD (mg/l)	BOD (mg/l)	Temp. (mg/l)	Conductivity (μMHOS)	Total Gas (litter/day)	CH ₄ (%)	CO ₂ (%)
1	7.06	1580.9	364.1	53.48	5698	1924	1895	577	29.0	12800	1.128	-	-
3	7.03	1552.4	317.8	51.34	5712	1965	1936	-	29.0	12900	1.204	-	-
6	7.01	1557.7	373.8	53.26	5890	2012	1905	598	29.5	12900	1.185	-	-
9	7.00	1539.7	327.6	54.31	5587	1879	1856	-	29.0	13000	1.103	-	-
12	7.01	1547.6	363.7	53.14	5985	2105	1989	586	29.0	12900	1.155	-	-
15	7.04	1552.3	375.4	56.56	5610	1899	1984	-	29.5	12800	1.216	-	-
18	7.05	1586.4	381.2	54.96	5719	1985	1988	588	29.0	12800	1.185	-	-
21	7.03	1532.7	377.6	53.35	5893	2039	2035	-	29.0	12800	1.107	-	-
24	7.07	1549.3	366.7	53.13	5737	1977	1995	595	29.0	12900	1.004	-	-
27	7.03	1596.4	359.2	55.17	5792	1954	1976	-	29.5	12800	1.101	-	-
30	7.04	1533.7	388.1	51.87	5907	1983	2103	579	29.0	12900	1.197	-	-
34	7.01	1549.2	355.7	52.65	5877	1974	1971	-	29.5	12900	1.152	31.48	6.98
36	7.03	1577.8	329.3	54.74	5533	2001	1958	591	29.5	12900	1.169	41.84	13.28
38	7.04	1591.4	381.6	51.94	5701	1960	2008	-	29.0	12800	1.190	37.07	11.48
40	7.03	1542.1	384.7	52.21	5783	1997	1964	590	29.5	12900	1.184	34.54	10.53
42	7.00	1566.8	378.8	55.47	5811	2096	2014	-	29.5	12900	1.089	37.23	10.46
Min.	7.00	1532.7	317.8	51.34	5533	1879	1856	577	29.0	12800	1.004	31.48	6.98
Max.	7.07	1596.4	388.1	55.47	5985	2105	2103	598	29.5	13000	1.216	41.84	11.18
Mean	7.03	1559.8	364.1	53.60	5764	1984	1973	588	29.2	12868	1.148	36.43	10.55
SD.	0.02	20.13	20.93	1.43	122.50	58.78	56.36	6.78	0.25	58.30	0.05	3.42	2.05

Note: Mean of TS in the digester is 7248 mg/l

Mean of TVS in the digester is 2794 mg/l

Table A-3 Performance data of the conventional digester performed with the HRT 25 days under steady state

Date	pH	Alkalinity (mg/l)	VFA (mg/l)	NH ₃ -N (mg/l)	TS (mg/l)	TVS (mg/l)	COD (mg/l)	BOD (mg/l)	Temp. (mg/l)	Conductivity (µMHOS)	Total Gas (litter/day)	CH ₄ (%)	CO ₂ (%)
1	7.05	1603.4	294.7	50.68	5289	1729	1454	524	28.5	12500	0.954	-	-
3	7.03	1625.7	265.4	51.25	5387	1786	1498	-	29.0	12500	1.102	-	-
6	7.01	1645.2	288.6	52.12	5398	1805	1481	537	29.0	12600	0.988	-	-
9	7.02	1647.8	279.9	52.92	5204	1689	1512	-	29.5	12500	1.036	-	-
12	7.01	1698.5	299.5	53.08	5402	1846	1478	523	29.0	12800	0.946	-	-
15	7.08	1636.2	270.3	52.48	5245	1705	1405	-	29.0	12600	1.094	-	-
18	7.03	1612.5	293.5	53.14	5308	1737	1509	525	29.5	12700	1.136	-	-
21	7.07	1607.7	278.6	53.75	5297	1698	1479	-	29.5	12600	1.109	-	-
24	7.09	1639.4	244.3	54.92	5189	1688	1531	533	28.5	12700	1.085	-	-
27	7.03	1611.6	280.4	50.96	5203	1745	1495	-	29.0	12800	0.932	-	-
30	7.05	1597.3	271.7	52.87	5397	1807	1508	544	29.0	12700	1.196	-	-
34	7.04	1612.7	284.7	51.59	5369	1814	1519	-	29.5	12800	1.024	46.27	17.41
36	7.05	1633.1	293.3	53.24	5234	1713	1488	520	29.0	12800	1.087	40.93	14.21
38	7.03	1676.8	270.4	53.93	5196	1811	1529	-	29.0	12900	1.119	47.20	11.22
40	7.02	1619.7	289.7	52.07	5266	1762	1490	536	29.0	12700	1.004	40.08	13.87
42	7.03	1609.4	269.9	51.97	5414	1834	1463	-	29.5	12700	0.989	43.06	13.90
Min.	7.01	1597.3	244.3	50.68	5189	1688	1405	520	28.5	12500	0.932	40.08	11.22
Max.	7.09	1698.5	299.5	54.92	5414	1846	1531	544	29.5	12900	1.196	47.20	17.41
Mean	7.04	1629.8	279.7	52.56	5299	1760	1489	530	29.2	12681	1.050	43.50	14.12
SD.	0.02	26.61	13.67	1.11	81.10	52.63	30.52	7.90	0.29	118.4	0.07	2.82	1.97

Note: Mean of TS in the digester is 7104 mg/l

Mean of TVS in the digester is 2847 mg/l

Table A-4 Performance data of the conventional digester performed with the HRT 30 days under steady state

