การพัฒนากระบวนการเวียนน้ำชะขยะอย่างเหมาะสมในระบบการย่อยสลายขยะอินทรีย์แบบไร้อากาศ

นาย พิพัฒน์ ธีระจักร

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
สาขาวิชาการจัดการสิ่งแวดล้อม (สหสาขาวิชา)
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2553

DEVELOPMENT OF SUITABLE LEACHATE RECIRCULATION PROCESS FOR

ANAEROBIC ORGANIC WASTE STABILIZATION

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A Dissertation Submitted in Partial Fulfillment of the Requirements

for the Degree of Doctor of Philosophy Program in Environmental Management

(Interdisciplinary Program)

Graduate School

Chulalongkorn University

Academic Year 2010

Thesis Title	Development of Suitable Leachate Recirculation Process for Anaerobic Organic Waste Stabilization
By	Mr. Pipat Teerachark
Field of Study	Environmental Management
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พิพัฒน์ ธีระจักร: การพัฒนากระบวนการเวียนน้ำชะขยะอย่างเหมาะสมในระบบการย่อยสลายขยะอินทรีย์แบบไร้อากาศ (DEVELOPMENT OF SUITABLE LEACHATE RECIRCULATION PROCESS FOR ANAEROBIC ORGANIC WASTE STABILIZATION) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. พิชญ รัชฎาวงศ์, 117 หน้า.

ปัจจุบันการศึกษากระบวนการพัฒนาการเวียนน้ำชะขยะอย่างเหมาะสมในระบบการย่อยสลายขยะอินทรีย์แบบไร้อากาศนั้นค่อนข้างจำกัด เนื่องจากการศึกษาที่ผ่านมาโดยส่วนมากจะควบคุมที่ค่าสิ่งแวดล้อมของระบบเช่นค่าพีเอชและสารอาหารซึ่งไม่เพียงพอต่อการทำให้ระบบมีประสิทธิภาพสูงสุด การเวียนน้ำชะขยะที่มากเกินไปหรือน้อยเกินไปจึงมักจะเกิดขึ้นบ่อยครั้ง

วัตถุประสงค์ของงานวิจัยนี้คือการพัฒนาการเวียนน้ำชะขยะอย่างเหมาะสมเพื่อให้ความสามารถในการย่อยสลายขยะอินทรีย์แบบไร้อากาศมีประสิทธิภาพสูงสุด, การหาความสัมพันธ์ระหว่างการเวียนน้ำชะขยะกับก๊าซมีเธนที่เกิดขึ้น และการหาระยะเวลาในการเข้าสู่ช่วงที่ระบบมีการย่อยสลายและผลิตก๊าซมีเธน

ถังหมักแบบไร้อากาศจำลอง 4 ใบถูกสร้างขึ้นสำหรับย่อยสลายขยะอินทรีย์ โดยทำการเวียนน้ำชะขยะต่างๆกันตามปริมาณภาระบรรทุกของกรดอินทรีย์ระเหยง่ายรายวัน เพื่อที่จะหาปริมาณที่เหมาะสมที่จะเร่งการย่อยสลายขยะอินทรีย์สูงสุด ค่าวิเคราะห์ทางสิ่งแวดล้อม ได้แก่ ปริมาณภาระบรรทุกของกรดอินทรีย์ระเหยง่าย, ความเข้มข้นของกรดอินทรีย์ระเหยง่ายในน้ำชะขยะ, ซีโอดี, อุณหภูมิ, ค่าความเป็นกรด-ด่าง, โออาร์พี, ความเป็นด่าง, สารอาหารในน้ำชะขยะ และก๊าซมีเทนที่เกิดขึ้น ถูกนำมาวิเคราะห์เพื่อแสดงสถานะของการย่อยสลายของขยะอินทรีย์ จากนั้นทำการวิเคราะห์หาความสัมพันธ์ของปริมาณภาระบรรทุกของกรดอินทรีย์ระเหยง่ายจากการเวียนน้ำชะขยะ กับปริมาณก๊าซมีเทนที่เกิดขึ้น

ปริมาณก๊าซชีวภาพและก๊าซมีเทนที่เกิดขึ้นสูงสุดจากการเวียนน้ำชะขยะรายวัน 9,800 มิลลิกรัมของกรดอินทรีย์ระเหยง่ายต่อวัน ปริมาณก๊าซมีเทนหลังจาก 160 วัน เท่ากับ 7,267 มิลลิลิตร, 9,046 มิลลิลิตร, 10,712 มิลลิลิตร และ 11,170 มิลลิลิตร ในถังหมักที่ 1, 2, 3 และ 4 ตามลำดับ การย่อยสลายขยะอินทรีย์ที่เร็วกว่าและปริมาณก๊าซมีเทนที่มากกว่าแปรตามปริมาณการเวียนกรดอินทรีย์ระเหยง่ายเข้าสู่ระบบ

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต Pipat T.

ปีการศึกษา 2553 ลายมือชื่ออ.ที่ปรึกษาวิทยานิพนธ์หลัก Pichaya R.

4989713520: MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS: ANAEROBIC/MODEL/DEGRADATION/STABILIZATION

PIPAT TEERACHARK: DEVELOPMENT OF SUITABLE LEACHATE RECIRCULATION PROCESS FOR ANAEROBIC ORGANIC WASTE STABILIZATION. ADVISOR: ASST.PROF. PICHAYA RACHADAWONG, Ph.D., 117 PP.

At present, only a few researches on leachate recirculation to enhance organic waste stabilization with biogas maximization were found. Attempts to enhance the system were by controlling environmental factors such as pH and nutrients that were not adequate for organic waste stabilization enhancement. Moreover, previous works of leachate recirculation development were only the guidelines to be employed with a lot of uncertainty since all of those guidelines did not concern to the degradable phase and food input through leachate recirculation so that the overloading or lower loading employment often occurred in anaerobic organic waste degradation system.

The purpose of this research was to define the optimum degradation from various leachate VFA loading input, to study the relationship between daily VFA loading input and daily methane production output on anaerobic organic waste degradation, and to define duration to reach optimum anaerobic organic waste degradation period from VFA loading input development.

The experiment was set as 4 bioreactors capable of running organic waste degradation. In addition, these bioreactors accepted VFA loading input to specify suitable VFA loading input for optimizing anaerobic organic waste degradation. Moreover, daily VFA loading input, leachate VFA concentration, COD, temperature, pH, ORP, alkalinity, nutrients and methane gas output were analyzed to define essential criteria on anaerobic organic waste degradation system. Finally, the result from the experiment was used to develop the correlation model between daily VFA loading input and methane gas output.

The result showed that the methane gas production was the highest for the daily 9,800 mg VFA loading input as indicated from the cumulative gas were 7,267 ml, 9,046 ml, 10,712 ml and 11,170 ml in reactor 1, 2, 3 and 4 with 1,225 mg, 2450 mg, 4,900 mg and 9,800 mg daily volatile fatty acids loading, respectively. The faster anaerobic stabilization during acid phase contributed to higher methane production could be occurred with the attempt of high leachate volatile fatty acid loading bioreactor.

Field of Study: Environmental Management — Student's Signature..Pipat T.

Academic Year: 2010 — Advisor's Signature..Pichaya R.

ACKNOWLEDGEMENTS

I would like to express my sincerely thank to Assistant Professor Dr. Pichaya Rachdawong, my advisor, for his valuable suggestions, assistance, guidance and strong encouragement throughout this research. I would like to take this opportunity to thank Assistant Professor Dr. Manaskorn Rachakornkij, Chairman of the committee, Professor Dr. Chongrak Polprasert, Assistant Professor Dr. Wiboonluk Pungrasmi, Dr. Tawan Limpiyakorn and Dr.Pichet Chaiwiwatworakul, members of thesis committee for valuable suggestions.

I also extend my sincere appreciation to the staffs and officers from National Research Center for Environmental and Hazardous Waste Management, Chulalongkorn University, for their companionship and their helps.

Special thanks are also made to all of students and staffs of International Postgraduate Programs in NCE-EHWM, Center of Excellence for Environmental and Hazardous Waste Management, Mr.Chaiwat, Mr.Jenwit, Mr. Noppasit and Mr. Litthikorn for their valuable suggestions and their assistance.

Most of all, I would like to gratitude thanks to my parents, my brother and my nephews for their love and inspiration throughout my thesis.

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LIST OF ABBREVIATIONS

MSW	=	Municipal Solid Waste
TDS	=	Total Dissolved Solid
RNA	=	Ribonucleic Acid
COD	=	Chemical Oxygen Demand
P	=	Phosphorous
N	=	Nitrogen
VOA	=	Volatile Organic Acids
ORP	=	Oxidation Reduction Potential
NH_3-N	=	Ammonia Nitrogen
Org-N	=	Organic Nitrogen
VOCs	=	Volatile Organic Compounds
BOD	=	Biological Oxygen Demand
PCD	=	Pollution Control Department
BMA	=	Bangkok Metropolitan Administration
VFA	=	Volatile Fatty Acid
CH4	=	Methane Gas
ORP	=	Oxidation Reduction Potential

CHAPTER I
INTRODUCTION

1.1 General

At present, municipal solid waste is one of the most serious problems in Thailand since large amount of waste generation due to rapid growing in population. Pollution Control Department (PCD) also reported that there was about 22 million tons of solid waste generated annually (Jaijongrak, 2003). Consequently, the appropriateness of waste management should be applied in order to deal with those problems. Landfills are the most widely used method of solid waste disposal in Thailand. This is primarily due to its ability to be designed, installed and operated at lower costs than other solid waste management alternatives. Moreover, Landfilling can deal with large amount of waste loading as the cheapest technique when comparing with other solid waste management. In addition, as the concern of energy shortage, landfilling can play a role as alternative fuel by the converting of organic into biogas. However, landfill has its own problems and is being developed to overcome problems such as leachate, gas emission, odor, etc. Production of leachate has led to many documented cases of groundwater and surface water pollution. Landfill gas emission can lead to malodorous circumstances, adverse health effects, explosive conditions, and global warming. Traffic, dust, animal and insert vectors of disease and noise often are objectionable to neighbors.

Under, the global warming and the depletion of resources concern, many attempts of renewable energy are made to substitute natural resources and fossil fuel utilization. Biogas is considered as one of the favorable technique to be used in Thailand since it could both reduce cost from waste treatment and capture methane gas to further utilize in generator and burner system. In addition, by-products from biogas fermentation could be used as plant fertilizer, as well.

Many communities, industries and animal farms are interested to settle the biogas project since most of their waste generated is very easy to be degraded by anaerobic fermentation to volatile fatty acid which is the substrate for methane generation output. Moreover, the investment cost is not too expensive when comparing to the benefit output from lower waste disposal cost and their energy consumption payment. Furthermore, Thai government under the department of energy ministry also takes incentives to communities, schools and industrial owners who implement biogas project by approximately 40-70% fund providing to them. Figure 1.1 described the biogas project from anaerobic organic waste degradation in one of Thailand industry. This project use fruit and vegetable waste input to be fermented for methane gas being utilized instead of LPG in canteen. Table 1.1 explained the detail of project investment and its benefit. It could be concluded that this project is so interesting since it spends only one and half year payback period. As the above details indicated, biogas production from waste is very beneficial to owner, government and world environment.

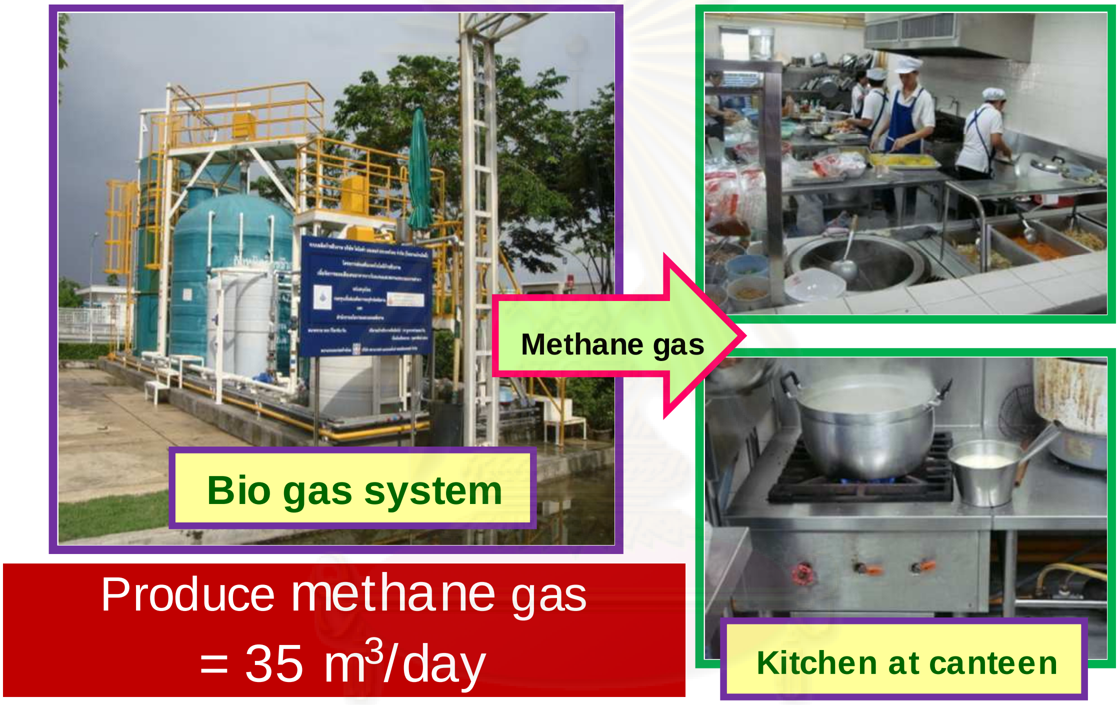

Figure 1.1 Biogas project from one of Thailand industry

However, there are many problems after biogas project implementation due to the lack of knowledge or unsuitable operation that causes biogas system failure. Low methane content, acid accumulation and long fermentation period are the examples from incorrect management. Hence, appropriate biogas operation must be studied and employed in order to avoid all of those related problems.

At present, only a few researches on leachate recirculation to enhance organic waste stabilization with biogas maximization were found. Attempts to enhance the system were by controlling environmental factors such as pH and nutrients that were not adequate for organic waste stabilization enhancement. Moreover, previous works of leachate recirculation development were only the guidelines to be employed with a lot of uncertainty since all of those guidelines did not concern to the degradable phase and food input through leachate recirculation so that the overloading or lower loading employment often occurred in anaerobic organic waste degradation system.

The development and the improvement of high performance bioreactors have been performed. However, several problems are to be handled: slow methanogenic organism growth, instability caused by toxic substrate or by overloading, even though large progress has been made, bad understanding of the process. It is thus largely recognized that control of anaerobic digestion processes is a mandatory step because of the possible destabilization of the process due to disturbance such as overloading or accidental toxic feeding. As depicted before, one of the key issues to be addressed in controlling anaerobic stabilization is to reject the disturbances that can destabilize the reactor. Hence, this study purpose is to develop the optimized anaerobic organic waste degradation by the attempt of various leachate volatile fatty acids loading through daily leachate recirculation employment.

1.2 Objectives:

1. To define the optimum anaerobic organic waste degradation from various leachate VFA loading input.
2. To study the relationship between daily VFA loading input and daily methane production output on anaerobic organic waste degradation.
3. To define duration to reach optimum anaerobic organic waste degradation period from VFA loading input development.

1.3 Scopes of study

1. Setting up 4 anaerobic organic waste bioreactors
2. Synthetic organic waste consists of fruits and vegetables waste is loaded to each reactor to assure accelerated stabilization and to establish the identity and maximize the homogeneity of the refuse

3. Various leachate recycle is daily employed as volatile fatty acid loading to compare the impacts of each scheme on stabilization rate and gas production under acid phase condition as

    3.1 Daily volatile fatty acid loading of 1,225 mg as the control bioreactor based on Jaijongrak study

    3.2 Daily volatile fatty acid loading of 2,450 mg (Twice as much as control bioreactor)

    3.3 Daily volatile fatty acid loading of 4,900 mg (Four times from control bioreactor)

    3.4 Daily volatile fatty acid loading of 9,800 mg (Eight times from control bioreactor)

4. Leachate recycle is employed to all reactors based on daily methane volume under methane phase generation since this technique is more suitable than fix loading (based on Rachdawong, 1994 and Jaijongrak, 2003 study)
5. The change of leachate recycle phase is reflected by number of parameters for instance; methane volume, leachate pH and leachate ORP.

CHAPTER II
LITERATURE REVIEWS

2.1 Principles of Decomposition in landfill

Solid wastes deposited in landfills decompose by a combination of chemical, physical, and biological processes. The decomposition produces solid, liquid, and gaseous byproducts, all of which may be of concern in the overall management of a landfill. The biological processes acting on the organic materials within the refuse commence soon after refuse placement. However, interdependencies among the three processes require that chemical and physical processes also be considered along with biological processes.

Physical decomposition of solid waste results from the breakdown or movement of the refuse components by physical degradation and by the rinsing and flushing action of water movement. Upon reaching field capacity (the moisture level beyond which any increases in moisture will drain by gravity), flow of dislodged refuse particles occurs as a result of pressure gradients, and diffusion as a result of concentration gradients. As the moisture level of the refuse increases, additional refuse particles are dislodged (Chain and DeWalle, 1997).

Chemical processes resulting in refuse decomposition include the hydrolysis, dissolution/precipitation, sorption/desorption, and ion exchange of refuse components. Chemical decomposition generally results in altered characteristics and greater mobility of refuse components, thereby enhancing the rate at which the landfill becomes more chemically uniform (Chain and DeWalle, 1997).

Although both physical and chemical decomposition of refuse materials are important in landfill stabilization, biological decomposition is the most important process. Specifically, biological decomposition is the only process that produces methane gas (Chain and DeWalle, 1997).

Biological decomposition occurs with naturally present bacteria. It is a complex process within landfill sites, consisting of various biologically mediated sequential and parallel pathways by which refuse is decomposed to various end products.

The products of the physico-chemical and biological and biological decomposition processes are depicted on Figure 2.1.

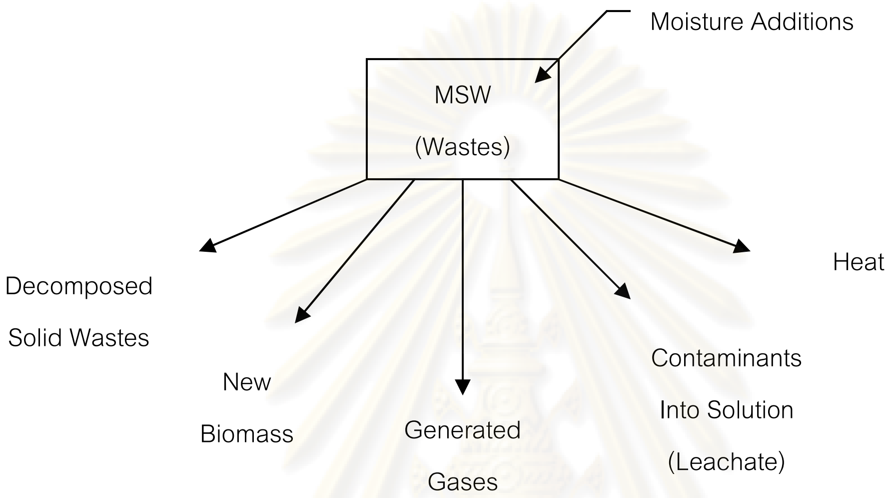

Figure 2.1 Byproducts of solid waste decomposition (Chain and DeWalle, 1997)

2.2 Landfill as a biochemical reactor

As a result of combination of processes referred to in Section 2.2, landfill is a form of biochemical reactor, similar to an anaerobic digester in a wastewater treatment plant. Of course, there are potentially important limitations on the degree to which the landfill contents are mixed. The result is variabilities in such features as moisture, refuse age, and composition in various locations within the refuse. Thus, knowledge of moisture content, leachate characteristics, and migration of the gas within refuse are essential to understanding the rate and current status of the decomposition processes.

Biological decomposition takes place in three stages, each of which has its own environmental and substrate requirements that result in characteristic end products (Chain and DeWalle, 1997).

Aerobic Decomposition

Aerobic processes require the presence of oxygen. Thus, aerobic decomposition occurs on initial placement of the refuse, while oxygen is still available. Aerobic decomposition may continue to occur on, and just below, the surface of the fill, as well. However, because of the finite amount of available oxygen buried within the refuse and the limitations on air transport into the fill, aerobic decomposition is responsible for only a small portion of the biological decomposition within the refuse.

During this first stage of decomposition, aerobic microorganisms degrade organic materials to carbon dioxide, water, partially degraded residual organics, and considerable heat. Aerobic decomposition is characteristically rapid, relative to subsequent anaerobic decomposition, and the oxygen demand of this refuse is high. A general relation for this decomposition is

Degradable waste +oxygen $\rightarrow$ CO_2 + H_2O+ biomass+heat + partially degraded materials

Acid-Phase Anaerobic Decomposition (Nonmethanogenic)

The second stage of refuse decomposition involves facultative microorganisms that become dominant as the oxygen is depleted. These microorganisms continue the decomposition processes. In this, the acid or acetogenic phase, high concentrations of organic acids, ammonia, hydrogen, and carbon dioxide are produced. Acid fermentation prevails, with characteristic end products being high levels of carbon dioxide, partially degraded organics (especially organic acids) and some heat, as described by the following equation:

Degradable waste $\rightarrow$ CO_2 + H_2O+ organism growth+ partially degraded organics

The production of carbon dioxide (high partial pressure) and large amounts of organics acids result in the lowering of the pH of the leachate to the range of 5.5 to 6.5, which in turn causes the dissolution of other organics and inorganics. The result is a chemically aggressive leachate with high specific conductance.

Anaerobic Decomposition (Methanogenic)

As the biodegradation of the refuse progresses, the oxygen becomes depleted, the redox potential is reduced, and the third stage of refuse decomposition involving the anaerobic methanogenic bacteria become dominant. These organisms produce carbon dioxide, methane, and water, along with some heat. Characteristically, these organisms work relatively slowly but efficiently over many years to decompose remaining organics.

The methanogenic bacteria utilize the products of the anaerobic acid stage, for example, hydrogen,

$$4H_2O + CO_2 \rightarrow CH_4 + H_2O$$

and acetic acid,

$$CH_3COOH \rightarrow CH_4 + CO_2$$

Consumption of the organic acids raises the pH of the leachate to the range of 7 to 8. Consequently, the leachate becomes less aggressive chemically and possesses a lower total organic strength. Organic acids that cannot be used directly by bacteria are converted to methane by an intermediate step. Volatile fatty acids act as a substrate for methanogenic bacteria, but high concentrations inhibit the establishment of a methanogenic community and at very high concentrations are toxic.

The methane bacteria that function in the methanogenic stage obtain energy from two reactions: (1) the reduction of CO_2 through the addition of H_2 to form CH_4 and H_2O and (2) the cleavage of the CH_3 COOH into CH_4 and CO_2. Although energy is captured by the microorganisms during this stage, very little synthesis of new cell material occurs (McCarty, 1963).

The time required for the methanogenic stage to commence may be from six months to several years after placement. The shorter time period is associated with situations of higher water content and flow rate. It is not worthy; however, that instability in the system or rapid variations in water movement may inhibit the methanogenic bacteria.

During the methanogenic phase, leachate characteristically has a near-neutral pH, low volatile fatty acid content and low total dissolved solids (TDS). Small portions of the organic refuse, the ligand-type aromatic compounds, are slow to degrade anaerobically. These compounds are important factors in adsorption and complexation (Lu et al., 1984).

The methanogenic stage does not mark the end of hydrolysis and fermentation that occurs in the acetogenic stage. These steps continue, but the methanogenic bacteria population grows to a level at which the bacterial rate of consumption of the acetic stage end products approaches the rate of production.

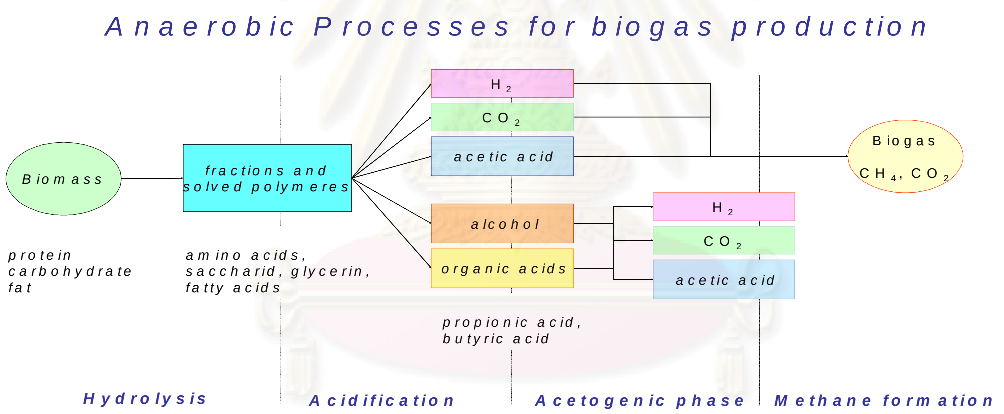

Figure 2.2 Anaerobic processes in landfill body (Stegmann, 1995)

2.3 Phases of Landfill Stabilization

Most landfills proceed through a series of rather predictable events which are influenced by climatological conditions, operation variables, management options and control factors operative in the landfill environment (Pohland et al., 1983). These events can be observed by monitoring certain leachate and gas parameters which serve to describe the following phases of stabilization:

Phase I: Initial Adjustment

This period prevails from initial waste placement through the closure of the landfill segment and to the time when environmental parameters first reflect the onset of stabilization processes. Incipient aerobic decomposition consumes oxygen and produces carbon dioxide.

Phase II: Transition

During this period, field capacity is exceeded and regular leaching begins. The oxygen entering the landfill with the waste is depleted and a transition from aerobic to anoxic and anaerobic conditions occurs. During this transition, the primary electron acceptor shifts from oxygen to nitrate and sulfate and then to carbon dioxide. Reducing conditions are established and intermediates such as volatile organic acids first appear in abundance.

Phase III: Acid Formation

The third phase is the period when significant amounts of volatile organic acids are produced by the continuing hydrolysis and fermentation of waste and leachate constituents. The accumulation of high quantities of volatile acids results in pH depression. Mobilization and complexation are found to be the principal mechanisms for increasing concentrations of heavy metal species in the leachate. Essential nutrients, nitrogen and phosphorus are released from waste and utilized at a rate commensurate with biomass development. Hydrogen gas is also produced and influences microbial metabolism and the types of intermediary products being form (Chian and DeWalle, 1976).

Phase IV: Methane Fermentation

During this period, the intermediate products are converted to methane and excess carbon dioxide by the methane forming organisms. The pH of leachate increases to neutral as the volatile organic acids are converted principally to methane and carbon dioxide, and carbonate-bicarbonate buffer system is again re-established. Oxidation-reduction potentials in the Methane Fermentation phase are highly negative and are indicative of highly reducing condition (Stratakis, 1991). Removal of heavy metals from leachate by precipitation and complexation with sulfide and carbonate anions proceeds. Excess sulfates and nitrates are reduced to sulfides and ammonia (Pohland, 1975). Leachate organic strength, as measured by chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), and total organic carbon (TOC), drastically decreases as a result of volatile acids consumption. The methane percentages, as well as the rate of gas production are at their highest during this period.

Phase V: Final Maturation

This period follows active biological stabilization of the readily available organics in the waste and leachate. Nutrients may become limiting, measurable gas production creases, oxidation-reduction potential may slowly rise as more oxidizing conditions are reestablished, and the more resistant organics may slowly degrade and influence mobility of other species.

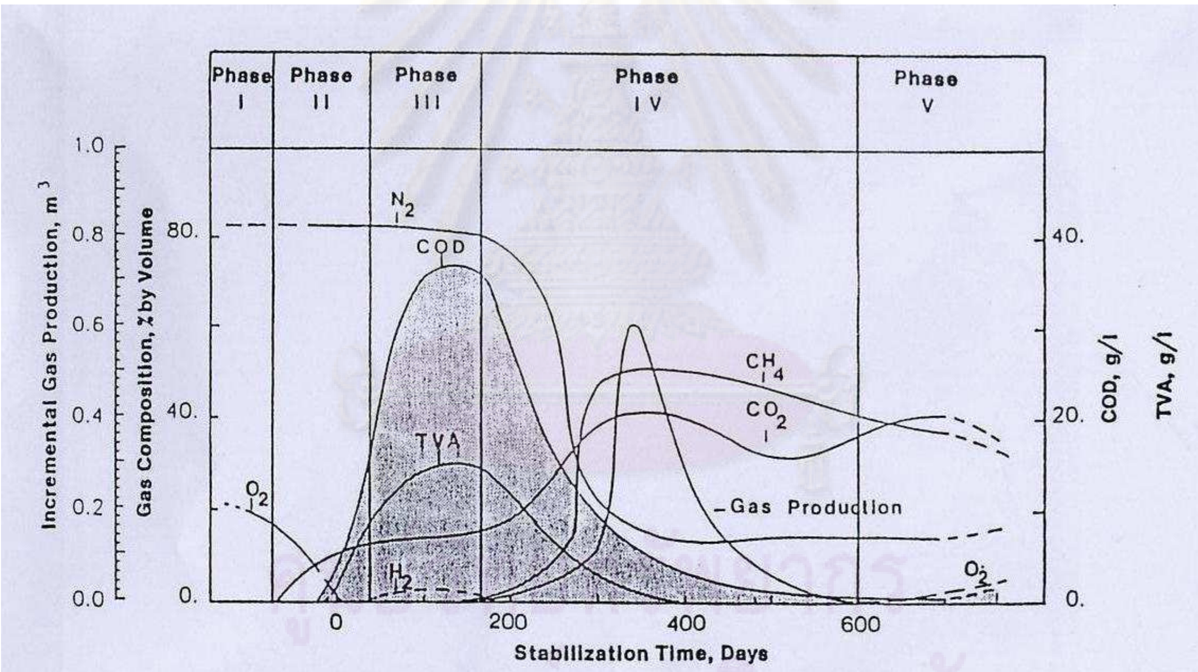

Figure 2.3 Five phases of landfill stabilization. (Pohland and Harper, 1986)

2.4 Factors Affecting Landfill Stabilization

Microbially-mediated waste stabilization in landfills, as in separate anaerobic digestion processes, is affected by a number of factors such as pH, temperature, availability of nutrients, the presence of inhibitory substances, moisture content, and preprocessing techniques. The effects that such variables have on stabilization processes usually manifest themselves in terms of leachate and gas characteristics throughout the active life of the landfill.

pH, a measurement of hydrogen ion concentration, is a crucial parameter in anaerobic waste conversion. The normal operational range is 6.5 to 7.6, with an optimum pH between 7.0-7.2 (Perkin and Owen, 1982; McCarty, 1964). The pH of an anaerobic system is a function of both volatile organic acids and alkalinity concentrations, as well as the partial pressure of carbon dioxide evolved during stabilization (McCarty and Smith, 1986). During the Acid Formation phase, the carbonate-bicarbonate alkalinity buffer system is displaced by the volatile acid buffer system, resulting in a reduction in pH (Stratakis, 1991). This reduction to low pH does not only affect the rates of hydrolysis, liquefaction, and gas production, but also encourages mobilization of heavy metals which may be capable of inhibiting the overall conversion process (Pohland et al., 1983).

Temperature, anaerobic processes usually function in either mesophilic (30 to 38 °C) or thermophilic (50 to 60 °C) temperature ranges (Kotze, et al., 1969). Ham and coworkers (1983) studied the rate of methane generation from solid waste within the temperature range of 21 to 48°C and indicated that the optimum range was 41°C. The optimum temperature ranges for mesophilic anaerobic digestion reported by McCarty is 30-32°C (Torien, et al., 1967). Parkin and Owen (1982) recommended that a temperature as close to 35°C as possible be maintained during anaerobic process start-up and recovery from upset. Regardless of operational temperatures chosen, consistency of temperature is considered to be important for maximizing stabilization process performance. Nevertheless, temperature fluctuation in landfills is expected, since landfill temperature is not regulated and usually exhibits the influence of atmospheric temperature and insulation provided by surrounding cells as well as cover layers.

Adequate supplies of nutrients, macronutrient, nitrogen and phosphorus, are needed in larger amounts, whereas micronutrients such as iron, nickel, cobalt, sulfur, calcium, molybdenum, tungsten, selenium, and some organics are required in minute quantities for bacterial cell maintenance and synthesis (Chian and DeWalle, 1977). Nitrogen is needed for the production of protein, enzyme, ribonucleic acid (RNA), and deoxyribonucleic acid (DNA). Phosphorus is used to synthesize energy-storage compounds (adenosine triphosphate-

ATP) as well as RNA and DNA. Chian and DeWalle concluded that the upper limits of leachate COD: P and COD: N was 4,360: 1 and 39:1, respectively. However, a COD:P ratio of 2,200:1 was determined sufficient for anaerobic digestion of fatty acids by McCarty and Speece (1963).

The presence of inhibitory substances is another concern. Conditions such as accumulation of volatile organic acids, high concentrations of ammonia nitrogen, sulfide, and heavy metals, or the presence of toxic substances are common causes of failure in many anaerobic digester operations. The extent of toxicity of each substance is associated with concentrations and forms, contact time, as well as acclimation ability of microbial consortia.

Ammonia is normally the decomposition product of urea or protein. Ammonia, a source of nitrogen for anaerobic bacteria, is stimulatory to the biological reactions. However, at high concentrations, it may be detrimental to microorganisms. Soluble ammonia gas, which constitutes the majority of ammonia nitrogen at a pH higher than 7.2, is inhibitory at considerably lower concentrations than the ammonia ion. Inhibitory effects have been observed for ammonia nitrogen concentrations of 1,500 mg/L, and concentrations above 3,000 mg/L have caused termination in gas production regardless of pH (Pohland et al., 1993).

Sulfide in anaerobic treatment originates from the reduction of sulfate or sulfur-containing inorganic compounds or the introduction of sulfide with wastes. Sulfides in soluble form have been reported to cause cessation in gas production at concentrations in excess of 200 mg/L, while concentrations of soluble sulfide varying from 50 to 100 mg/L can be tolerated in anaerobic treatment with little or no acclimation required (Parkin and Owen, 1982). The presence of heavy metals such as iron can lesson this effect, since metal sulfides can be formed and easily removed from solution by precipitation.

Small concentrations of heavy metals are necessary for proper functioning of bacterial enzyme systems. On the other hand, excess concentrations may lead to damage due primarily to the binding of metals with functional groups on proteins or replacing naturally occurring metals in enzymes. Heavy metals can combine with sulfide, carbonate, or hydroxide to form precipitates. Nonetheless, their mobility is also dependent on pH and the extent of sorption and desorption, ion exchange, as well as chelation reactions taking place within refuse mass. Usually, only heavy metals that exist in free cation forms at concentrations above threshold are harmful to microbial life (Mosey, 1963).

Although stabilization process may be impaired by some types of organic substances, e.g., chlorinated hydrocarbons, studies by Pohland (1983) indicated that finite amounts of halogenated organic compounds can be detoxified in landfill environments through reductive dehalogenation reactions. Yet, chloroform has been found to be extremely toxic, even at a concentration as low as 0.5 mg/L, and was a cause of inhibition in a number of anaerobic waste treatment plants in England.

Moisture content is considered important in anaerobic waste stabilization processes, since most physical and biochemical reactions occur in liquid phase or at the interface between phases (Chian et al., 1977). Liquid also serves as a transport medium for microorganisms and substrate, providing contact opportunity for reactions to proceed. Sufficient moisture content is critical for rapid stabilization within landfills, and the optimum ranges for maximum methane production were observed by Dewalle and coworkers (1976) to vary between 60 and 78%. Typically, 25% moisture is a lower limit required for decomposition to begin (Yaron et al., 1984). Major sources of moisture in landfill are from rainwater or snowmelt infiltrating final covers, water entering with solid waste, and water contained in various types of cover materials.

Distribution of moisture is also an important aspect. In a system with good moisture distribution, longer contact time between microorganism and substrate as well as greater amounts of accessible substrate are expected, resulting in higher waste conversion efficiency. This is evident for landfills where leachate recirculation is employed, since this technique is realized to promote a more thorough distribution of moisture throughout the refuse mass (Pohland and Harper, 1986; Pohland, 1980; Leckie et al., 1979).

Mechanical volume reduction methods include shredding, milling, and grinding decreases the size of solid waste materials and increases the surface areas where bacteria can attach and proliferate, thus aiding in decomposition processes (Stratakis, 1991). Baled solid waste tends to retard the flow of water and may cause uneven distribution of moisture, leading to less complete and slower biodegradation (Pohland et al., 1985). Sorting and recycling divert nonbiodegradable portions of the solid waste, minimize channeling and short-circuiting and maximize effective exploitation of landfill space.

2.5 Indicator Parameters Descriptive of Landfill Stabilization

There are certain traditional indicator parameters that can be used to indicate and to describe the presence, intensity, and longevity of each phase of landfill stabilization. Both gas and leachate parameters are monitored and analyzed for this purpose.

Chemical oxygen demand (COD) is a chemical parameter indicative of the organic strength of leachate in terms of the amounts of oxygen needed to obtain oxidation of the chemically oxidizable fractions contained within the waste. The concentration of volatile organic acids (VOA) is closely related to the biodegradability portion of the leachate constituents, since during the Acid Forming phase, the majority of the COD is composed of VOA. pH and oxidation-reduction potential (ORP) are physical-chemical parameters and indicative of the oxidation-reduction and acid-base condition, respectively. Availability of essential nutrients, nitrogen and phosphorus, are assessed through the analyses of leachate ammonia nitrogen and orthophosphate, which are the readily available forms of both elements (Chian and DeWalle, 1976).