Date	pH	Alkalinity (mg/l)	VFA (mg/l)	NH ₃ -N (mg/l)	TS (mg/l)	TVS (mg/l)	COD (mg/l)	BOD (mg/l)	Temp. (mg/l)	Conductivity (μMHOS)	Total Gas (litter/day)	CH ₄ (%)	CO ₂ (%)
1	7.09	1621.5	288.5	49.65	4779	1362	1143	427	29.0	12700	1.352	-	-
3	7.08	1645.2	278.4	50.24	4801	1387	1109	-	29.0	12700	1.289	-	-
6	7.04	1690.1	268.1	51.29	4877	1426	1248	414	29.5	12500	1.301	-	-
9	7.05	1687.2	279.3	48.56	4632	1324	1204	-	29.0	12700	1.405	-	-
12	7.08	1689.9	266.1	49.37	4905	1489	1198	435	29.5	12600	1.396	-	-
15	7.09	1659.4	294.5	52.07	4687	1346	1174	-	29.0	12700	1.221	-	-
18	7.07	1639.7	281.4	48.88	4908	1393	1197	423	29.0	12600	1.412	-	-
21	7.08	1627.7	277.6	52.71	4914	1408	1208	-	29.0	12700	1.409	-	-
24	7.08	1644.3	262.3	52.39	4839	1432	1245	439	29.0	12600	1.446	-	-
27	7.05	1639.5	291.7	51.83	4945	1389	1208	-	29.5	12600	1.389	-	-
30	7.07	1670.8	295.8	50.97	4897	1411	1195	425	29.0	12700	1.297	-	-
34	7.06	1676.4	277.2	48.44	4902	1395	1154	-	29.0	12600	1.366	42.55	12.38
36	7.06	1666.3	281.9	51.57	4987	1406	1239	430	29.0	12600	1.295	49.30	13.94
38	7.07	1654.7	280.1	51.06	4889	1447	1178	-	28.5	12500	1.233	44.26	14.34
40	7.06	1677.8	292.7	49.98	4781	1351	1160	421	29.0	12700	1.324	44.99	21.21
42	7.04	1684.1	290.5	51.23	4852	1419	1244	-	29.0	12600	1.329	52.09	23.33
Min.	7.04	1621.5	262.3	48.44	4632	1324	1109	414	28.5	12500	1.221	42.55	12.38
Max.	7.09	1690.1	295.8	52.71	4987	1489	1248	439	29.5	12700	1.446	52.09	23.33
Mean	7.07	1660.9	281.6	50.64	4849	1399	1194	426	29.1	12631	1.342	46.64	17.04
SD.	0.02	21.94	9.90	1.33	90.78	39.76	38.57	7.43	0.24	68.18	0.06	3.52	4.37

Note: Mean of TS in the digester is 6893 mg/l

Mean of TVS in the digester is 2779 mg/l

Table A-5 Performance data of the conventional digester performed with the HRT 35 days under steady state

Date	pH	Alkalinity (mg/l)	VFA (mg/l)	NH ₃ -N (mg/l)	TS (mg/l)	TVS (mg/l)	COD (mg/l)	BOD (mg/l)	Temp. (mg/l)	Conductivity (µMHOS)	Total Gas (litter/day)	CH ₄ (%)	CO ₂ (%)
1	7.12	1697.5	268.4	53.21	5019	1428	1219	476	29.0	12100	1.178	-	-
3	7.09	1685.4	298.5	50.15	5123	1467	1223	-	28.5	12100	1.046	-	-
6	7.08	1701.6	266.5	52.05	5198	1489	1278	462	28.5	12300	0.929	-	-
9	7.10	1681.9	278.4	52.48	4971	1397	1304	-	29.0	12100	1.012	-	-
12	7.08	1674.2	280.9	51.79	5221	1524	1255	488	29.0	12200	0.925	-	-
15	7.09	1680.8	301.4	52.97	4987	1409	1321	-	29.5	12300	1.104	-	-
18	7.09	1697.4	273.7	52.39	4937	1471	1318	485	29.5	12200	1.129	-	-
21	7.07	1686.8	286.1	51.49	5186	1487	1235	-	29.0	12300	1.014	-	-
24	7.08	1693.5	279.5	50.85	5097	1491	1267	469	29.5	12300	1.188	-	-
27	7.10	1669.6	294.7	53.12	5199	1507	1314	-	29.5	12200	1.089	-	-
30	7.09	1679.4	290.8	52.94	5180	1512	1335	480	29.5	12200	1.107	-	-
34	7.08	1689.4	287.6	52.65	5112	1484	1305	-	29.5	12100	1.113	34.32	6.65
36	7.09	1687.2	299.4	51.23	5188	1519	1367	465	29.0	12200	1.106	32.03	5.72
38	7.08	1694.1	278.2	52.28	4913	1516	1269	-	29.0	12300	1.085	38.84	5.97
40	7.08	1682.3	276.3	52.66	5054	1483	1278	472	29.5	12300	1.021	34.70	8.67
42	7.07	1677.9	267.4	51.93	5107	1510	1312	-	29.5	12400	1.144	39.69	6.56
Min.	7.07	1669.6	266.5	50.15	4913	1397	1219	462	28.5	12100	0.925	32.03	5.72
Max.	7.12	1701.6	301.4	53.21	5221	1524	1367	488	29.5	12400	1.188	39.69	8.67
Mean	7.09	1686.2	282.9	52.14	5093	1480	1287	474	29.2	12225	1.074	35.92	6.71
SD.	0.01	8.72	11.17	0.84	98.49	37.54	40.40	8.72	0.35	90.14	0.08	2.90	1.04

Note: Mean of TS in the digester is 7615 mg/l
 Mean of TVS in the digester is 2897 mg/l

Table A-6 The efficiency in COD removal of the conventional anaerobic digester under steady state

Date	Influent (mg/l)	HRT 20 days		HRT 25 days		HRT 30 days		HRT 35 days	
		Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)
1	10311	1895	81.62	1454	85.90	1143	88.91	1219	88.18
3	11879	1936	83.70	1498	87.39	1109	90.66	1223	89.70
6	11947	1905	84.05	1481	87.60	1248	89.55	1278	89.30
9	10092	1856	81.61	1512	85.02	1204	88.07	1304	87.08
12	13156	1989	84.88	1478	88.77	1198	90.89	1255	90.46
15	9826	1984	79.81	1405	85.70	1174	88.05	1321	86.56
18	12160	1988	83.65	1509	87.59	1197	90.16	1318	89.16
21	9876	2035	79.39	1479	85.02	1208	87.77	1235	87.49
24	11181	1995	82.16	1531	86.31	1245	88.87	1267	88.67
27	10839	1976	81.77	1495	86.21	1208	88.86	1314	87.88
30	12836	2103	83.62	1508	88.25	1195	90.69	1335	89.60
34	11856	1971	83.38	1519	87.19	1154	90.27	1305	89.00
36	12016	1958	83.71	1488	87.62	1239	89.69	1367	88.62
38	12487	2008	83.92	1529	87.76	1178	90.57	1269	89.84
40	13842	1964	85.81	1490	89.24	1160	91.62	1278	90.77
42	13545	2014	85.13	1463	89.20	1244	90.82	1312	90.31
Min.	9826	1856	79.39	1405	85.02	1109	87.77	1219	86.56
Max.	13842	2103	85.81	1531	89.24	1248	91.62	1367	90.77
Mean	11740	1973	83.01	1489	87.17	1194	89.72	1287	88.91
SD.	1244	56.36	1.75	30.52	1.32	38.57	1.14	40.40	1.19

Table A-7 The efficiency in BOD removal of the conventional anaerobic digester under steady state