The abundance of methane, carbon dioxide, nitrogen, and oxygen in landfill gas is also characteristic of stabilization. Therefore, when considered along with a aforementioned parameters, the manifestation of gas production during the predominant stabilization phase (Phase IV) is obtained. Gas production data are also used to evaluate the extent of waste transformation as organics are converted to carbon dioxide and methane.

The intensity of these parameters is dependent upon the prevailing phase of landfill stabilization and is also influenced by operational management strategies, i.e., moisture management, buffer addition, and removal of inhibitory compounds; the nature of the wastes; and closure and post-closure methods eventually applied (Pohland et al., 1993).

2.6 Composition of leachate

The characterization of leachate provides important information necessary for the control of landfill functions and for the design and operation of leachate treatment facilities, facilitates risk analysis of leachate impact on the environmental should liners leak, permits comparison of the impact of alternative landfill design or operating protocol on the environment, and discloses the interaction of leachate parameters.

Material is removed from the waste mass via mechanisms that include leaching of inherently soluble material, leaching of soluble products of biological and chemical transformation, and washout of fines and colloids. The characteristics of the leachate are highly variable depending on the composition of the waste, rate of water infiltration, refuse moisture content, and landfill design, operation, and age. These variations are demonstrated in Table 2.1, where ranges in concentrations of significant leachate components are presented as a function of stabilization phase.

Table 2.1 Landfill leachate concentration ranges as the function of degree of landfill stabilization (Reinhart and Townsend, 1997)

Parameter	**Phase II**	**Phase III**	**Phase IV**	**Phase V**
	Transition	**Acid Formation**	**Methane Formation**	**Final Maturation**
BOD, mg/L	100-10,000	1,000-57,000	600-3,400	4-120
COD, mg/L	480-18,000	1,500-71,000	580-9,760	31-900
TVA, mg/L as acetic acid	100-3,000	3,000-18,000	250-4,000	0
BOD/COD	0.23-0.87	0.4-0.8	0.17-0.64	0.02-0.13
NH_3-N	120-125	2-1,030	6-430	6-430
pH	6.7	4.7-7.7	6.3-8.8	7.1-8.8
Conductivity, μmhos/cm	2,450-3,310	1,600-17,100	2,900-7,700	1,400-4,500

2.7 Related studies

Rachdawong (1994) studied on the potential for using waste carpets as part of cover and liner system at municipal solid waste landfills. Two simulated landfill reactors were constructed, one with leachate recycle and one without. Both reactors were filled with food waste to assure accelerated stabilization, establish the identity and maximize the homogeneity of the refuse. The results showed that the leachate recirculation management strategy employment enhanced waste stabilization processes occurring in simulated landfill in terms of the time period required for stabilization and the extent of stabilization obtained, as reflected in gas volumes produced, gas production rates, gas composition and leachate indicators. Recycle reactor, which leachate was contained, buffered and recycled, promoted contact opportunity for biomass with substrate, nutrients and moisture that could be used for microbial growth and proliferation as opposed to the single pass bioreactor, which substrate was continuously removed from the system. In addition, leachate generation from landfills practicing single pass leaching would pose greater treatment challenge and the possibility of more adverse environmental impact if it was to migrate from landfill boundaries.

Steyer and Moletta (1998) studied the control of anaerobic digestion processes through disturbances monitoring. The purpose of their study was to develop a control strategy for an anaerobic digestion processes. Their goal was to maintain the loading rate as high as possible and to keep low and stable the concentration of treated effluent, the basic idea of their strategy was to add disturbance on purpose on the input flow rate and then analyzed the response of some key parameters in order to determine whether or not it was possible to increase the loading rate. In the case of a negative effect of the disturbance that it induced an overload of the reactor; the loading rate was decreased whereas, in the case of no negative effect of the disturbance, the loading rate was increased. The influent to be treated was a raw wine distillery wastewater used in two fluidized bed reactors of different volumes (15 l and 120 l working volumes) to test the control strategy. First, the disturbance of higher organic loading was applied to the process and the result showed that the disturbance did not induce noticeable changes in the output TOC concentration because of the small amount of carbon added in comparison with the reactor volume. On the other hand, the biogas response was high enough to be detected and analyzed. The second experiment was tested with the change of the COD contents in the influent, together with the increase of hydraulic retention time, explains the increase of the organic loading rate and the result showed the significant biogas increasing contributed to organic loading enhancement step. Next experiment, the 120 l reactor was monitored over a period of 10 months with the control strategy to study the evolution of organic loading rate and the carbon removal. At the very beginning of the operation, the loading rate was increased very rapidly. But at the same time, the carbon removal dramatically dropped down showing thus an overload behavior. Then the system automatically decreased the input flow rate; consequently, the carbon removal increased. Since, the reactor seemed to have recovered a good removal potential, the organic loading rate was increased slowly up with the result of high carbon removal efficiency. The hydraulic retention time was studied and it seemed also to be an important parameter for the overall carbon removal. At hydraulic retention time over 2 hours, there was no significant influence and the removal was closed to the maximum. Below this value, the carbon removal dropped very quickly. The result showed that the reactor was more stable for long HRT and was more subject to instabilities for low HRT. The next experiment was done with two different perturbations of COD. The first one was done using vinasses diluted twice as influent input COD and the second was done using raw vinasses. The result stated that the absence of response during the first disturbance was normal since the combination of increasing the input flow rate together with decreasing the input influent concentration leaded to a stable organic loading. On the other hand, using raw vinasses throughout the whole disturbance leaded to double the organic loading rate and thus, to a significant response of the biogas flow rate. The influence of a change of the influent COD concentration was also investigated to analyze the reaction of the control system when facing a sudden underload or a sudden overload of the process. The underload has been done by diluting the influent by 2 resulted in a sudden decrease of biogas flow. However, after a few cycles, the system was adapted to the new conditions and regularly increased the input flow rate, the biogas increased considerably. However, later the system was stabilized, the controller then reacted to overload condition, thus the input flow rate stepwised back to the initial value, the control biogas system returned to normal operation. The VFA accumulation in a digester was also considered. High organic loading rates showed good removal performance with relatively high VFA amounts. However, VFA concentration over than 6 kg/m3 showed inhibition behavior through biogas reduction.

Benson and Othman (1992) studied hydraulic and mechanical characteristics of a compacted municipal solid waste compost. Laboratory tests were performed to determine the particle size distribution, compaction characteristics, hydraulic conductivity and shear strengths of the compacted compost. Test have also been conducted to evaluate the resistance of compost to change caused by desiccation and freeze-thaw, the effects of extended permeation and the concentration of contaminants leached during permeation. The results of the study show that compost can be compacted into a dense mass with low hydraulic conductivity ($2*10^{-10}$ ms^{-1}). It is also more resistant to increase in hydraulic conductivity caused by desiccation and freeze-thaw than compacted clay. Compacted compost also has greater shear strength than compacted clay therefore is likely to remain stable on typical landfill slopes.

Kommilis, Ham, and Stegmann (1999) suggested that controlled leachate recirculation, moisture and waste composition could result in a balanced anaerobic ecosystem. Leachate recirculation and addition of inoculums appeared to be effective if used in combination with nutrient and buffer addition.

Turajane (2001) investigated solid waste degradation behavior. The comparison of methane production efficiency from high solid anaerobic digestion with and without leachate recycle was performed. Batch anaerobic digestion was operated for 200 days. Initial conditions, such as quantities and compositions of solid waste as well as of anaerobic sludge seeded, were kept the same for both reactors. There were three phases of leachate recirculation in the first phase was up to ten percents of the moisture available in bioreactor. The volume of leachate recycled in second and last phase were 25 and 50 percent, respectively. Initial amount of waste was 45 kg with the density of 450 kg/m3. Increasing the recycle ratios from 10, 25 and 50 percent resulted in rising of biogas production to 25.74, 156.2 and 129.14 liters, with methane percentage of 40.88, 48.61 and 52.45, respectively. Therefore, leachate recycle system was beneficial to enhance the conversion of organic waste to methane.

Jaijongrak (2003) studied the leachate recirculation scheme in bioreactor landfill to enhance gas production and reduce stabilization time for organic waste. Three lab scale bioreactor landfills were set up. First, the recycle reactor, based on leachate volume and percent methane at fixed step; second, the recycle reactor, based on COD mass and volume of methane in which the leachate volume was adjusted according to the reactor's output of yesterday, and finally, the non recycle reactor. All reactors were investigated under methane generation after pH is more than 7, ORP is less than -250 mV and methane percentage is over 50%. The results from this research confirmed that the leachate recycling practice showed higher efficiency in landfill stabilization as reflected by gas production rate, methane production rate, percent methane, and leachate indicator parameters, for instance, pH, ORP and COD. When compared two leachate recycle schemes, the reactor with recycle based on COD mass and volume of methane had higher cumulative methane production than recycle reactor based on leachate volume and percent methane at fixed step.

Teerachark (2005) studied the compost utilization on degradation of organic waste contaminated with Lead. Four simulated landfill bioreactors were constructed to run anaerobic organic waste degradation. First reactor was loaded with 7 kg as the control reactor. Second reactor was loaded with 7 kg organic waste plus Lead heavy metal spiked during acid phase. Third reactor was loaded with 7 kg organic waste plus compost liner. Final reactor was loaded with 7 kg organic waste with Lead spiked during acid phase and compost liner. The result showed that Lead heavy metal effected to organic waste stabilization since it was toxic to biological system especially for acid phase stabilization since heavy metal could leach through acid leachate and damaged the bacteria growth when it was recycled. However, the effect was reduced when compost was utilized since compost has many fibers to adsorb heavy metal.

Utapao (2005) studied the methane potential of fruit and vegetable waste from anaerobic biodegradation. Fifteen species of fruit and vegetable waste were preliminary selected to analyze for volatile solid and lignin content to classify into easy degradable type through biodegradable volatile solids (BVS) and hard degradable type through refractory volatile solids (RVS) and the result showed that cabbage, celery cabbage, cauliflower, kale were the easy degradable type since BVS proportion was more than RVS content or low lignin content has been found. In contrast, water mimosa, water melon peel and banana peel were the hard degradable type since the result showed high content of RVS or lignin.

Valencia and Van der zon (2008) studied the effect of hydraulic conditions on waste stabilization. The mixed gravel, gravel in layers, normal density and low density bioreactor were built to investigate the effect of different hydraulic condition on the waste stabilization process. The mixed gravel and low density bioreactor showed the result of stabilization enhancement since the recirculated leachate was better distributed due to higher pore availability, thus providing better conditions for micro-organisms metabolism. This was explained by the improved hydraulic conditions of homogenous mixture with gravel and less density application which helped these simulators to reach neutral pH levels faster. In addition, the mixed gravel simulators (and to some extent the less density simulator) performed better due to an increased moisture content which was caused by the constant recirculation of such moisture. In the mixed gravel simulators, it was observed that the leachate extraction process never reduced its flow velocity. In addition, these simulators exhibited lower residual and leachate carbon content than the rest, suggesting better waste degradation and transfer the liquid to gas phase.

Stabnikova and Xue Yan-Liu (2008) studied anaerobic digestion of food waste in a hybrid anaerobic solid–liquid system with and without leachate recirculation in an acidogenic reactor. The result showed that recirculation of the leachate in the acidogenic reactor was proposed to enhance food waste anaerobic digestion in the anaerobic system. Recirculation of the leachate in the acidogenic reactor provided better conditions for extraction of organic matter from the treated food waste and enhanced buffering capacity preventing excessive acidification in the acidogenic reactor. At the same time during acid phase, the concentration of VFA and COD from leachate recirculation bioreactor is higher than that from control bioreactor. Hence, use of leachate recirculation in the acidogenic reactor diminished time needed to produce the same quantity of methane by 40% in comparison with anaerobic digestion of food waste without recirculation.

Lo and Liu (2009) studied Biostabilization assessment of MSW co-disposed with MSW fly ash in anaerobic bioreactors. Three bioreactors were employed to examine the effects of MSW fly ash addition on MSW anaerobic digestion. Two fly ash was used as bioreactor liner for 10 and 20 g per liter MSW, respectively; whereas, another bioreactor was run as control for this experiment. The result showed that the ash-added bioreactors stimulate gas generation rates compared to the control as indicated through near-neutral pH values is suitable for anaerobic digestion, possibly due to alkali metal release associated with OH^{-1} and

CO_3^{-2}, which could potentially provide buffer alkalinity and neutralize VAs produced. In addition, higher VS indicates that the bacterial community, during the highly methanogenic activity period, in the ash-added bioreactors was potentially higher than in control. This result implied that potentially higher gas generation rates could be achieved in the ash-added bioreactors than in the control. Released alkali metals, such as Ca, Mg, K and Na, as a function of pH, for the three anaerobic bioreactors were in the range 50–2,500 mg/l, which displayed optimal rather than detrimental effects. Moreover, it was further noted that fly ash provided rather high specific surface with the potential to enhance the microbial habitat and attack. As a result, gas production rate in the ash-added bioreactors was enhanced. From the above results, it was concluded that enhanced gas production rate by methanogenic activity in the fly ash-added bioreactors was potentially stimulated by optimal alkali and trace metals concentrations with near-neutral pH. These phenomena indicated that proper amounts of MSW fly ash, co-disposed or co-digested with MSW, could facilitate bacterial activity, digestion efficiency and gas production rates.

CHAPTER III
METHODOLOGY

3.1 Configuration of the simulated landfill reactors

The four simulated landfill reactors were constructed using PVC pipe. Each reactor had a diameter of 0.20 m and a height of 0.4 m with total capacity of 12 L as seen in Figure 3.1. The columns were assembled with 0.28 m outer diameter PVC flanges to provide support for the top and bottom lids. A coating of silicone was applied to the interior and exterior of the flanged joints to ensure that the junctions would be water and gas tight.

The reactors were also equipped with three ports, one port at the bottom was used for leachate drainage and sampling while three inlet/outlet ports were placed at the top lid to collect gas, sample gas and add liquid by using a distribution system made of PVC. The collection of the gas is connected with PE hose to trap gas generation into inverted glass cylinder.

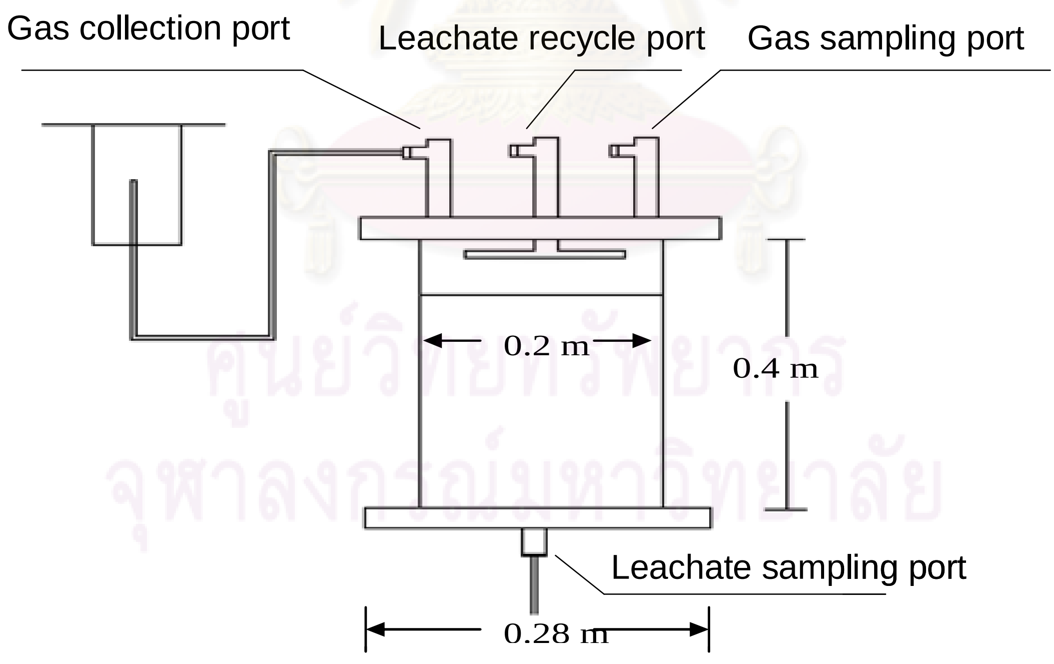

Figure 3.1 Schematic diagram of anaerobic degradation bioreactor

Landfill gas produced in the reactors was collected and measured by an inverted glass cylinder method. This technique utilized one 0.5-L glass cylinder placed invertly in 1-L glass cylinder which was filled with confining solution (20% Na_2SO_4 in 5 % H_2SO_4) (Sawyer and McCarty, 1989). The inner cylinder was lifted until the level of the confining solution in both cylinders equilibrated, and the amount of gas produced in a certain period was indicated by the volume occupied by gas in the inner cylinder. Reactor construction, anaerobic procedures and experiments were explained in diagram 3.1.

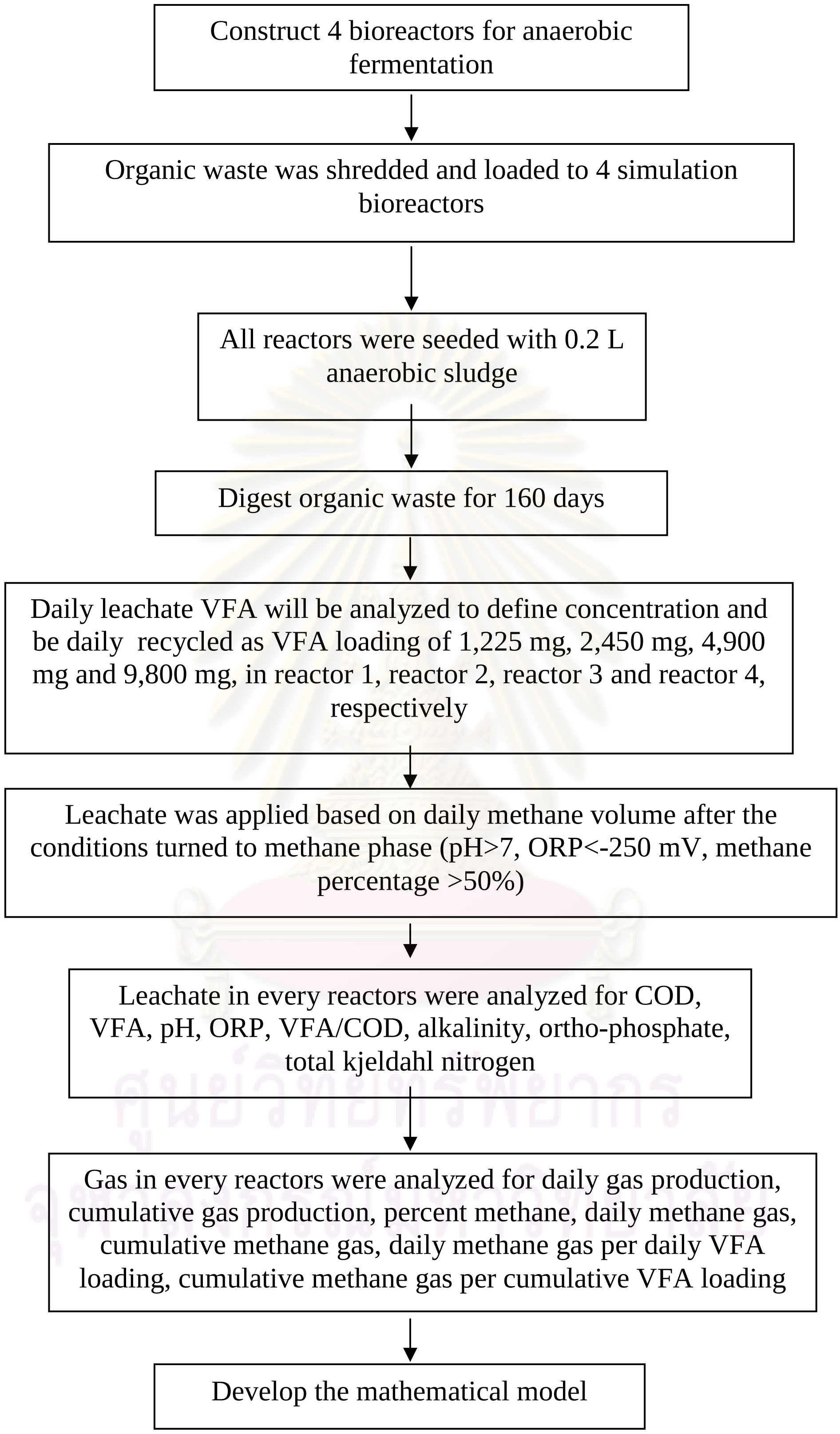

Diagram 3.1 Anaerobic procedures and experiments and experiments

3.2 The reactor loading

Each reactor is loaded with 2.5 kg of shredded solid waste and 0.2 L of anaerobic digested sludge obtained from Nong-Kham wastewater treatment plant. The simulated solid waste mixture representing typical solid waste composition of Tha-Din-Dang market and consists of 90% vegetables and 10% fruit by weight. Shredded refuse of composition presented in Table 3.1. Before solid waste was loaded into reactors, a 1 mm diameter holes nylon screen was placed above the layer of 2 cm diameter gravel at the bottom of each reactor. Reactor loading and its daily operation was described in figure 3.2. The variations of daily leachate loading under acid phase were as following. First reactor operates as control reactor loaded with 2.5 kg of simulated organic waste with leachate recirculation employment as 1x VFA loading (1,225 mg) from theoretical background (Jaijongrak 2003). The second reactor is loaded with 2.5 kg of simulated organic waste with leachate recirculation employment as 2x VFA loading (2,450 mg). The third reactor is loaded with 2.5 kg of simulated organic waste with leachate recirculation employment as 4x VFA loading (4,900 mg). Finally, the fourth reactor is loaded with 2.5 kg of simulated organic waste with leachate recirculation employment as 8x VFA loading (9,800 mg). All reactors were fixed those loading until the condition was ready to methane phase degradation (pH> 7, ORP <-250 mV, methane percentage >50%) with daily leachate employment based on daily methane volume.

Table 3.1 Solid waste compositions in simulated anaerobic bioreactors

Type	Total weight (wet) (kg)	Percent (by weight)
White-stemmed ipomoea	0.75	30
Brassica chinensis	0.25	10
Chinese cabbage	0.25	10
Lettuce	0.25	10
Cow-pea	0.25	10
Tomato	0.25	10
Ka-Na	0.5	20
Total	2.5	100

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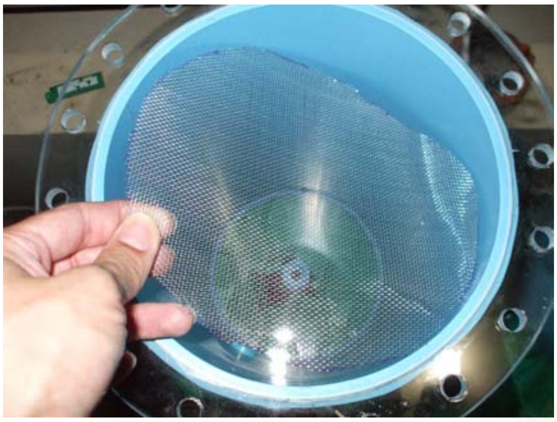
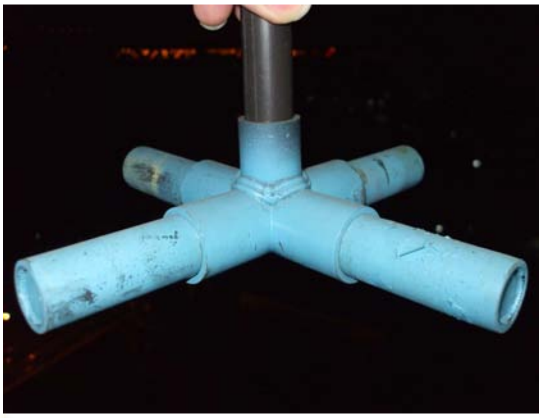
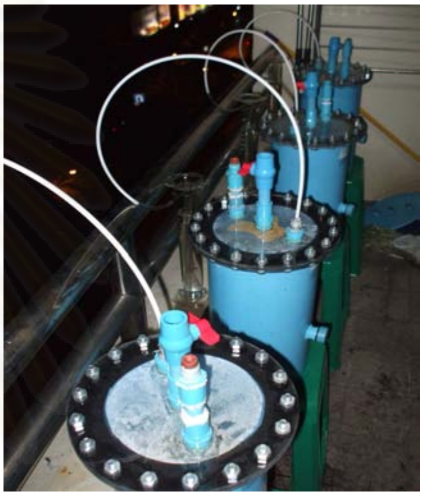


Screening and gravel for leachate filter

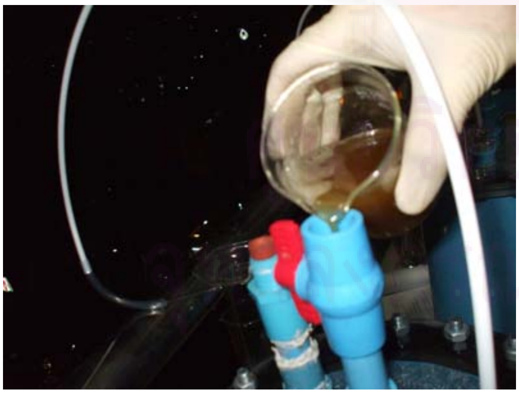


Leachate distributor

Shredded organic waste input



Simulated anaerobic organic waste bioreactors



Leachate recirculation

Daily leachate analyze

Biogas collecting

Methane measurement by GC

Figure 3.2 The design and operation features of the simulated anaerobic organic waste reactor

3.3 Sludge Seeding

To initiate and enhance the rate of solid waste degradation and stabilization with methane production in each reactor system, each reactor was seeded with 0.25 L of anaerobic digester sludge collected from Nong-Kham municipal wastewater treatment plant. Seed sludge supernatant characteristics are presented in Table 3.2. This seeding procedure was initiated on the refuse loading day in all reactors.

Table 3.2 Anaerobic digester sludge characteristics

Parameter	Analysis
Chemical oxygen demand, mg/L	1600 mg/L
Total solids, mg/L	27024 mg/L
Total Volatile solids, mg/L	15904 mg/L
Alkalinity, mg/L as $CaCO_3$	100 mg/L
Volatile fatty acid, mg/L as acetic acid	45 mg/L
pH	6.84
ORP	-151.7

3.4 Examination of inputs and outputs from previous works

Table 3.3 The application of anaerobic organic wastes degradation from previous studies

Previous study	Days	pH	ORP (mV)	Methane percentage	Leachate recycled (ml)	Methane volume/COD mass (ml CH4/ mg COD)	Methane volume/VFA mass (ml CH4/ mg VFA)
Rachdawong (1994)							
Organic waste (Municipal solid wastes)	1-118	4.98-5.79	176.0 mV to -177.0 mV	2.9%-18.9%	0 ml	NA	NA
	119-183	5.48-5.85	-56 mV to -147 mV	19.1-32.3%	150-300 ml	0.004	0.017
	184-360	5.60-7.07	-101 mV to -228 mV	28.0%-59.8%	120 ml-650 ml	0.090	0.225
Jaijongrak (2003)							
Organic waste (Fruit and vegetable wastes)							
-No leachate recirculation	1-195	3.85-5.18	40.2 mV to -152.0 mV	2.3%-42.46%	0 ml	NA	NA
-Plan A	1-185	3.71-6.45	-6mV to -251.5 mV	2.2%-42.29%	900 ml	0.010	NA
(Leachate recycle based on methane percentage)	186-195	6.55-7.10	-266.4 mV to -382.4 mV	46.45%-53.29%	2,700 ml	0.005	NA
-Plan B	1-185	5.05-6.48	-55.2 mV to -249.8 mV	5.5%-37.48%	600-2,800 ml	0.010	NA
(Leachate recycled based on daily methane volume)	186-195	6.64-6.93	-157.8 mV to -348.0 mV	35.69%-39.23%	4,000-7,000 ml	0.010	NA
Teerachark (2006)							
Organic waste (Fruit and vegetable wastes)	1-99	5.42-7.37	108.2 mV to -272.3 mV	2.3%-36.35%	0-350 ml	0.005	0.011
	100-123	6.52-7.40	-224.0 mV to -401.6 mV	34.27%-55.26%	750 ml-1,250 ml	0.008	0.021

Table 3.3 explained the application of anaerobic organic wastes degradation from previous studies and to explain and define leachate and gas parameters from various leachate recirculation employments. The study was investigated from Rachdawong (1994), Jaijongrak (2003) and Teerachark (2006). Leachate environmental pH under acid phase defined from each study was quite similar that stayed under the range of 4.98-5.85, 5.05-6.48, 5.42-7.37 from Rachdawong (1994), Jaijongrak (2003) and Teerachark (2006), respectively. Leachate pH range under methane phase was 5.60-7.07, 6.64-7.10, 6.52-7.40 and 6.95-8.10. Leachate ORP under acid phase from all studies was quite similar that stayed within the range of 176 mV to -177 mV, -6 mV to -251.5 mV, 108.2 to -272.3 mV and from Rachdawong (1994), Jaijongrak (2003) and Teerachark (2006). While, leachate ORP during methane phase was -101.0 mV to – 288mV, -157.8 mV to -348.0 mV and -224.0 mV to -401.6 mV from Rachdawong (1994), Jaijongrak (2003) and Teerachark (2006) study. Methane percentage during acid phase from Rachdawong (1994), Jaijongrak (2003) and Teerachark (2006) was 2.9%-32.3%, 2.2%-42.29% and 2.3%-36.35%, respectively. While methane percentage during methane phase from Rachdawong (1994), Jaijongrak (2003) and Teerachark (2006) rose to 28.0%- 59.8%, 46.45%-53.29% and 34.27%-55.26%. The ratio of average daily CH_4/

daily COD mass loading was employed as 0.01 from plan A Jaijongrak (2003) study. The other studies of daily CH_4/ dally COD loading employment was 0.004 from Rachdawong work (1994), 0.005 from Teerachark work (2006) The ratio of daily CH_4/ daily VFA loading during acid phase was detected in Rachdawong (1994) work and Teerachark work (2006) as 0.017 and 0.011 respectively.

3.5 Importance of leachate volatile fatty acid study

The process of anaerobic digestion consisted of three steps: solubilization, acidogenesis and methanogenesis (Kim et al., 2003) and involved continuous bacterial reaction (Buzzini et al., 2006). In the first step, solid organic materials such as food waste must be solubilized for effective degradation by continuous anaerobic microbial digestion. As the second step, acidogenic bacteria produce fermentation intermediates, mainly volatile fatty acids, and lastly, methane and carbon dioxide are produced from these intermediates by methanogenic bacterial metabolism. In each step of the process, the gas production and decomposition rates of organic waste were influenced by environmental factors such as temperature, pH and substrate concentration (Komemoto et al., 2009). During the anaerobic fermentation reactor, VFA were the important mid-productions. Most of the CH_4 produced in conventional anaerobic digesters was derived from VFA such as acetic acid and butyric acid. It was known that CH_4 productions are affected greatly by degradation pathway of substrate, so there were many researches which were developing about it. During the process biopolymers were initially hydrolyzed and fermented to volatile fatty acids (VFA), H_2 and CO_2, by the hydrolytic/ fermentative bacteria. VFA such as propionate, butyrate and isobutyrate were subsequently oxidized by acetogenic bacteria producing acetate, H_2 and CO_2, and finally these products are converted to CH_4 by methanogens (Schink, 1988). As shown in many studies, the conversion rates of VFAs to CH_4 vary in the order of acetic acid (HAc)> ethanol (HEt) > butyric acid (HBu) > propionic acid (HPr) (Ren et al., 2003). Before being degraded to CH_4, all VFAs are first degraded to HAc, and their conversion rates also vary in the order of HEt > HBu > HPr. Accumulation of HPr always results in failure of methanogenesis (Ren et al., 2005). Among all VFAs, acetic acid and butyric acid are the most favorable for methane formation, while contribution of acetic acid is more than 70% (Khanal, 2008). An unrestrained reactor operation could lead to disturbances in the balance between the different microbial groups, which might lead to reactor failure. Leachate recirculation technique was realized to promote more distribution of moisture and substrate throughout the refuse mass (Pohland and Harper, 1986). Leachate recirculation employed volatile fatty acid mass loading in the system to promote methane gas. However, loading rate increase signified in VFAs which dropped pH and decreased activity with methanogens (Bueken, 2005). As details above, VFA was the most significant parameter to control anaerobic degradation system.

3.6 Moisture application and management

Preliminary analyses indicated that the synthetic solid waste had approximately 88% of moisture content. The liquid collected at the bottom of each reactor on the next day will be recycled to the top of reactor. This water application procedure was repeated until the amount of liquid introduced each day, would equal to the amount of liquid collected on the next day. This date was then defined as Day 0, or when indicated field capacity was reached and leachate production began. A sample of leachate from each cell was collected at that time and analyzed for all indicator parameters. Initially, leachate recirculation phase shift condition of Jaijongrak (2003) was applied as the guideline of daily leachate recirculation volume that is changed according to the degree of waste stabilization and gas production. At beginning, leachate recirculation was attempted based on plan A Jaijongrak study (Jaijongrak, 2003) which was defined as daily volatile fatty acid loading of 1x (1,225 mg) from current study and was shown in Table 3.4. Leachate variation of 2x (2,450 mg), 4x (4,900 mg) and 8x (9,800 mg) was studied to define the variation of VFA loading input on anaerobic organic waste degradation during acid phase. In addition, the attempt of leachate recycle based on daily methane gas output and daily volatile fatty acid which based on Plan B Jaijongrak study (Jaijongrak, 2003) was shown in Table 3.5. This was made after the condition in anaerobic degradation was turned to methane phase. Leachate recirculation volume and leachate loading was described in Figure 3.3, Table A-1 and Figure 3.4, Table A-2, respectively.

Table 3.4 Leachate recirculation volume from plan A Jaijongrak study (Jaijongrak, 2003)

CH_4 Range	Leachate Recycle Volume	VFA loading
0-15%	0	0
16-30%	5% of initial moisture in system	1,225 mg
30-50%	15% of initial moisture in system	3,675 mg

Table 3.5 Leachate recirculation volume based on daily methane gas from plan B Jaijongrak study (Jaijongrak, 2003)

CH_4 Range	Volume of methane/ COD mass
0-15%	0
16-30%	0.002
30-50%	0.005
> 50%	0.010

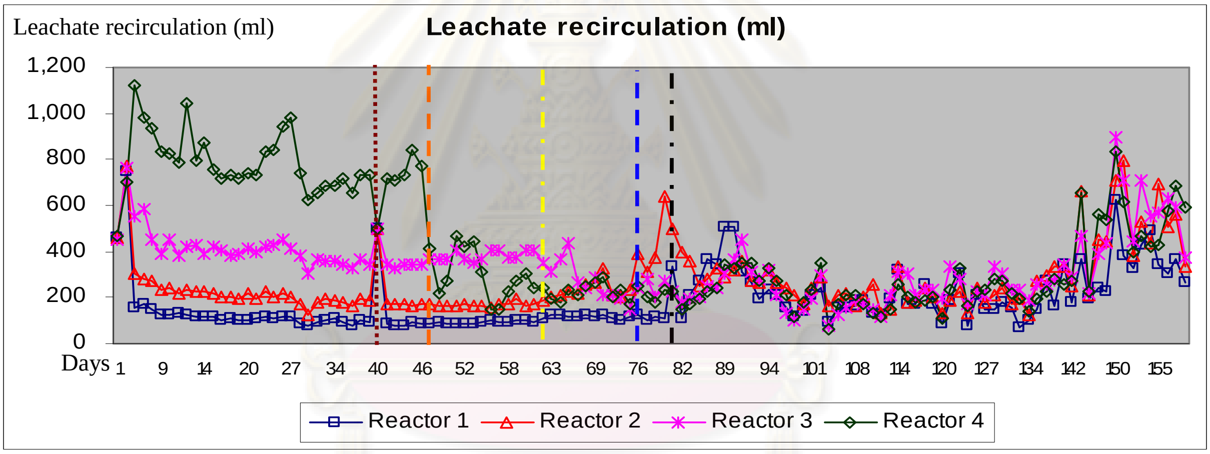
Leachate recirculation was developed through Jaijongrak study (2003) as the guideline table from Turajane leachate recirculation for fruit and vegetable wastes (1998) and was explained in Table 3.4 and Table 3.5. Based on previous literature review, Jaijongrak (2003) studied leachate recirculation employment between leachate recirculation plan A (Table 3.4) and leachate recirculation plan B (Table 3.5). Result implied that leachate recirculation as initial moisture content from plan A (Table 3.4) showed faster acid to methane with higher cumulative methane volume during early phase until the condition was ready to methane phase degradation. After suitable leachate pH and ORP could be established, leachate recirculation plan B (Table 3.5) showed better degradation result as indicated from higher daily and cumulative methane volume. Hence, initial leachate study was employed as plan A until the condition was ready to methane gas generation. The loading employment leachate plan A from Turajane (1998) table was gradually increased which based on methane percentage as the criteria for bacteria growth. 5% of initial moisture content was recycled back during initial phase that methane percentage was under 10-30%. Daily volatile fatty acid loading employment adapted from Turajane (1998) in Table 3.4 as 5% of initial moisture content was explained in Appendix C that was equaled to 1,225 mg volatile fatty acid loading. Leachate recirculation was varied to two times (2,450 mg VFA loading), four times (4,900 mg VFA loading) and eight times (9,800 mg VFA laoding) to study the suitable leachate recirculation employment on anaerobic organic waste degradation during initial phase. Leachate volatile fatty acid loading was further normalized as VFA loading / methane output and organic loading rate in term of g VFA/ liter/ day for leachate recirculation application. Leachate recirculation plan B on methane phase was indicated from leachate pH, ORP and methane percentage. Criteria of methane phase establishment were described in Table 3.6 as following detail.