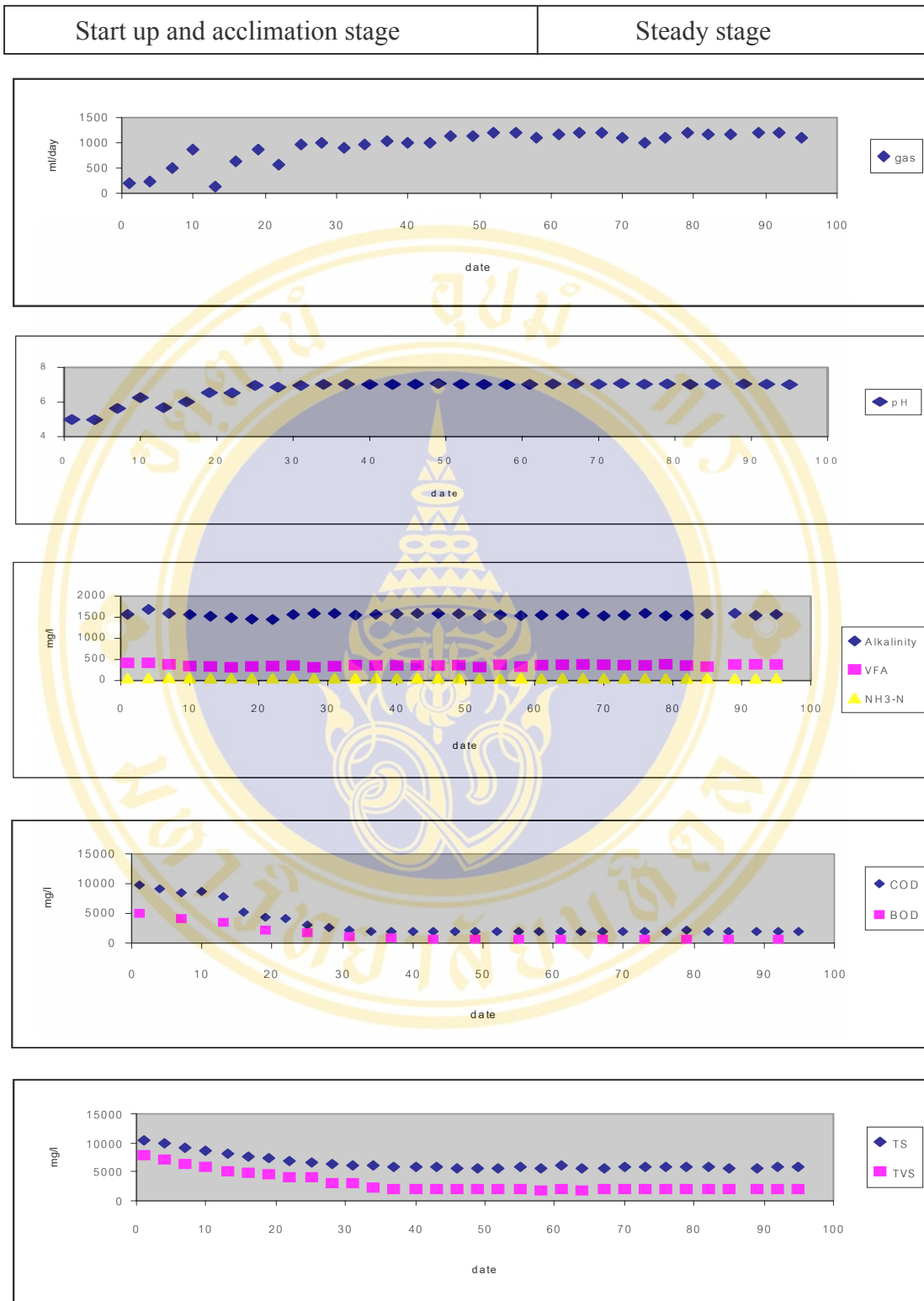
Date	Influent (mg/l)	HRT 20 days		HRT 25 days		HRT 30 days		HRT 35 days	
		Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)
1	5012	577	88.49	524	89.55	427	91.48	476	90.50
6	5489	598	89.11	537	90.22	414	92.46	462	91.58
12	5612	586	89.56	523	90.68	435	92.25	488	91.30
18	5839	588	89.93	525	91.01	423	92.76	485	91.69
24	5597	595	89.37	533	90.48	439	92.16	469	91.62
30	5397	579	89.27	544	89.92	425	92.13	480	91.11
36	5581	591	89.41	520	90.68	430	92.30	465	91.67
40	5742	590	89.72	536	90.67	421	92.67	472	91.78
Min.	5012	577	88.49	520	89.55	414	91.48	462	90.50
Max.	5839	598	89.93	544	91.01	439	92.76	488	91.78
Mean	5533	588	89.36	530	90.40	426	92.28	474	91.41
SD.	235.01	6.78	0.41	7.90	0.45	7.43	0.37	8.72	0.40

Table A-8 The efficiency in TS removal of the conventional anaerobic digester under steady state

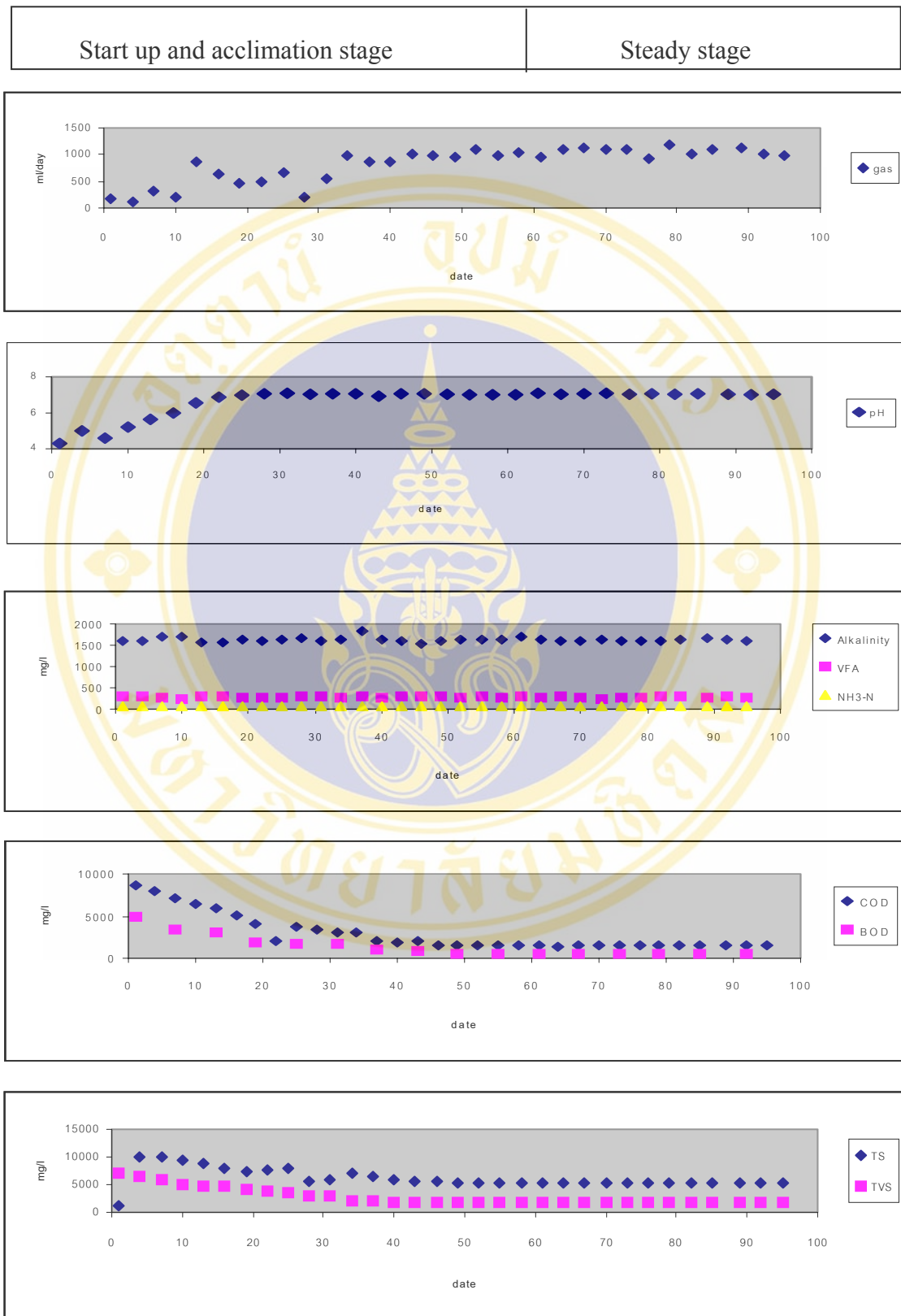
Date	Influent (mg/l)	HRT 20 days		HRT 25 days		HRT 30 days		HRT 35 days	
		Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)
1	13178	5698	56.76	5289	59.86	4779	63.74	5019	61.91
3	13996	5712	59.19	5387	61.51	4801	65.70	5123	63.40
6	14026	5890	58.01	5398	61.51	4877	65.23	5198	62.94
9	12373	5587	54.85	5204	57.94	4632	62.56	4971	59.82
12	15170	5985	60.55	5402	64.39	4905	67.67	5221	65.58
15	13148	5610	57.33	5245	60.11	4687	64.35	4987	62.07
18	16110	5719	64.50	5308	67.05	4908	69.53	4937	69.35
21	12171	5893	51.58	5297	56.48	4914	59.63	5186	57.39
24	14154	5737	59.47	5189	63.34	4839	65.81	5097	63.99
27	14987	5792	61.35	5203	65.28	4945	67.00	5199	65.31
30	13871	5907	57.41	5397	61.09	4897	64.70	5180	62.66
34	12975	5877	54.71	5369	58.62	4902	62.22	5112	60.60
36	13904	5533	60.21	5234	62.36	4987	64.13	5188	62.69
38	13888	5701	58.95	5196	62.59	4889	64.80	4913	64.62
40	14893	5783	61.17	5266	64.64	4781	67.90	5054	66.06
42	14738	5811	60.57	5414	63.27	4852	67.08	5107	65.35
Min.	12171	5533	51.58	5189	56.48	4632	59.63	4913	57.39
Max.	16110	5985	61.35	5414	67.05	4987	69.53	5221	69.35
Mean	13973	5764	58.54	5299	61.88	4849	65.13	5093	63.36
SD.	1019	122.50	3.02	81.10	2.74	90.78	2.38	98.49	2.72

Table A-9 The efficiency in TVS removal of the conventional anaerobic digester under steady state