Table 3.6 Summary of indicating parameters on methane phase of landfill organic waste degradation

Influencing factors	Criteria	References
Moisture	Optimum: 6% and above	Pohland (1986); Rees (1980)
Oxygen	Optimum redox potential for methanogens:	
	-200 mV	Farquhar and Rovers (1973)
	-250 mV	Jaijongrak (2003)
	-300 mV	Christensen and Kjelden (1989)
	< -100 mV	Pohland (1980)
pH	Optimum pH for methanogenesis:	
	6 to 8	Ehrig (1983)
	7 to 8	Jaijongrak (2003)
	6.4 to 7.2	Farquhar and Rovers (1973)
Methane percentage	Optimum methane for methanogenesis:	
	45%-60%	Farquhar and Rovers (1973)
	> 50%	Jaijongrak (2003)
	50%-65%	Mata-Alvarez et al (1986)
Alkalinity	Optimum alkalinity for methanogenesis: 2,000 mg/l	Farquhar and Rovers (1973)
	Maximum organic acid concentration for	Farquhar and Rovers (1973)
	methanogenesis: 3,000 mg/l	
	Maximum acetic/ alkalinity ratio for	Ehrig (1983)
	methanogenesis: 0.8	
Temperature	Optimum temperature for methanogenesis;	
	40 C	Rees (1980)
	41 C	Hartz et al (1982)
	34-38 C	Mata-Alvarez et al (1986)
Hydrogen	Partial hydrogen pressure for acetogenesis:	
	< 10^{-6} atm	Barlaz et al (1987)
Nutrients	Generally adequate	Christensen and Kjelden (1989)
	COD: P 2,200:1	McCarty and Speece (1963)
	COD:N 39:1	Chian and DeWalle (1977)

Table 3.6 was the summary of influencing factors on landfill organic waste degradation. The optimum redox potential for methanogenesis was implied as -200 mV from Farquhar and Rovers (1973), -250 mV from Jaijongrak (2003) and – 300 mV from Christensen and Kjelden study (1989). Redox potential during methane phase was indicated as – 250 mV which based on Jaijongrak work (2003) and this was medium value between Farquhar and Rovers (1973) and Christensen and Kjelden study (1989). Optimum pH for methanogenesis was in the range of 6-8, 7-8, and 6.4-7.2 from Ehrig (1983), Jaijongrak (2003) and Farquhar and Rovers (1973), respectively. pH for methane phase degradation was investigated as medium which referred to Ehrig (1983) and Jaijongrak (2003). Methane

percentage under methane phase was 45%-60%, > 50% and 50%-65% from Farquhar and Rovers (1973), Jaijongrak (2003) and Mata-Alvarez (1986). Methane percentage from this study was set as > 50% which refered to Juanga et al. (2004) and Jaijongrak (2003) and Mata-Alvarez (1986). These criteria (pH > 7, ORP < -250 mV and methane percentage > 50%) was set as the methane phase generation to employ leachate recirculation plan B (Table 3.5) which based on daily methane gas output. Leachate recirculation plan B as Turajane guideline was studied by Jaijongrak (2003) and it exhibited good result of stabilization time and daily methane gas generation. The amount of leachate recycle volume plan B corresponded to organic loading which was daily adjusted to volume of methane generation as the employment of food input to be suitable to methanogenic bacteria progress. COD mass loading was converted to direct food input as VFA mass loading and was calculated as the example in Apendix C.



.... Application of buffer neutralization

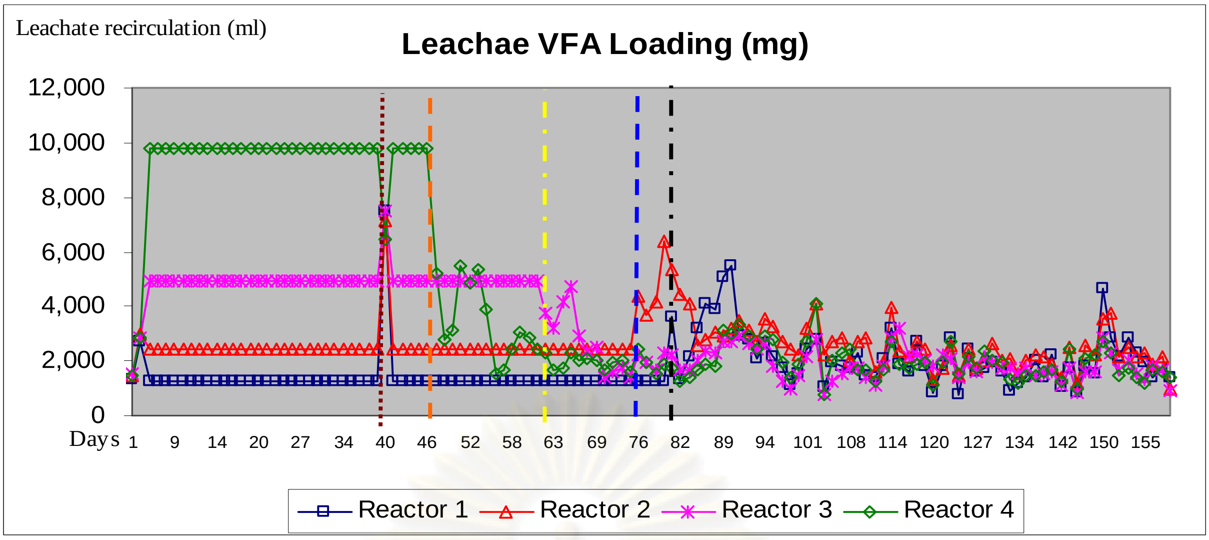
--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

--------Application of leachate recirculation based on methane volume in reactor 1

Figure 3.3 Leachate recirculation volumes from the simulated anaerobic organic waste reactor



.... Applicatin of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

--------Application of leachate recirculation based on methane volume in reactor 1

Figure 3.4 VFA loading employment through leachate recirculation from the simulated anaerobic organic waste reactors.

Simulated organic waste reactors were employed to test variable VFA loading inputs to the system. Initially, leachate recirculation was employed as in Jaijongrak (2003) experiment which based on leachate recycle and methane percentage at fixed step with 1,225 mg VFA loading employment in current reactor 1 study. VFA loading of 2,450 mg, 4,900 mg and 9,800 mg were varied in reactor 2, 3 and 4, respectively. Leachate VFA loading depending on daily VFA concentration analysis would be of the varied amount of leachate recycle volume. Initially, leachate was all recirculated for 3 days until the field capacity was reached. Daily leachate recycle volume was varied on Day 6 with the result of 154 ml in bioreactor1, 303 ml in reactor 2, 554 ml in reactor 3 and finally 1,120 ml in reactor 4. In addition, leachate recirculation would be varied based on daily methane gas volume after the condition in bioreactor were in methane phase which could initially noticed from pH, ORP and methane percentage value. The characteristic of leachate recirculation based on daily methane gas output has been attempt on Day 48, Day 62, Day 76 and Day 81 in reactor 4 reactor 3, reactor 2 and reactor 1, respectively.

3.7 Sampling and analytical protocols

Leachate and gas were produced in the simulated landfill reactors everyday as solid waste degradation progressed under anaerobic conditions. The quality and quantity of gas and leachate varied as different phases of stabilization occurred. Therefore, monitoring for changes in parameters indicative of landfill stabilization was used to identify the sequential phases of solid waste degradation.

Leachate samples were collected from the bottom of the reactors, and were analyzed for chemical oxygen demand (COD), biological oxygen demand (BOD), pH, oxidation-reduction potential (ORP), orthophosphate, total nitrogen, alkalinity, volatile fatty acid The daily temperature, daily gas production rate, and gas composition were also observed. Gas composition, measured as percent by volume, was determined for methane and carbon dioxide. Detail about frequency and method of analyses are listed in Table 3.7

Table 3.7 Methods and frequencies of simulated anaerobic organic waste leachate and gas parameters

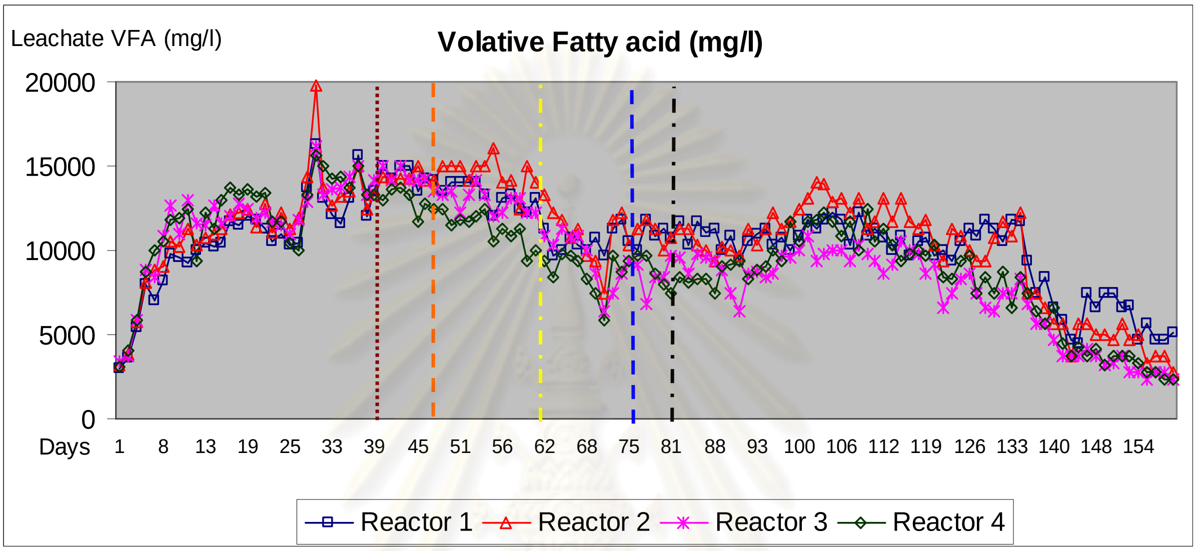
Measurement	**Procedure**	**Frequency**
pH	pH meter	Everyday
ORP	ORP meter	Everyday
COD	Standard Methods for the examination of water and wastewater # 5210,5210 (Titration Method)	Every 3 days
Total nitrogen	Standard Methods for the examination of water and wastewater water and wastewater # 4500 (Kjeldahl Method)	Once a month
Ortho-phosphates	Standard Methods for the examination of water and wastewater water and wastewater # 4500 (Vanadomolybdophosphoric Acid Method)	Once a month
Alkalinity	Standard Methods for the examination of water and wastewater water and wastewater # 2320 (Titration Method)	Every 3 days
Gas production	Inverted Glass Cylinder Method	Everyday
Percent Methane	Gas Chromatography with TCD detector	Every 3 days
Water content	Standard Methods for the examination of water and wastewater water and wastewater # 2540 (Total solid dried)	Every week
VFA	Standard Methods for the examination of water and wastewater water and wastewater r#2310 (Titration method)	Everyday
VS	Standard Methods for the examination of water and wastewater water and wastewater #2540 (Loss on ignition)	Beginning and the end

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Leachate organic analysis

4.1.1 Volatile Fatty Acids



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

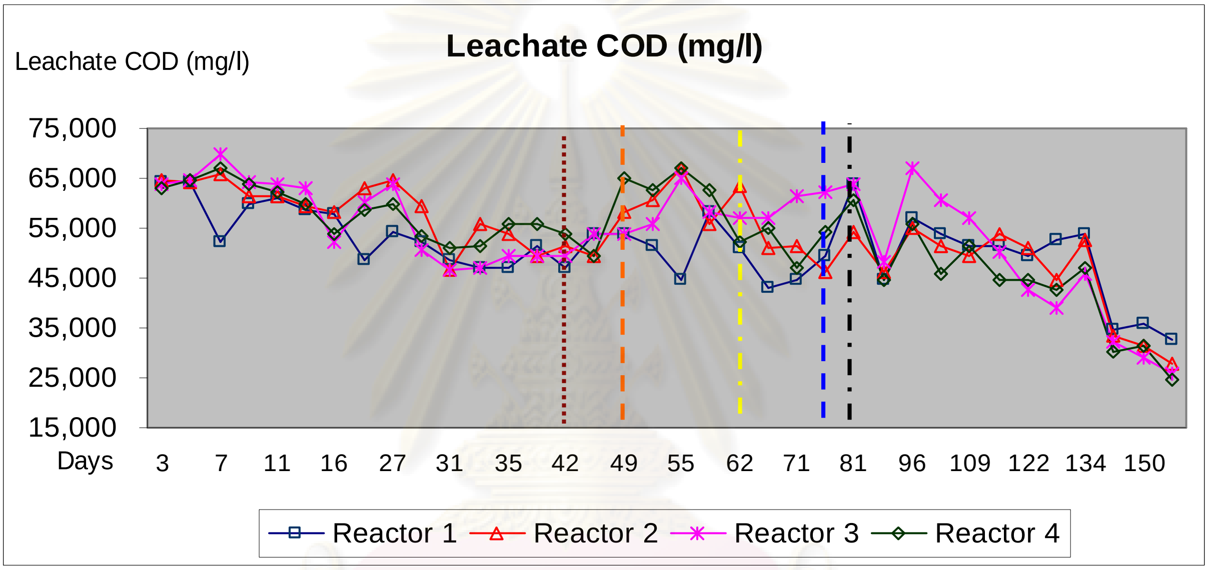
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.1 VFA variations in leachate produced from the simulated anaerobic organic waste reactors.

Volatile fatty acids are the product of degradation and fermentation of organic fractions in waste materials. Total volatile fatty acids represent a significant fraction of the biodegradable elements in leachate during the acid formation phase. The concentration of volatile fatty acid is an important parameter to the degree of stability of anaerobic process. VFA data of all simulated anaerobic bioreactor was showed in Figure 4.1 and Table A-3

The initial VFA concentration in leachate samples started from 2934, 3214, 3409 and 3068 mg/l in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. Leachate VFA rose to the range 7,900-8,750 mg/l after 6 days of operation before the attempt of leachate variation has been made. The attempt of leachate VFA loading of 1225, 2450, 4900 and 9800 mg has been daily loaded on Day 6 through leachate recycle in reactor 1, reactor 2, reactor 3 and reactor 4, respectively with the result of gradually VFA concentration increase. VFA concentration from all reactors fluctuated in the range of 10,000-20,000 mg/l with the highest concentration after 29 days of operation resulting in the parallel pH drop for all simulated bioreactors and low methane gas production. Even though, volatile fatty acids were substrates to generate the biogas, pH level during this period in the range of 5-6 was not suitable for methanogenic bacteria growth. During Day 1- Day 40, volatile fatty acid concentration with high VFA loading input through leachate recirculation in reactor 4 exhibited higher VFA trend than other simulated bioreactors. The pH of high VFA loading bioreactor during this period was in the same range as the other bioreactors that stood in the range of 5.43-6.21. In contrast, the lowest VFA loading input to reactor 1 showed the result of lowest VFA concentration in leachate as indicated from the average VFA concentration during Day 35 was 10370, 11161, 11427, and 11606 mg/l in reactor 1, 2, 3 and 4, respectively. Furthermore, high VFA loading in reactor 4 showed faster VFA drop contributed to higher methane gas generation since the VFA during Day 60 was 12,188 mg/l, 15,000 mg/l, 12,188 mg/l, 9,375 mg/l with daily methane gas generation of 76 ml, 96 ml, 103 ml, 159 ml in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. The result confirmed that high volatile fatty acid loading to bioreactor could be well utilized as daily substrate input to the system to produce methane gas output. The attempt of leachate recirculation based on daily methane volume was made after leachate pH turned to 7 and ORP was lower than -250 mV (Jaijongrak, 2003, Teerachark, 2006) after Day 81, Day 76, Day 62 and Day 48 in reactors 1, 2, 3, and 4, respectively. Those environmental conditions were suitable to the methanogenic bacteria growth and resulted to the fluctuated volatile fatty acid concentration on Day 81 to Day 122 within the range of 9,375 mg/l- 12,188 mg/l, 9,375- 13,125 mg/l, 6,429- 11,250 mg/l and 5,833- 12,500 mg/l in reactors 1, 2, 3 and 4, respectively. During this period, leachate volatile fatty acid was well utilized as substrate to be methane gas production, while the volatile fatty acid was daily loaded though daily leachate recirculation resulting to leachate VFA fluctuation during this period. After 123 days of operation, leachate volatile fatty acid concentration was gradually decreased as the result of most volatile fatty acid utilization to methane gas. During this period, reactor 3 and reactor 4 exhibited lower volatile fatty acid concentration when comparing to leachate volatile fatty acid in reactor 1 and reactor 2 as indicated from the result of leachate concentration during Day 150 was 7,500 mg/l, 5000 mg/l, 3,214 mg/l and 3,214 mg/l in reactor 1, 2, 3 and 4, respectively. Suitable condition for methane phase in reactor 3 and reactor 4 was established earlier than those in reactor 1 and reactor 2. The cumulative methane gas output in reactor 3 and reactor 4 were higher than those in reactor 1 and reactor 2, as well. Finally, the anaerobic organic waste degradation showed the stabilization progress since leachate volatile fatty acid concentration on Day 160 dropped to 5,156 mg/l, 2,813 mg/l, 2,344 mg/l and 2,344 mg/l in reactor 1, 2, 3 and 4, respectively.

4.1.2 Chemical oxygen demand



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

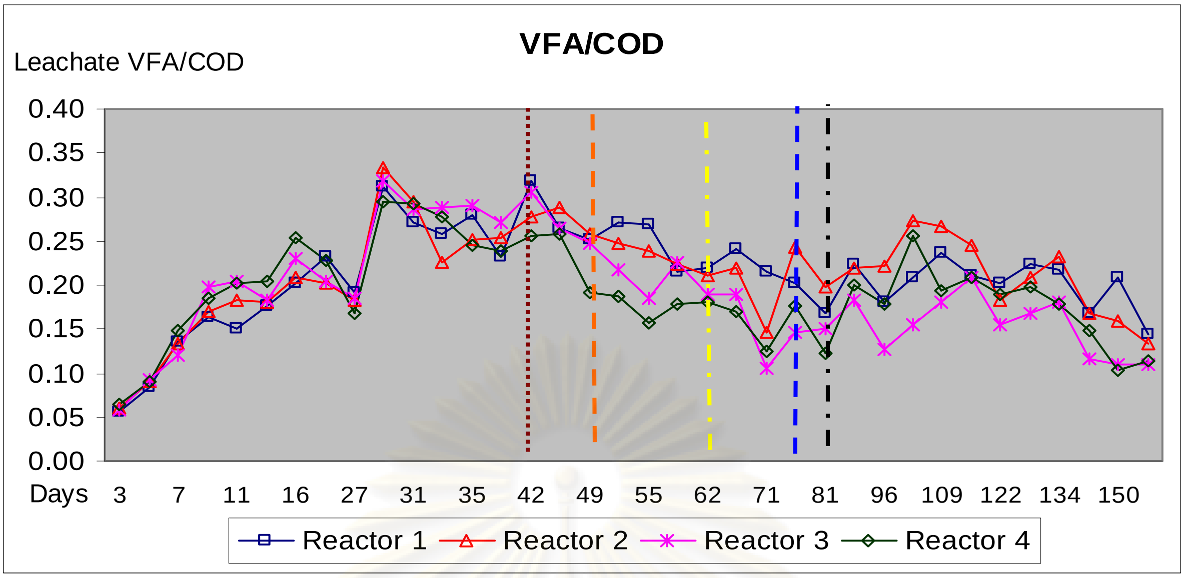
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.2 Daily variation of COD concentration from the simulated anaerobic organic waste reactors.

Leachate chemical oxygen demand (COD) was measured as an indicator of organic strength. COD data of leachate from all reactors were presented in Figure 4.2 and Table A-4 Appendix A.

COD concentrations were analyzed by average of three dilution value at 2%, 4% and 6%, respectively. The initially high leachate COD concentration from all reactors indicated that the solid waste added contained readily solubilized organic materials. Initially, Leachate COD was relatively high that started from 64,192, 64,736, 63,648 and 63,104 mg/l in reactor 1, reactor 2, reactor3 and reactor 4, respectively. The attempt of variable leachate loading was employed after 6 days of operation which resulted to small differences in COD concentration. Leachate COD from high VFA loading bioreactors such as reactor 3 and reactor 4 had higher COD concentration than low loading bioreactors such as reactor 1 and reactor 2. The VFA was found to be a major contributor to the COD present during Day 6-Day 50 since high VFA loading input added the VFA concentration in bioreactor system and also showed the rise in COD concentration, as well. Leachate COD from all bioreactor was gradually decrease from 59,840, 61,472, 64,192, 63,648 mg/l on Day 9 and to 43,010 mg/l, 51,130 mg/l, 57,010 mg/l and 55,140 mg/l on Day 67 in reactor1, 2, 3 and 4, respectively. The declining in COD was relatively due to the anaerobic waste degradation with result of biogas generation and the rise in methane gas production. Leachate COD during Day 67 to Day 109 fluctuated in the range of 43,010-51,520 mg/l, 46,400-54,880 mg/l, 48,400-67,200 mg/l amd 44,800-60,800 mg/l in reactor 1, 2, 3 and 4, respectively. After 109 days of operation, Leachate COD concentration from all reactors was decreased since volatile fatty acids, the major contributor to COD, was utilized as substrate for methane gas generation. COD decrease was predominantly observed in reactor 3 and reactor 4 since those bioreactors exhibited higher cumulative methane gas generation. COD concentration left after 160 days of operation was 32,480 mg/l, 28,000 mg/l, 25,760 mg/l and 24,640 mg/l in reactor 1, 2, 3 and 4, respectively.

4.1.3 Volatile fatty acid/ Chemical oxygen demand (VFA/COD)



.... Application of buffer neutralization

-------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.3 Leachate VFA/COD ratio from the simulated anaerobic organic waste reactors.

Leachate VFA/COD indicated the anaerobic organic waste degradation pattern and was defined in Figure 4.3, Table A-5 Appendix A.

Initially, leachate VFA/COD on Day 16 were 0.20, 0.21, 0.23 and 0.25 in reactors 1, 2, 3 and 4, respectively. Leachate VFA/COD in reactor 4 was slightly higher than leachate VFA/COD from other reactors since reactor 4 showed high ability of acid phase due to intermediate products that were faster hydrolyzed into volatile fatty acid and were partly utilized as substrate for methane gas generation. Daily methane result on Day 16 that was 24 ml, 45 ml, 43 ml and 68 ml in reactor 1, 2, 3 and 4 also supported the previous assumption. Leachate VFA/COD trend in reactor 4 increased to 0.29 on Day 29 exhibited the highest volatile fatty acid production potential during this period which resulted in lower daily methane gas during Day 29 to Day 36 (29-64 ml). However, after leachate buffer was attempted on day 40, leachate VFA/COD gradually decreased to 0.16 on Day 55 since volatile fatty acid could be well utilized as substrate for methane gas generation. This resulted in abrupt increment of daily methane gas in reactor 4 as indicated from daily methane gas on Day 59 was 170 ml. Leachate VFA/COD in reactor 1 and reactor 2 was quite steady during day 30 to day 55 that stayed within the range of 0.24-0.32 with low daily methane gas generation. Even though leachate buffer was attempted on Day 40 in reactor 1 and reactor 2, the system was not fast to utilize volatile fatty acid during this period. Daily methane gas of reactor 1 on Day 59 was only 62 ml which was three times lower than that of reactor 4. VFA/COD down trend graph during Day 40 to Day 70 also confirmed this result since the down trend slope was steepest in reactor 4, as the indication of well VFA substrate utilization. VFA/COD down trend slope in reactor 3 was steeper than that in reactor 2 and reactor 1. Result indicated that fastest acid degradation to methane phase occurred from highest volatile fatty acid loading input in reactor 4. Higher volatile fatty acid loading input showed faster degradation establishment, as well. Leachate VFA/COD from all reactors tended to drop after 76 days of operation and therefore, exhibited the readiness of methane phase degradation. The result of VFA/COD and daily methane on Day 81 was 0.17, 107 ml in reactor 1, 0.20, 133 ml in reactor 2, 0.15, 146 ml in reactor 3 and 0.12, 142 ml in reactor 4, respectively. All reactors were under optimized methane gas generation and showed similar daily methane gas output that stayed within the range of 60-170 ml. On Day 157, leachate VFA/COD was 0.14, 0.13, 0.11 and 0.11 and 0.11 in reactors 1, 2, 3 and 4, respectively and could be considered low since VFA substrate was almost depleted. Hence, daily methane gas on day 157 dropped to 51 ml, 73 ml, 80 ml and 74 ml in reactors1, 2, 3 and 4, respectively.

4.2 Leachate environmental analysis

4.2.1 Temperature

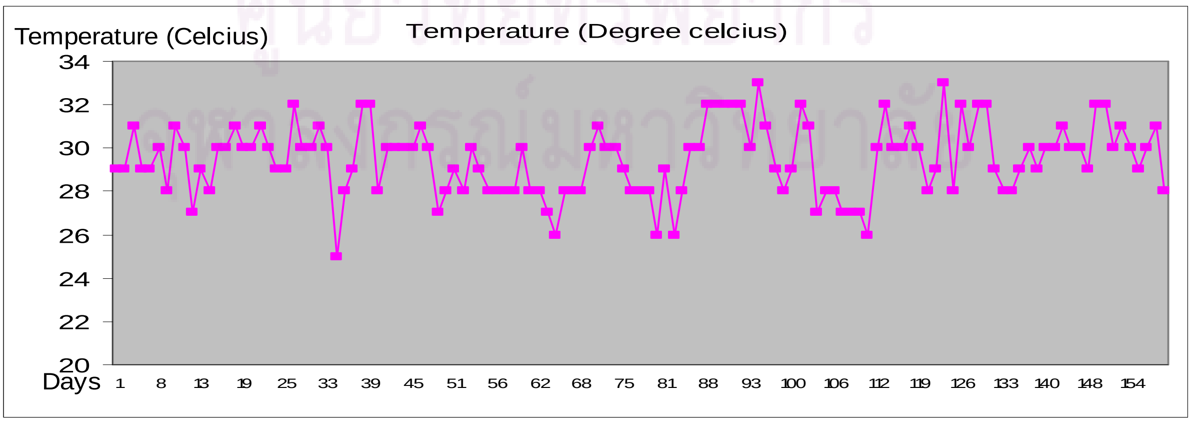
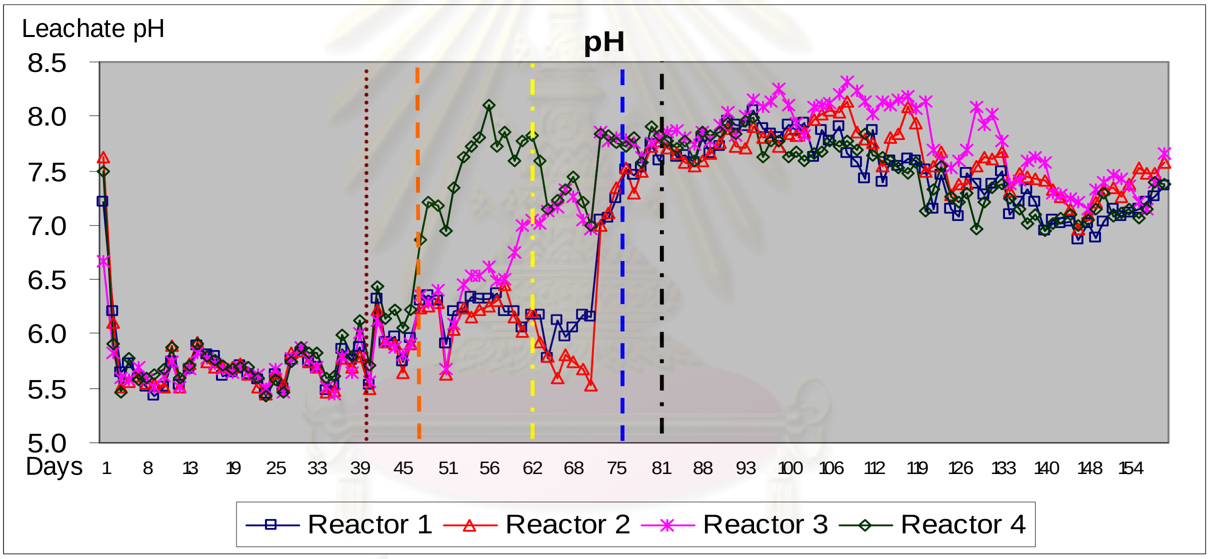


Figure 4.4 Temperature profile during anaerobic fermentation

Temperature was in the range of 25-33 ℃ throughout the experiments and was dependent on laboratory temperature fluctuations. The ambient room temperature were presented in Figure 4.4 and Table A-6 Appendix A during the majority of the experimental period, almost all of the temperature fluctuation was in the range of 28-32 ℃ indicating the optimum temperature ranges for mesophilic anaerobic digestion of 30-32 ˚C (Torien, 1967). This suggested that effects on biological conversion would be active under those conditions.

Leachate parameters analyzed and presented herein are utilized for investigation of the progression of landfill stabilization processes, especially the degree or age of waste stabilization taking place in the simulated reactors.

4.2.2 Leachate pH



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

---------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

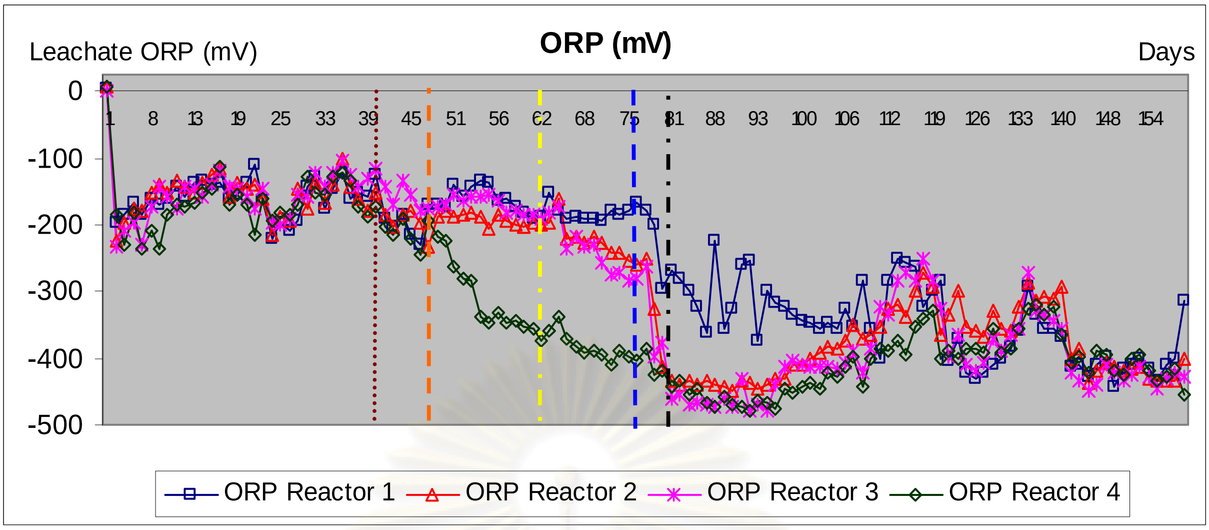
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.5 pH of leachate from the simulated anaerobic organic waste reactors.

The pH of anaerobic system is a function of the existing buffer system and component species ionization. The predominant pH is dependent upon interaction between volatile organic acids, alkalinity, and partial pressure of evolving carbon dioxide gas. In the acid formation phase of landfill stabilization pH values are normally low due to the presence of volatile organic acid and their buffering effects on system pH. When the available VOAs are converted to methane and carbon dioxide during methane fermentation phase, pH usually raises to values characteristics of the bicarbonate buffering system. The pH of leachate from all reactors were shown in Figure 4.5 and Table A-7 Appendix A

pH started up in the range of 6.67 to 7.62 as the initially raw waste characteristic. However, leachate pH was abruptly dropped to 5.56 to 5.72 after 6 days of operation which contributed to the extensive hydrolysis reaction with acid production occurrence. After the leachate variation has been used on Day 6, Leachate pH in every bioreactor showed the similar trend graph which contributed to the same trend graph explicitness within the range of 5.43 to 5.88 during 40 days of operation as the result of high volatile fatty acid presented in every bioreactors. Moreover, the high VFA loading through high volume of leachate recirculation did not affect to the pH drop in simulated anaerobic bioreactor due to its buffering. The leachate pH during Day 31 to Day 40 in high VFA loading reactor (reactor 4) was higher than the other bioreactors. In addition, the attempt of leachate neutralization was occurred on Day 40 with the result of gradual pH rose to 7 in high leachate recirculation bioreactor (reactor 4 after 49 days, reactor 3 after 62 days). pH from other bioreactors were relatively constant in the range 6.0-6.5 during Day 41 to Day 62. High VFA loading related to high buffered leachate recycle that was recirculated and distributed back into reactors which assisted buffering in the system. Leachate pH in reactor 1 and reactor 2 was turned into 7 after 73 days of operation explicated the slower anaerobic degradation when comparing to the leachate pH system in reactor 3 and reactor 4 since medium pH in leachate shows the suitable environment condition during methane phase degradation. Leachate pH in every bioreactor was stable in the range of 7.00-8.24 during Day 73 to Day 160. This suggested that effects on methane gas generation would be active under those conditions.

4.2.3 Leachate ORP (Oxidation Reduction Potential)



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

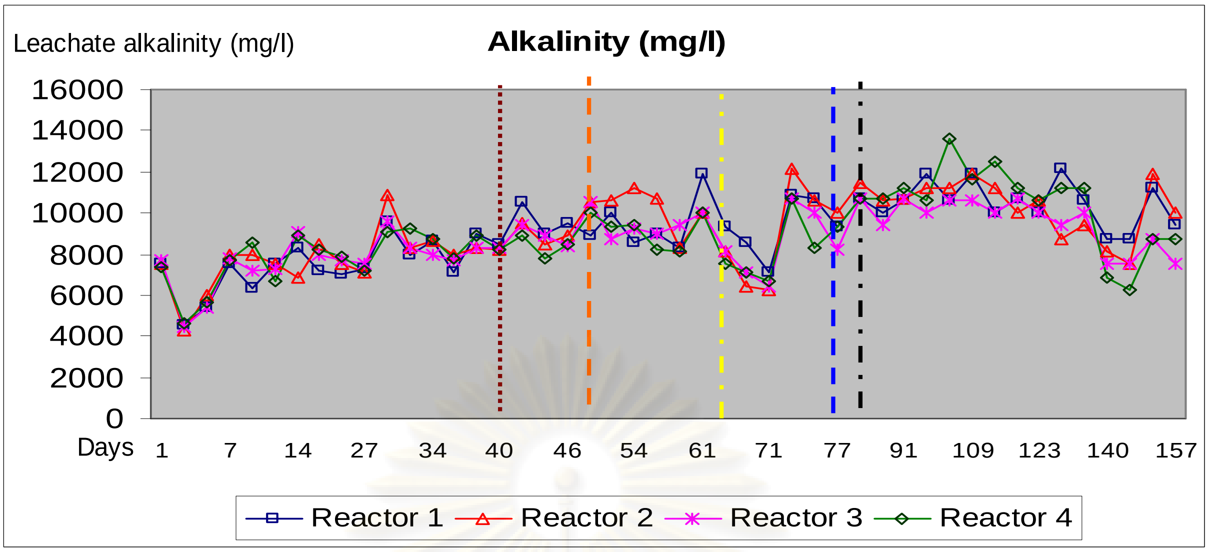
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.6 ORP in leachate from the simulated anaerobic organic waste reactors.

Oxidation-reduction potential (ORP) was measured to indicate the oxidizing or reducing conditions prevailing in the landfill bioreactors. Once the trapped air introduced with the refuse was depleted, the simulated landfill systems became anoxic, and proceeded to anaerobic. Then, the ORP became negative. Measured ORP values for all reactors are presented in figure 4.6 and Table A-8 Appendix A. the transition from oxidizing to reducing conditions in the four landfill cells was consistent with the development of acidogens, acetogens, and methanogens which gave rise to various intermediate and final products influencing the change in ORP value.