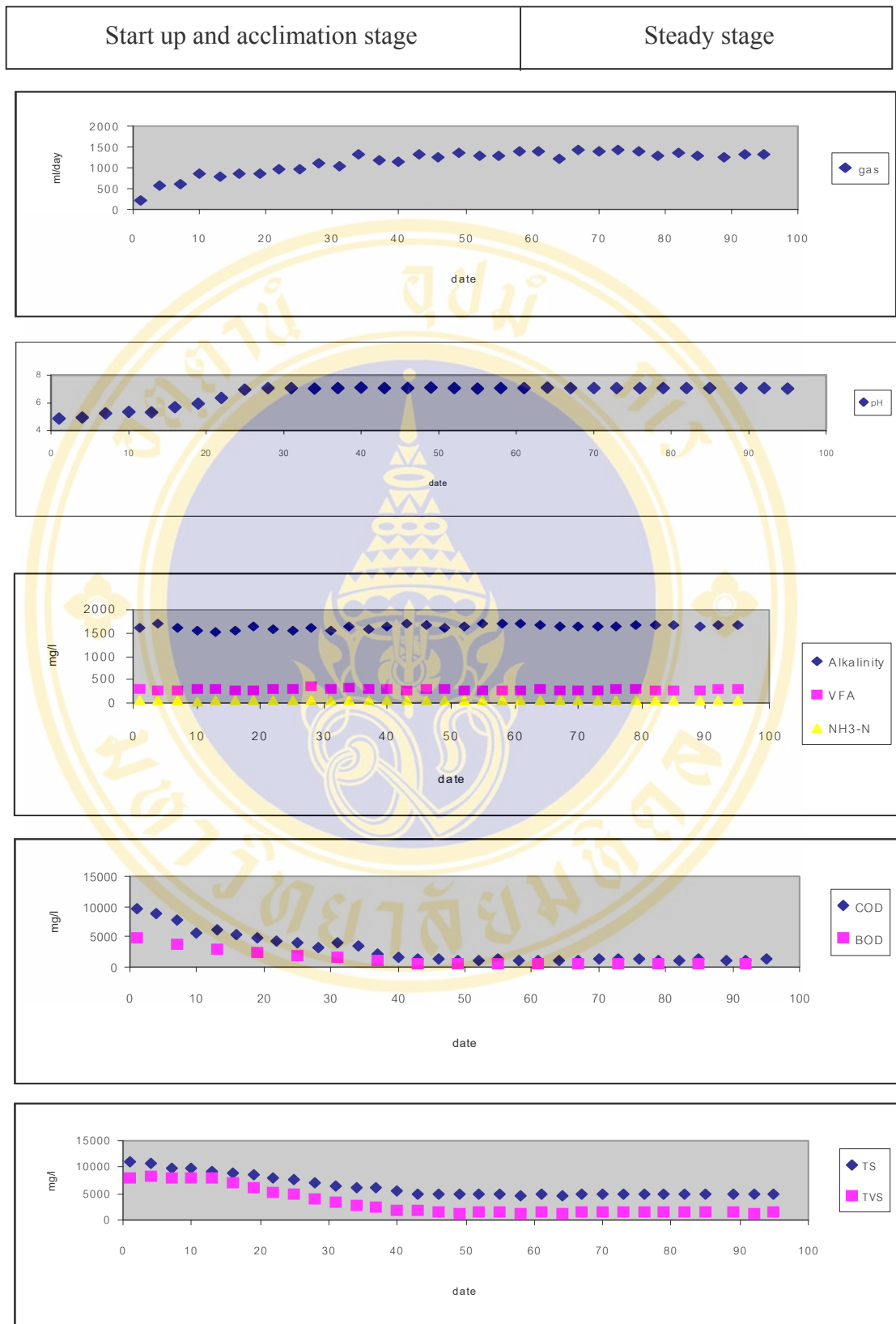
Date	Influent (mg/l)	HRT 20 days		HRT 25 days		HRT 30 days		HRT 35 days	
		Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)	Effluent (mg/l)	Removal Efficiency (%)
1	8164	1924	76.43	1729	78.82	1362	83.32	1428	82.51
3	8262	1965	76.22	1786	78.38	1387	83.21	1467	82.24
6	8476	2012	76.26	1805	78.70	1426	83.18	1489	82.43
9	8042	1879	76.64	1689	79.00	1324	83.54	1397	82.63
12	8963	2105	76.51	1846	79.40	1489	83.39	1524	83.00
15	7958	1899	76.14	1705	78.58	1346	83.09	1409	82.29
18	9017	1985	77.99	1737	80.74	1393	84.64	1471	83.69
21	8112	2039	74.86	1698	79.07	1408	82.64	1487	81.67
24	8397	1977	76.46	1688	79.90	1432	82.95	1491	82.24
27	8955	1954	78.18	1745	80.51	1389	84.49	1507	83.17
30	8297	1983	76.10	1807	78.22	1411	83.00	1512	81.78
34	8104	1974	75.64	1814	77.62	1395	82.79	1484	81.69
36	8388	2001	76.14	1713	79.58	1406	83.24	1519	81.89
38	8377	1960	76.60	1811	78.38	1447	82.73	1516	81.90
40	8490	1997	76.48	1762	79.25	1351	84.09	1483	82.53
42	8391	2096	75.02	1834	78.14	1419	83.09	1510	82.00
Min.	7958	1879	74.86	1688	77.62	1324	82.64	1397	81.67
Max.	9017	2105	78.18	1846	80.74	1489	84.64	1524	83.69
Mean	8399	1984	76.35	1760	79.02	1399	83.34	1480	82.35
SD.	316.20	58.78	0.83	52.63	0.83	39.76	0.57	37.54	0.55



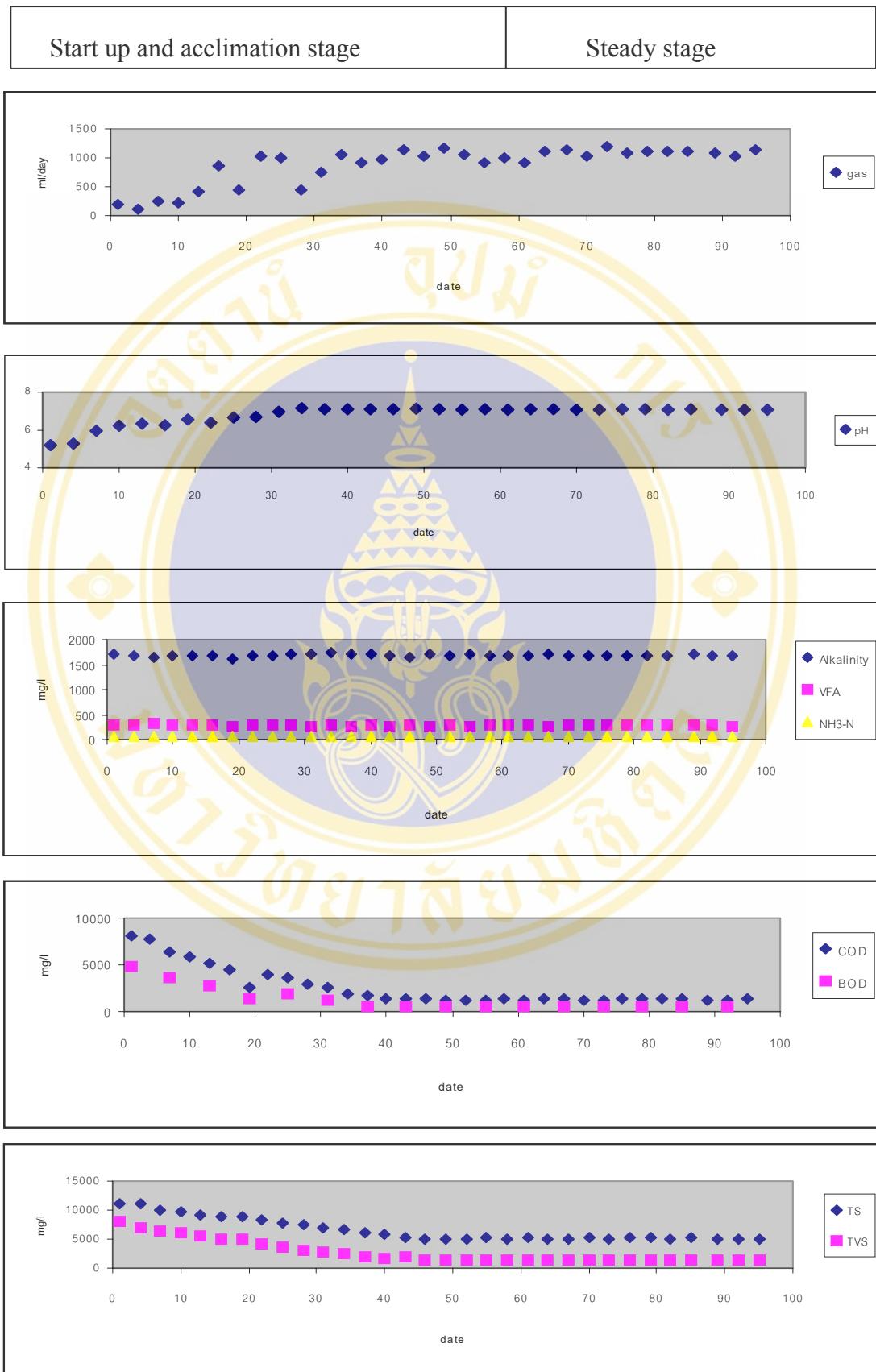
FigureA-1 Performance of the conventional digester with the HRT20 days.