The initial value of leachate ORP was 5.2, 8.4, 1.8 and 5.6 mV in reactor1, 2, 3 and 4, respectively. Leachate ORP in every reactor was abruptly drop to -168.4, -174.6, -196.5 and -182.5 on Day 6 which preliminary due to the oxygen has been depleted and the condition was turned to anoxic and anaerobic, respectively. The attempt of leachate loading variation has been made on Day 6 which resulted to different ORP characteristic. During early acid phase, leachate ORP from high VFA loading input to reactor 3 and 4 showed more negative of ORP value than low VFA loading input to reactor1 and reactor 2 inferring that high leachate recycle volume can exhibit more reducing condition in anaerobic degradation system especially for early acid phase during Day 7 to Day 40 with the result of higher biogas production and higher methane percentage, as well. Leachate ORP from all bioreactors fluctuated in the range of -100 to -210 mV during acid phase meaning that the environmental system was still not be suitable for methanogenic bacteria growth since almost key parameters in the system were predominant in the oxidation form as indicated from stable low methane percentage in every bioreactors. Consequently, the attempt of leachate neutralization has been attempted to all reactors on Day 40 which explicit the high negative ORP value within the range of -339.1 mV to -372.6 mV in reactor 4 after 54 days of operation. Whereas, the ORP value from other bioreactors was less increase in the range of -134.7 mV to -191.0 mV ,- 140.1 mV to -219.8 mV , -134.2 mV to -237.0 mV in reactor 1, reactor 2 and reactor 3, respectively. High daily volatile fatty acid loading into reactor could enhance the faster anaerobic degradation since the ORP value in reactor 4 was much more negative emphasized the reducing condition in the anaerobic system that enhance the methane phase degradation. ORP was turned to more negative than -250 mV which indicated the methane degradation readiness (Jaijongrak, 2003) in reactor 1, 2, 3 and 4 after 80, 75, 71 and 51 days of operation, respectively exhibited the faster anaerobic acid phase degradation from higher leachate volatile fatty acid loading input as indicated from the result of ORP after 71 days of operation was -195.0, -228.3. -258.2 and -394.7 mV paralleled to daily methane gas generation 61, 81, 137 and 140 ml in reactor 1, 2, 3 and 4, respectively. After the attempt of leachate volatile fatty acid loading contributed to the daily methane gas output has been made, ORP from all bioreactors could stand higher negative than – 250 mV since the ORP value during Day 80 to Day 123 was in the range of (-223.1) to (-404.5) mV, (-271.6) to (-447.5) mV, (-252.3) to (-479.5) mV and (-328.1) to (-478.5) mV in reactor 1, 2, 3 and 4, respectively. This condition exhibited the optimized environmental condition for methane phase degradation and could be utilized to create the mathematical model for methane gas generation system.

4.2.4 Leachate Alkalinity



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.7 Leachate alkalinity from the simulated anaerobic organic waste reactors.

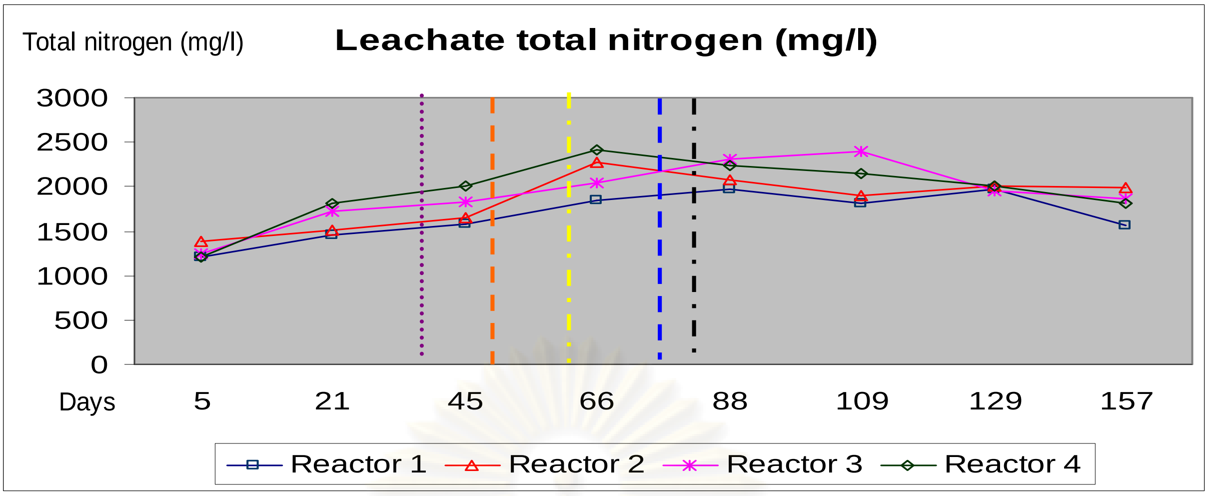
The alkalinity of water is a measure of its capacity to neutralize acids and is due primarily to the salts of weak acids. If the acid concentrations (H_2CO_3 and VFA) exceed the available alkalinity, the landfilling bioreactor will sour. This will be severely inhibiting the microbial activity, especially the methanogens. When methane production becomes ceases the VFA may continue to accumulate. Methanogens prefer nearly neutral pH conditions with a generally accepted optimum range of approximately 6.5–8.2 (Speece, 1996). The total alkalinity of leachate during the acid formation phase is dominated by the volatile organic acids and the associated buffer system due to the high concentrations present and the fact that they are stronger acids than those constituting the bicarbonate buffer system. The total alkalinity concentrations are presented in Figure 4.7 and Table A-9 Appendix A.

The initial leachate alkalinity from four bioreactors was 4,545, 4,250, 4,474 and 4,596 mg/l as $CaCO_3$ in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. After frequently leachate has been recirculated to all bioreactors, the leachate alkalinity slightly increased to 7,000, 7,500, 7,727 and 7,857 mg/l as $CaCO_3$ after 21 days of operation; however, the alkalinity during this period was competitive with volatile organic acids as the total alkalinity was quite stable in the range 7,000-9,000 mg/l as $CaCO_3$ during 38 days of operation. As the result of leachate neutralization, alkalinity on Day 48 rose to 8,889 mg/l, 10,556 mg/l, 10,500 mg/l and 10,000 mg/l in reactor 1, 2, 3 and 4, respectively. The rose of alkalinity would be helpful to the pH balance in anaerobic bioreactor system since alkalinity would compete with volatile fatty acid and carbon dioxide partial pressure in order to balance the acidic condition in the system. The alkalinity from all reactors demonstrated similar trend graph that quite stable in the range of 7,500 mg/l to 11,875 mg/l during Day 40 to Day 63. During Day 73 to Day 160, leachate alkalinity was quite stable within the range of 9,286-11,875 mg/l, 10,000-11,875 mg/l, 9,375-10,714 mg/l and 9,286-13,571 mg/l in reactor 1, 2, 3 and 4, respectively. This alkalinity could adequately compete to volatile fatty acid and carbon-dioxide partial pressure during methane phase generation as indicated from the pH value that could settle above 7.

4.3 Leachate nutrients analysis

Nitrogen and Phosphorus are the essential nutrients required for anaerobic organic waste stabilization. Nitrogen is needed for the production of protein, enzyme, ribonucleic acid (RNA) and deoxyribonucleic acid (DNA). Phosphorus is used to synthesize energy-storage compounds (adenosinetriphophate- ATP) as well as RNA and DNA (Chain and De Walle, 1976). Result of leachate nitrogen and phosphorus were explained as following detail.

4.3.1 Total kjeldahl nitrogen



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

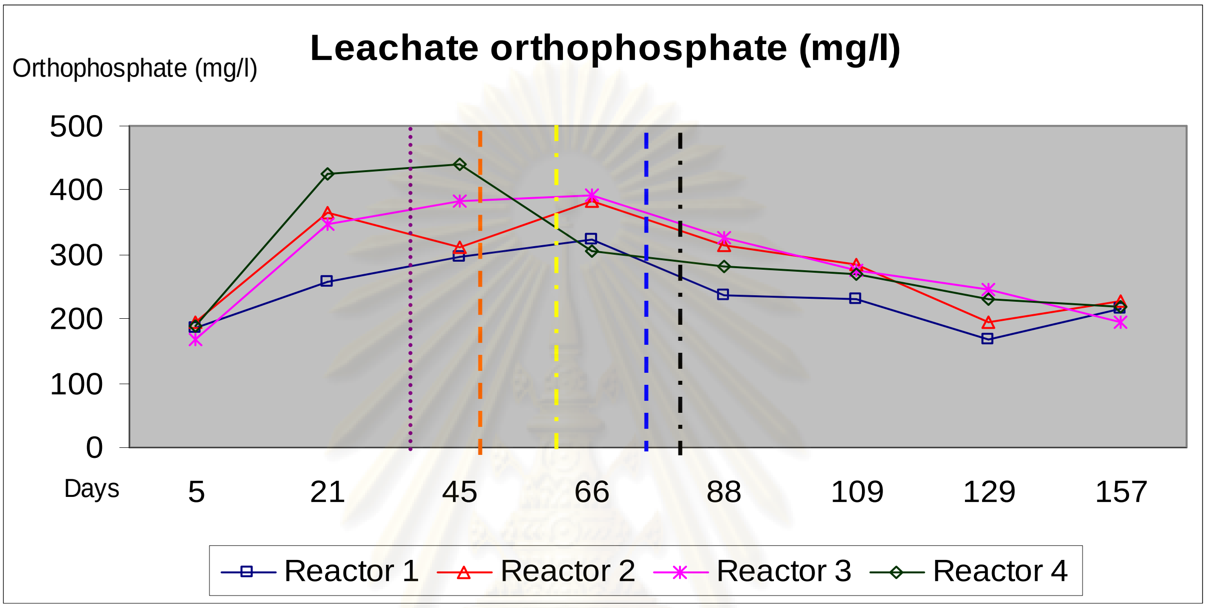
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.8 Leachate total nitrogen from the simulated anaerobic organic waste reactors

The total kjeldahl nitrogen is the combination of ammonia nitrogen and organic nitrogen. Ammonia nitrogen is a readily available form for microbial utilization of nitrogen, and is produced from decomposition of organic materials containing nitrogen. Nitrogen that represents in organic materials is called organic nitrogen. Measurement of total nitrogen was performed to assess nutrient availability in simulated landfill reactors. The results of analyses are expressed in mg/L of nitrogen and are presented in Figure 4.8 and Table A-10 Appendix A.

Initial total nitrogen was 1,205, 1,316, 1,248 and 1,210 mg/L in reactor 1, 2, 3, 4, respectively. The initial leachate total nitrogen from all reactors was similar, suggesting uniformity in refuse composition. However, leachate total nitrogen seemed to be different after daily leachate volatile fatty acid variation. Leachate total nitrogen result on Day 45 was 1,583, 1,644, 1,824 and 2,006 in reactor 1, 2, 3 and 4, respectively. Highest leachate total nitrogen nutrient was observed from highest daily volatile fatty acid loading in reactor 4 since highest daily leachate volume was employed and resulting in highest rate of substrate leaching to the system. In addition, high volume of nutrient was daily recirculated back to bioreactor system from. Leachate total nitrogen from all reactors was sufficient for this anaerobic degradation as indicated from the result of COD:N ratio that was entirely under 33:1 to 14:1 and was higher than the value of 39:1 from Dewalle 's study (Dewalle, 1977).

4.3.2 Orthophosphate



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.9 Leachate orthophosphate from the simulated anaerobic organic waste reactors.

Orthophosphate was measured as an indication of phosphorus availability to anaerobic microbial utilization. Orthophosphate data expressed in mg/L of phosphorus are presented in Figure 4.9 and Table A-11 Appendix A.

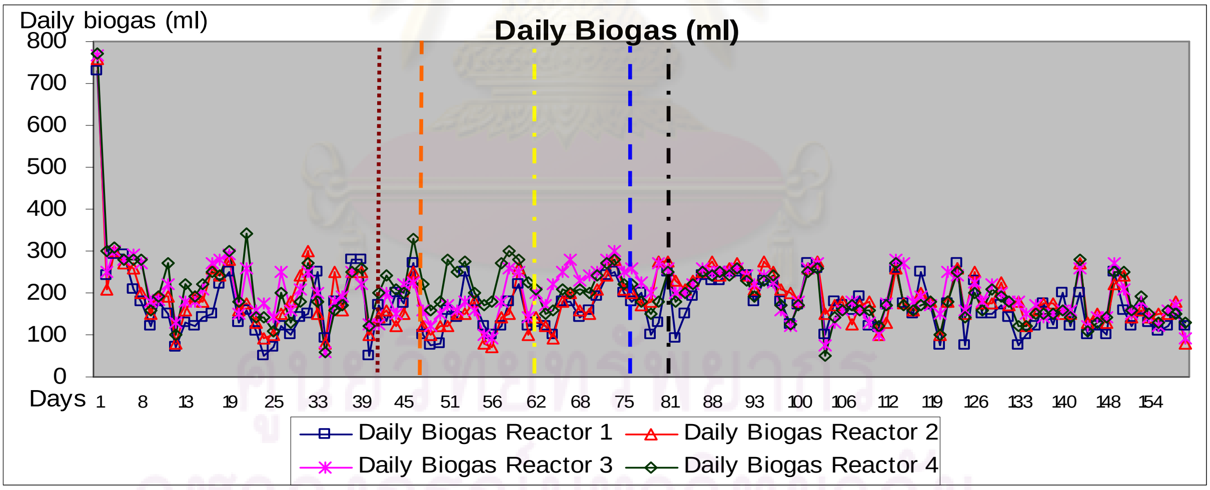
Leachate orthophosphate was initially 186, 196,168 and 188 mg/l in reactor 1, 2, 3 and 4, respectively. Leachate orthophosphate gradually increased during first 66 days operation as waste was hydrolyzed and degraded. After that, leachate orthophosphate decreased with time due to orthophosphate assimilation by microorganisms. This behavior was in conformity with an extensive use of phosphorus and its possible precipitation. During first 45 days, leachate orthophosphate was the highest in reactor 4 since highest volume of daily leachate recycled to the system, cycling orthophosphate back to the bioreactor. Leachate orthophosphate from all reactors was sufficient for anaerobic organic waste degradation as indicated from COD:P ratio that stayed within the range of 133:1 to 384:1 that was higher than the minimum ratio of 2,200:1 based on McCarty and Speece study (McCarty and Speece, 1963).

4.4 Gas analysis

Gas volume and gas composition from three simulated landfill reactors were monitored as the main indicators of the progression of solid waste stabilization processes and as an indicator of the rate of biological activity and organic material conversion within the landfill environment.

4.4.1 Daily biogas production

Daily gas productions volumes were shown in figure 4.10 and Table B-1 Appendix B.



……… Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

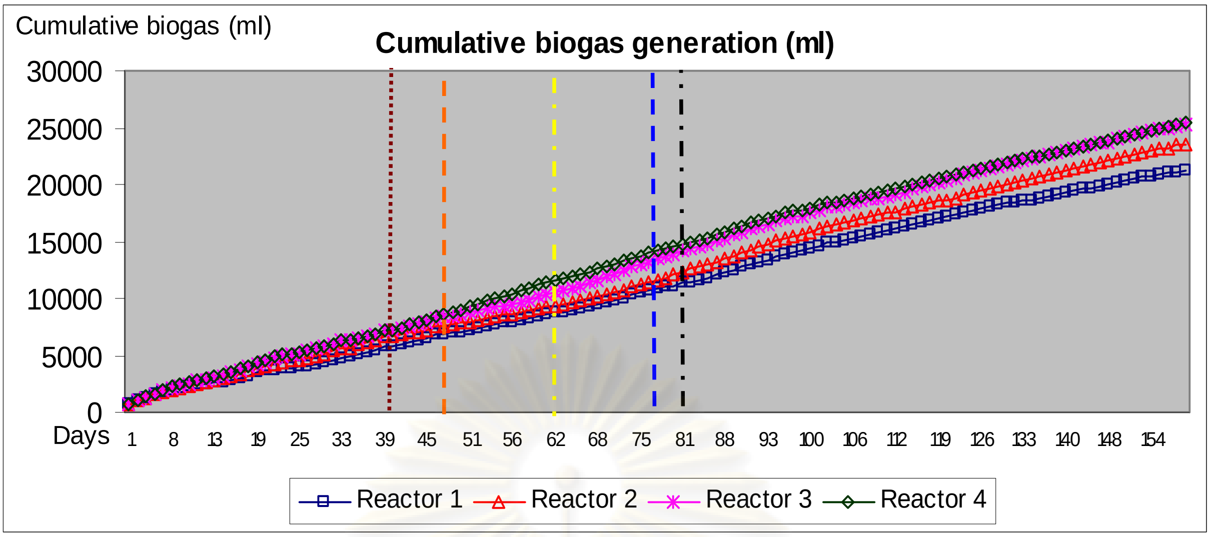
--------Application of leachate recirculation based on methane volume in reactor 2

--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.10 Daily biogas productions from the simulated anaerobic organic waste reactors.

Initially, daily biogas was quite high for all bioreactors. This was due to the fast hydrolysis of anaerobic organic waste degradation with CO2 as the major component. Daily biogas after 5 days of operation was in the same range of 290-310 ml within all bioreactors. However, Daily biogas pattern from each bioreactor tended to be different after the variation of leachate recirculation has been started. During acid phase, high daily biogas generation could be observed in high daily VFA loading input through leachate recirculation in reactor 3 and reactor 4 when comparing to daily biogas from low daily VFA loading input in reactor 1 and reactor 2. The daily biogas on Day 21 was 160 ml, 175 ml, 260 ml and 340 ml in reactor 1, reactor 2, reactor 3, and reactor 4, respectively. This was due to the fact that high VFA loading input through leachate recirculation could be utilized as the substrate for biogas generation, without unacceptable level of VFA concentration in the system, and was confirmed from the result of similar pH and leachate VFA concentration from high and low VFA loading bioreactors. Daily biogas generation was different during 40 days of operation in the range of 50-280 ml, 80-300 ml, 60-290 ml and 60-340 ml in reactor1, reactor 2, reactor 3 and reactor 4, respectively. The highest daily biogas during Day 40 to Day 62 has been observed in reactor 4 after the attempt of leachate neutralization has been started on Day 40. High daily volatile fatty acid loading in reactor 4 received fast degradation as indicated from neutral pH and high negative ORP value on Day 48. This favored the methane generation as the main component in biogas product. This was confirmed from the result of daily biogas during Day 48 to Day 67 was in the range of 75-250 ml, 70-260 ml, 90-280 ml, 170-300 ml in reactor 1, 2, 3 and 4, respectively. In addition, the attempt of leachate volatile fatty acid loading based on daily methane gas generation within the suitable condition was applied to reactor 4 on Day 48. This attempt was made to reactor 3 after 62 days of operation which resulted to the good daily biogas production in reactor 3, as well. Reactor 2 and reactor 1 was changed to the VFA loading based on daily methane gas after the condition was turned to the suitable environment for optimized methane phase degradation (pH>7, methane percentage > 50% (Jaijongrak, 2003)) after 76 and 81 days of operation, respectively. During day 82 to Day 160, all bioreactors could performed good biogas generation which daily biogas production from all bioreactors exhibited similar trend graph that fluctuated in the range 50-280 ml.