FigureA-2 Performance of the conventional digester with the HRT25 days.



FigureA-3 Performance of the conventional digester with the HRT30 days.



FigureA-4 Performance of the conventional digester with the HRT35 days.

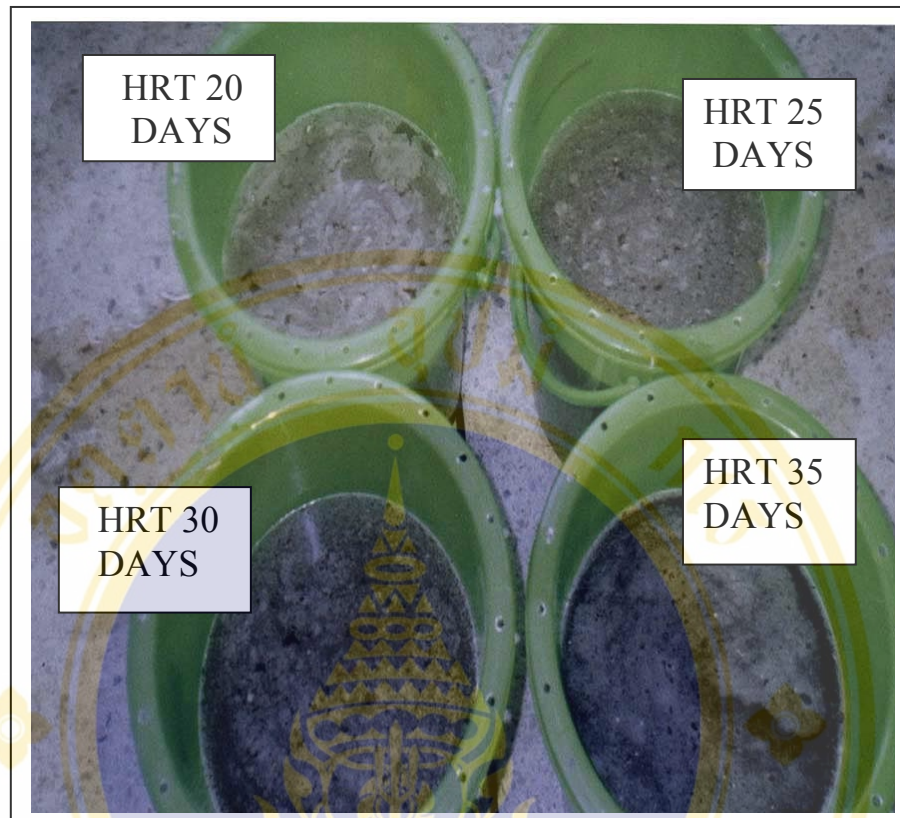


Figure A-5 Mixed slurry of the digesters performed with the HRT of 20, 25, and 30 and 35 days.



Figure A-6 Influent (wastewater) and settled slurry of the digesters performed with the HRT of 20, 25, 30 and 35 days.

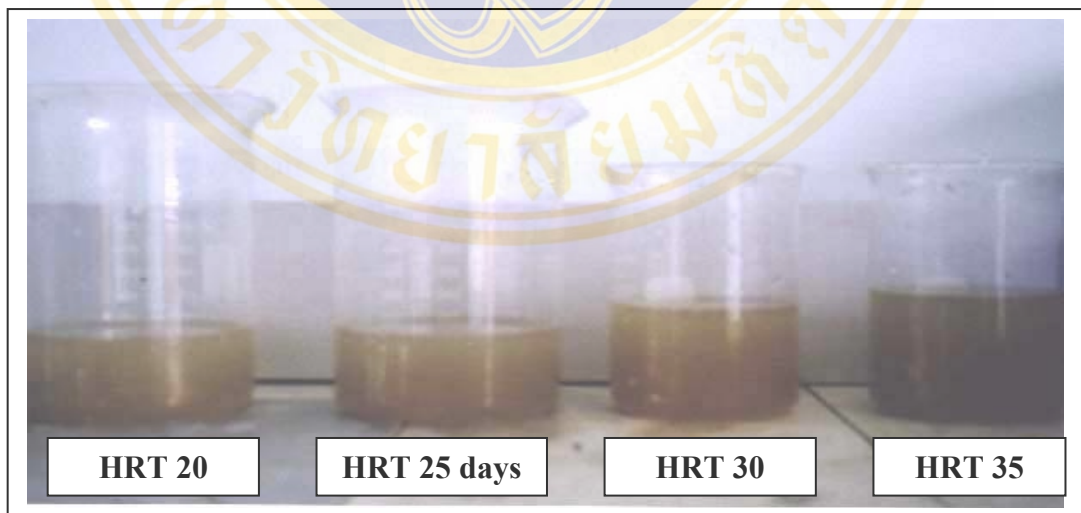


Figure A-7 Supernatant of settled slurry from the digesters performed with the HRT of 20, 25, 30 and 35 days.

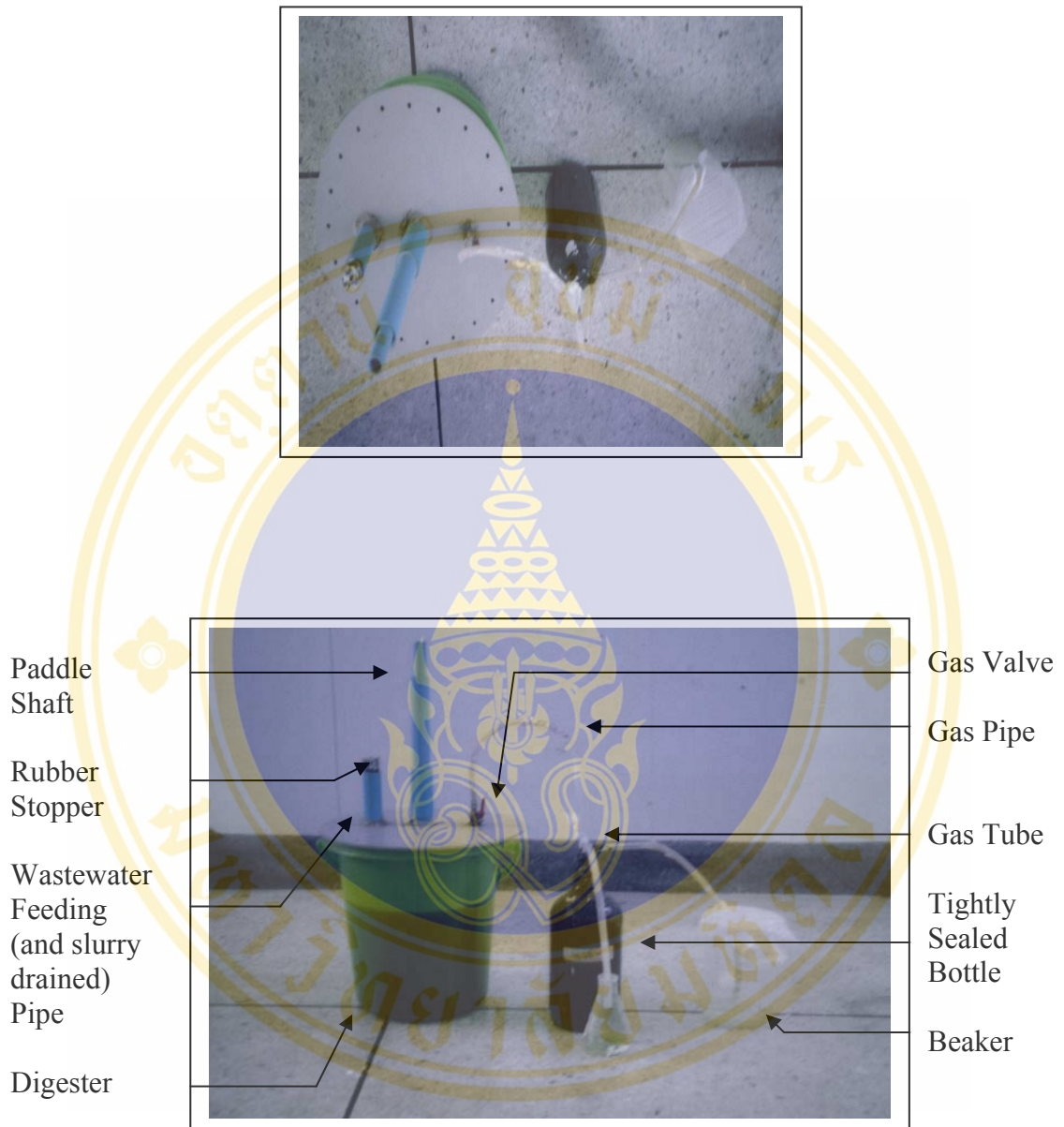


Figure B-1 Conventional anaerobic digester and gas measurement unit.



Figure B-2 Gas collection for determining methane and carbondioxide.

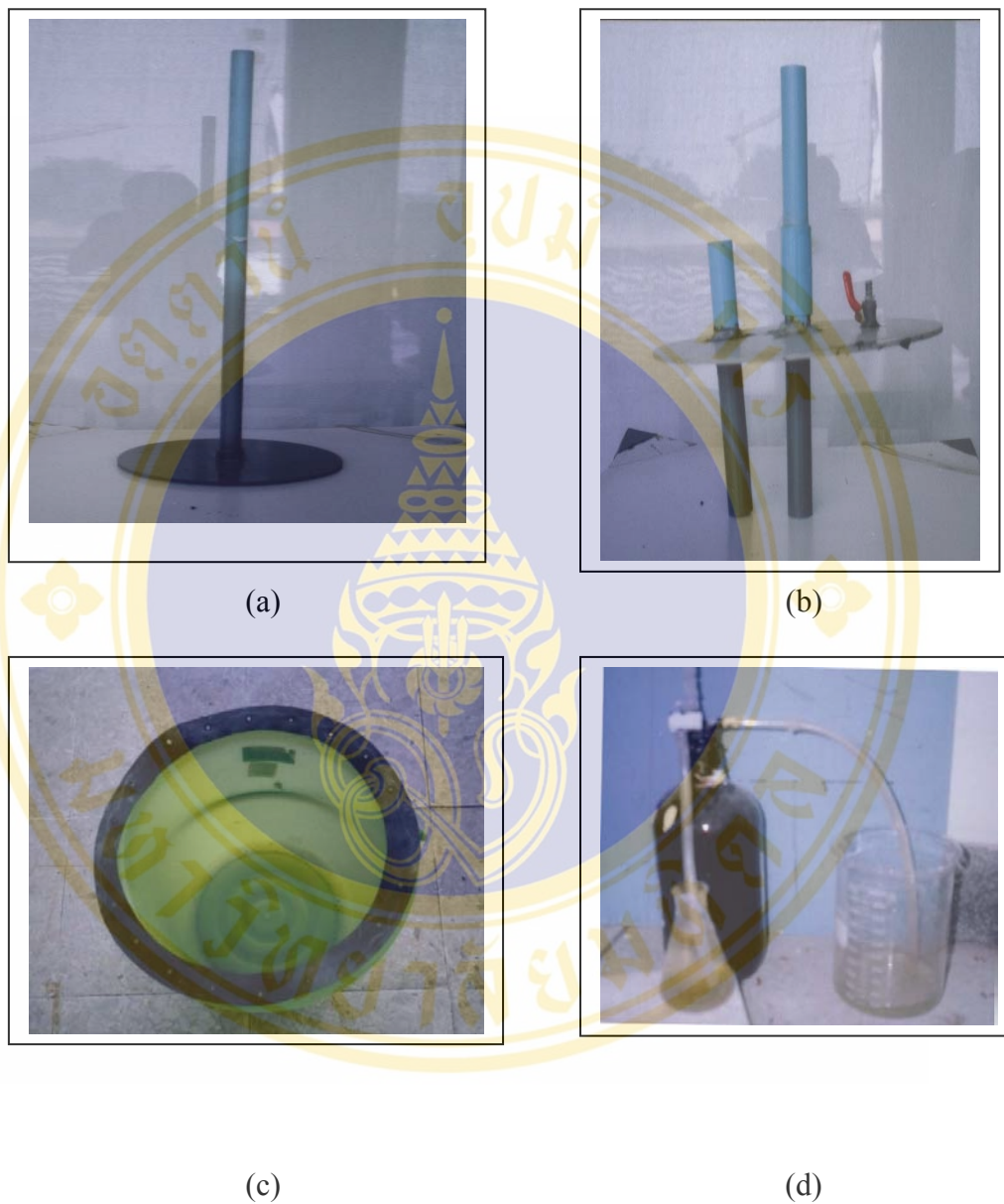


Figure B-3 The mixing paddle (a), the cover (b), the trapezoid plastic bucket (c) and Gas collecting and measurement unit (d).

COD

The difference efficiency in COD removal in each HRTs was showed as follow:

TABLE C-1 Descriptive Statistic in COD Removal efficiency (percentage).

COD

HRT	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
HRT20	83.0131	1.80964	.45241	82.0488	83.9774	79.39	85.81
HRT25	87.1731	1.36070	.34018	86.4481	87.8982	85.02	89.24
HRT30	89.7156	1.17455	.29364	89.0898	90.3415	87.77	91.62
HRT35	88.9137	1.22836	.30709	88.2592	89.5683	86.56	90.77
Total	87.2039	2.95188	.36898	86.4665	87.9413	79.39	91.62

From the table show that the HRT 30 day have the best efficiency in COD removal (89.72%).

TABLE C-2 Defference between group by using one-way Anova (Duncan) of COD removal efficiency.

Duncan

HRT	N	Subset for alpha = .05		
		1	2	3
HRT20	16	83.0131		
HRT25	16		87.1731	
HRT35	16			88.9137
HRT30	16			89.7156
Sig.		1.000	1.000	.114

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 16.000.

From the table show that the efficiency in COD removal between HRT 30 and HRT 35 day was not difference.

BOD

The difference efficiency in BOD removal in each HRTs was showed as follow:

TABLE C-3 Descriptive Statistic in BOD Removal efficiency (percentage).

BOD

	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
HRT20	89.3575	.43500	.15379	88.9938	89.7212	88.49	89.93
HRT25	90.4012	.47712	.16869	90.0024	90.8001	89.55	91.01
HRT30	92.2762	.39515	.13971	91.9459	92.6066	91.48	92.76
HRT35	91.4062	.42862	.15154	91.0479	91.7646	90.50	91.78
Total	90.8603	1.18422	.20934	90.4334	91.2873	88.49	92.76

From the table show that the HRT 30 day have the best efficiency in BOD removal (92.28%).

TABLE C-4 Defference between group by using one-way Anova (Duncan) of BOD removal efficiency.

Duncan

HRT	N	Subset for alpha = .05			
		1	2	3	4
HRT20	8	89.3575			
HRT25	8		90.4012		
HRT35	8			91.4062	
HRT30	8				92.2762
Sig.		1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 8.000.

From the table show that he efficiency in BOD removal was difference in each digester.

TS

The difference efficiency in TS removal in each HRTs was showed as follow:

TABLE C-5 Descriptive Statistic in TS Removal efficiency (percentage).

TS

HRT	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
HRT20	58.5381	3.11616	.77904	56.8776	60.1986	51.58	64.50
HRT25	61.8775	2.83346	.70836	60.3677	63.3873	56.48	67.05
HRT30	65.1281	2.45952	.61488	63.8175	66.4387	59.63	69.53
HRT35	63.3588	2.81092	.70273	61.8609	64.8566	57.39	69.35
Total	62.2256	3.67354	.45919	61.3080	63.1432	51.58	69.53

From the table show that the HRT 30 day have the best efficiency in TS removal (65.13%).

TABLE C-6 Defference between group by using one-way Anova (Duncan) of TS removal efficiency.

Duncan

HRT	N	Subset for alpha = .05		
		1	2	3
HRT20	16	58.5381		
HRT25	16		61.8775	
HRT35	16		63.3588	63.3588
HRT30	16			65.1281
Sig.		1.000	.142	.080

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 16.000.

From the table show that the efficiency in TS removal between HRT 25 and HRT 35 day, HRT 30 and HRT 35 day was not difference.

TVS

The difference efficiency in TVS removal in each HRTs was showed as follow:

TABLE C-7 Descriptive Statistic in TVS Removal efficiency (percentage).

TVS

HRT	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
HRT20	76.3544	.85302	.21325	75.8998	76.8089	74.86	78.18
HRT25	79.0181	.85620	.21405	78.5619	79.4744	77.62	80.74
HRT30	83.3369	.59034	.14759	83.0223	83.6514	82.64	84.64
HRT35	82.3538	.56688	.14172	82.0517	82.6558	81.67	83.69
Total	80.2658	2.87935	.35992	79.5465	80.9850	74.86	84.64

From the table show that the HRT 30 day have the best efficiency in TVS removal (83.34%).

TABLE C-8 Defference between group by using one-way Anova (Duncan) of TVS removal efficiency.

Duncan

HRT	N	Subset for alpha = .05			
		1	2	3	4
HRT20	16	76.3544			
HRT25	16		79.0181		
HRT35	16			82.3538	
HRT30	16				83.3369
Sig.		1.000	1.000	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 16.000.

From the table show that he efficiency in TVS removal was difference in each digester.

PERCENTAGE OF METHANE IN BIOGAS

The difference percentage of methane in each digester was showed as follow:

TABLE C-9 Descriptive Statistic in Percentage of Methane in Biogas.

PercentageMethane

HRT	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
HRT20	36.4320	3.82074	1.70869	31.6879	41.1761	31.48	41.84
HRT25	43.5080	3.15664	1.41169	39.5885	47.4275	40.08	47.20
HRT30	46.6380	3.93361	1.75916	41.7538	51.5222	42.55	52.09
HRT35	35.9160	3.23727	1.44775	31.8964	39.9356	32.03	39.69
Total	40.6235	5.72704	1.28061	37.9432	43.3038	31.48	52.09

From the table show that the HRT 30 day have the best percentage of methane gas (46.64%).

TABLE C-10 Defference between group by using one-way Anova (Duncan) of Percentage of Methane in Biogas.

Duncan

HRT	N	Subset for alpha = .05	
		1	2
HRT35	5	35.9160	
HRT20	5	36.4320	
HRT25	5		43.5080
HRT30	5		46.6380
Sig.		.821	.183

Means for groups in homogeneous subsets are displayed.

a Uses Harmonic Mean Sample Size = 5.000.

From the table show that the percentage of biogas between HRT 20 and HRT 35 day, HRT 25 and HRT 30 day was not difference.

Amount of Biogas

The difference of amount of biogas in each digester was showed as follow:

TABLE C-11 Descriptive Statistic in Amount of Biogas (liter/day).

AmountBiogas

	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
				Lower Bound	Upper Bound		
HRT20	1.14806	.055974	.013994	1.11824	1.17789	1.004	1.216
HRT25	1.05006	.076897	.019224	1.00909	1.09104	.932	1.196
HRT30	1.34150	.066187	.016547	1.30623	1.37677	1.221	1.446
HRT35	1.07437	.077836	.019459	1.03290	1.11585	.925	1.188
Total	1.15350	.133905	.016738	1.12005	1.18695	.925	1.446

From the table show that the HRT 30 day have the best amount of biogas (1.342 liter/day).

TABLE C-12 Difference between groups by using one-way ANOVA (Duncan) of Amount of Biogas.

Duncan

HRT	N	Subset for alpha = .05		
		1	2	3
HRT25	16	1.05006		
HRT35	16	1.07437		
HRT20	16		1.14806	
HRT30	16			1.34150
Sig.		.328	1.000	1.000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 16.000.

From the table show that the amount of biogas between HRT 25 and HRT 35 day was not difference.

BIOGRAPHY



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