4.4.2 Cumulative biogas production



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

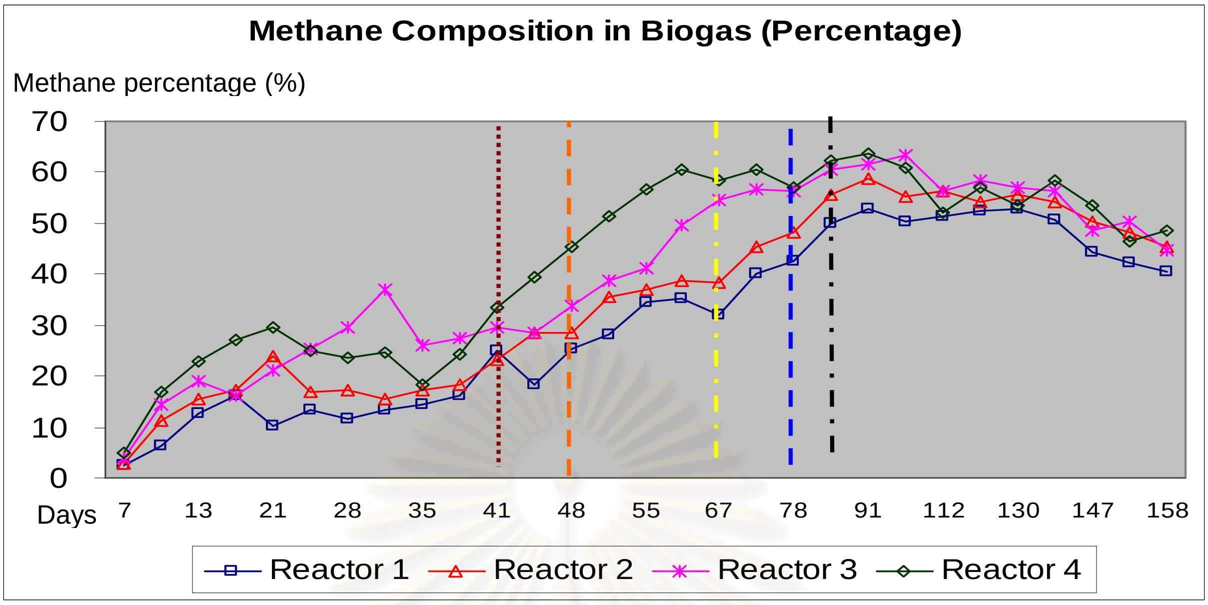
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.11 Cumulative biogas productions from the simulated anaerobic organic waste reactors.

Cumulative biogas production was detected to identify the stabilization pattern from VFA loading factor variation in anaerobic waste degradation and was shown in figure 4.11 and Table B-2 Appendix B.

Initially, cumulative biogas production from all bioreactors was similar in the range of 1,550-1,660 ml before variation of leachate recycle has been attempted. After the variation of leachate recycle has been made, the difference of cumulative biogas has been noticed with the result of higher cumulative biogas production from high daily VFA loading input through leachate recirculation in reactor 3 and reactor 4 as indicated from the cumulative biogas after 24 days of operation was 3,920 ml, 4,475 ml, 5,025 ml and 5,160 ml in reactor 1, 2, 3 and 4, respectively. The result implied that leachate recirculation contributed to high VFA loading input and better moisture distribution in the system that could generate more cumulative biogas production. Since VFA was considered as the major substrate for bacteria to generate the biogas output which has been confirmed from the result of cumulative biogas production after 40 days of operation which was 5,805 ml, 6,685 ml, 7,260 ml and 7,250 ml in reactor 1, 2, 3 and 4, respectively. The cumulative biogas production after 40 day operation was quite similar in reactor 3 and reactor 4. However, after leachate neutralization on Day 40 and leachate recirculation based on methane gas volume on Day 48 in reactor 4 has been conducted, the difference of cumulative biogas production could be noticed with the result of highest to lowest biogas production after 67 days of operation in reactor 4, reactor 3, reactor 2 and reactor 1, respectively. The result indicated that the highest daily volatile fatty acid loading input from this experiment (9,800 mg in reactor 4) could exhibited the fastest moving through the acid phase to the methane phase degradation as indicated by neutral pH, highest negative ORP value and highest methane percentage on Day 48. In addition, reactor 3 (4,900 mg of daily VFA loading) showed high biogas production potential on Day 62 since the pH and ORP was quite favor to the methane phase degradation. The attempt of leachate VFA loading based on daily methane generation was done on Day 62 in reactor 3 which speeded up the cumulative biogas production to be closed to those in reactor 4 though the entire experiment. The cumulative biogas generation in reactor 1 and reactor 2 was quite lower than those in reactor 3 and reactor 4 since the cumulative biogas value during Day 160 was 21,260 ml, 23,505 ml, 25,255 ml and 25,365 ml in reactor 1, 2, 3 and 4, respectively. High biogas output would contribute to the possibility of high methane production and faster anaerobic degradation, as well. The result showed that leachate recirculation during acid phase should receive than 4,900 mg volatile fatty acid loading per day to optimize the anaerobic degradation system.

4.4.3 Methane composition in biogas



········· Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

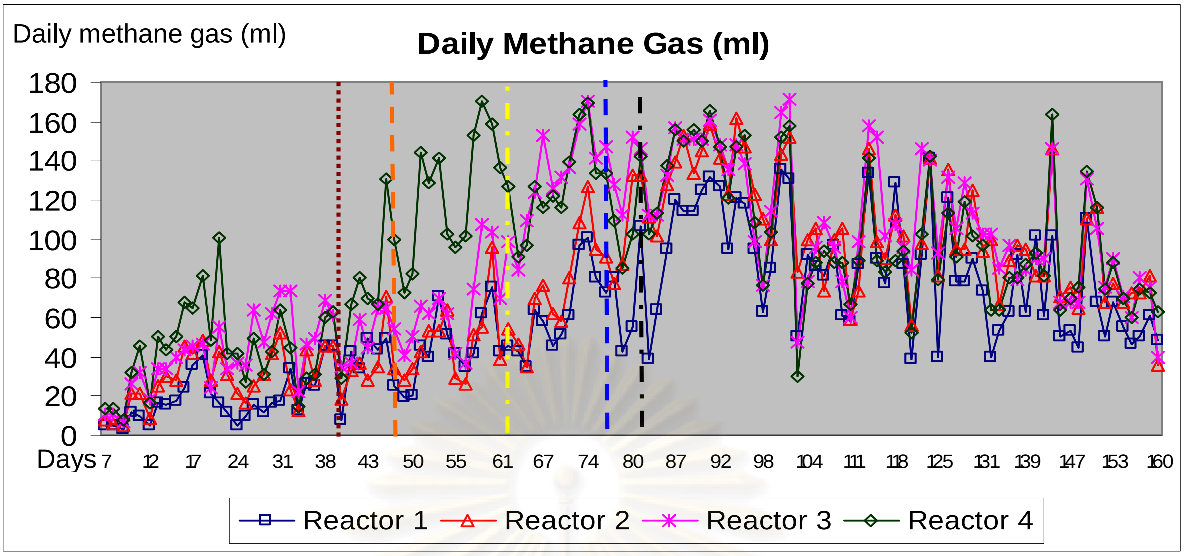
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.12 Methane compositions (percentage) in biogas from the simulated anaerobic organic waste reactors.

Methane composition in biogas was the key parameter to explicit the anaerobic organic waste stabilization since the methane percentage in biogas would describe whether the methanogenic bacteria or methane phase would activate or not. Methane composition in biogas was shown in figure 4.12 and Table B-3 Appendix B.

Methane percentage from every bioreactor was quite similar after 7 days of operation which was stable in the range of 2.5-5%. However, after the variation of daily leachate recirculation based on amount of VFA loading input occurred, the difference of methane percentage in biogas was established. Methane percentage from high leachate VFA loading bioreactor in reactor 3 and reactor 4 was higher than those from low leachate VFA loading bioreactor in reactor 1 and reactor 2 as indicated from the methane percentage after 25 days operation was 13.29%, 16.75%, 25.36% and 24.82% in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. Furthermore, the result after 38 days of operation could be confirmed on this matter since methane percentage from reactor 1 to reactor 4 was 16.23%, 18.16%, 27.50% and 24.18%. Consequently, the result could be inferred that higher daily VFA loading input could promote waste stabilization to methane. However, the methane percentage during Day 21 to Day 38 was still low since pH in the system was not suitable to methanogenic condition as indicated from the stably low methane percentage of 10.22-16.23%, 17.26-24.06%, 21.13-36.81% and 18.12-29.54% in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. After leachate neutralization has been performed on Day 40, the methane percentage during Day 55 rose to 34.40%, 36.84%, 41.24%, and 56.62% in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. The result showed that the highest daily volatile fatty acid loading from this experiment (9,800 mg in reactor 4) could be faster turn the acid phase to the methane phase degradation as indicated from the highest methane percentage in reactor 4 biogas component. In addition, after the leachate recirculation based on daily methane gas output has been done in reactor 4 on Day 48, the methane percentage was gradually increase in the range of 51.38%- 60.46% expressed very active condition under methane phase degradation. Furthermore, the high value of methane percentage within the range of 49.56%-54.65% was observed in reactor 3 after 61 days of operation which can be inferred that daily volatile fatty acid loading of 4,900 mg in reactor 3 could be more rapidly stabilization when comparing to lower daily volatile fatty acid loading input in reactor 1 and reactor 2. In addition, methane percentage in reactor 1 and 2 was over 50% after the environment in anaerobic degradation was suitable (pH > 7, ORP < -250 mV (Jaijongrak, 2003)) and it was happen after 85 days of operation. This result could confirm daily volatile fatty acid loading of 4,900 mg and 9,800 mg in reactor 3 and reactor 4 could promote anaerobic degradation, especially for acid phase degradation. However, after all bioreactors exhibited the optimum methane phase degradation during Day 85 to Day 139, methane percentage from all reactors could stand within the range 50.32 -63.80 % explicated the high methane percentage yield during methane phase. However, methane percentage from all reactors tended to be dropped after 139 days of operation since volatile fatty acid concentration, considered as substrate for methanogenic bacteria in process to generate the methane gas output, was decreased. This situation may be implied that the food started to be depleted and not adequate to feed methanogenic microbes in the system. The result of methane percentage after 160 days operation was dropped to 40.48, 45.26, 44.53 and 48.65 in reactor 1, 2, 3 and 4, respectively.

4.4.4 Daily methane gas



……… Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

---------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

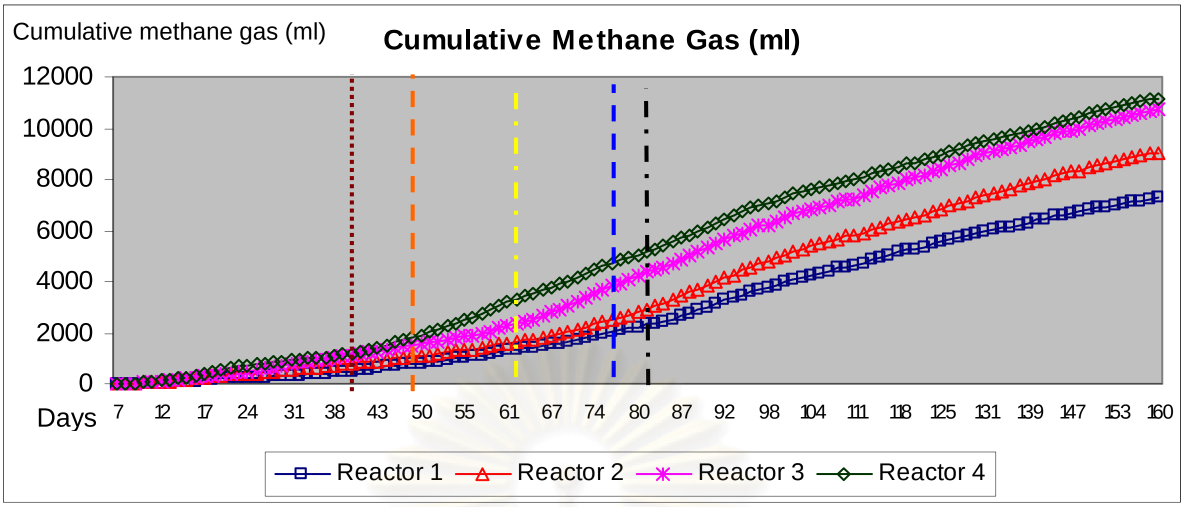
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.13 Daily Methane gas in biogas from the simulated anaerobic organic waste reactors.

The daily methane gas was also the key parameter for anaerobic organic waste degradation which performed the organic waste stabilization pattern. Daily methane gas was shown in figure 4.13 and Table B-4 Appendix B.

Initially, the daily methane gas was quite low as indicated from the daily methane gas of 3-8 ml after 9 days of operation since the anaerobic organic waste stabilization was on early acid phase that almost the component in biogas was carbon dioxide. The difference of daily methane gas after the variation of leachate recirculation has been attempted with the result of higher daily methane gas from high daily VFA loading input in reactor 3 and reactor 4 when comparing to the daily methane gas in reactor 1 and reactor 2 which contributed to the result of more methane percentage and biogas production as indicated from daily methane gas on 15 days of operation was 18 ml, 28 ml, 40 ml and 50 ml in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. Daily methane gas during Day 15 to Day 40 was quite low in the range of 5-45 ml, 9-52 ml, 19-69 ml and 15 -100 ml in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. Hence, the attempt of leachate neutralization has been performed on Day 40 which resulted in abrupt increase of daily methane gas in reactor 4 as indicated from the daily methane gas output 131 ml on Day 46 since pH was adjusted to be suitable to the methanogenic bacteria and it was high recycled back to reactor to optimize the daily methane gas production. The other reactors methane volume was not too much increased when compared to reactor 4 which received high daily volatile fatty acid loading. The result showed that high daily volatile fatty acid loading through leachate recirculation could add the moisture and substrate in the system without adverse effect from volatile fatty acid accumulation. This enhanced faster degradation during acid phase. High daily methane gas within the range of 91 -170 ml during Day 51 to Day 67 was observed in reactor 4. Reactor 3 was also displayed high daily methane gas after 59 days of operation as indicated from the result of 107 ml methane gas output which parallel to the rose in pH and higher negative ORP value, while reactor 2 and 1 on that day was only 62 ml and 55 ml, respectively. After reactors 1 and 2 could adapt to suitable environmental condition for methane gas generation (pH > 7, methane percentage > 50% (Jaijingrak, 2003)), daily leachate VFA loading input based on daily methane gas output was applied on day 76 and day 81 in reactor 2 and reactor 1, respectively. This significantly affected daily methane gas output that could be closed to daily methane gas generation in reactor 3 and reactor 4. The CH_4 gas production on Day 114 was 134 ml, 146 ml, 158 ml and 141 ml in reactor 1, 2, 3 and 4, respectively. During Day 81 to Day 150, daily methane gas from all bioreactors showed similar trend graph that fluctuated in the range 38 - 171 ml. The reason of daily methane gas fluctuation may be due to daily temperature fluctuation during cold seasoning that impacted the methanogenic bacteria in process and gas expansion. In addition, less daily methane gas from all reactors after 150 days operation could be noticed since leachate volatile fatty acid concentration was dropped together with relatively lower methane percentage in biogas. Daily biogas during day 160 was 49 ml, 36 ml, 40 ml and 64 ml in reactor 1, 2, 3 and 4, respectively. The result may be implied that almost substrate was depletion that could not be utilized for methane gas output and organic waste tended to be stabilization.

4.4.5 Cumulative methane gas production



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

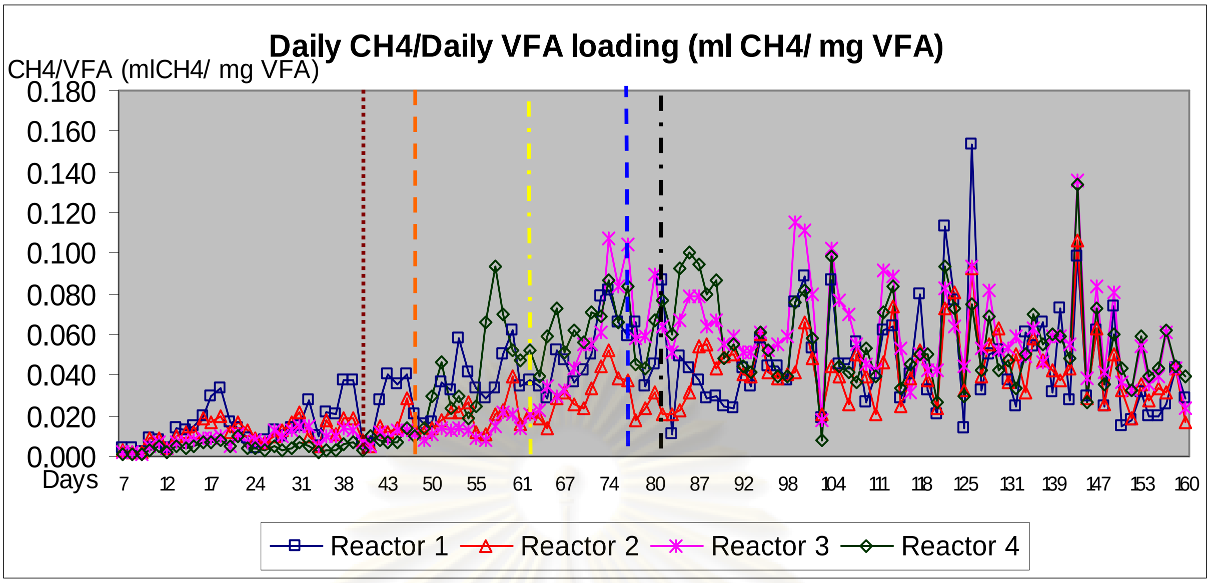
--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.14 Cumulative methane gas from the simulated anaerobic organic waste reactors.

The cumulative methane gas was also the key parameter for anaerobic organic waste degradation which performed the organic waste stabilization and optimized output. Cumulative methane gas was shown in figure 4.14 and Table B-5 Appendix B.

The cumulative methane gas implied the activation of methane gas in anaerobic organic waste degradation system. Initially, the cumulative methane gas from all reactors was quite low as indicated from the result of cumulative methane gas after 40 days of operation was 509 ml, 793 ml, 1134 ml and 1205 ml in reactor 1, reactor 2, reactor 3 and reactor 4, respectively. This was preliminary due to the condition was run under acid phase on anaerobic degradation that pH stayed in the range of 5-6 that was not suitable to the methanogenic bacteria growth. The result also showed that high daily VFA loading through leachate recirculation in reactor 3 and reactor 4 enhance anaerobic degradation during acid phase as indicated from slightly more methane percentage and cumulative methane gas production. The attempt of leachate neutralization has been made on Day 40 which resulted to abrupt increase of cumulative methane gas in reactor 4; whereas, the other reactors did not show significant increase in cumulative methane gas production. The result of abrupt increase of cumulative methane trend graph in reactor 4 after leachate neutralization may contribute to high daily volatile fatty acid loading that could be well utilized as substrate under favorable condition for methane phase degradation. Result also showed that high daily leachate VFA loading was very beneficial to shorten the degradation time during acid phase. In addition, the attempt of leachate recirculation based on daily methane gas generation and volatile fatty acid loading has been conducted on Day 48 in reactor 4 where influencing components of methane phase in biogas, pH and ORP was at the optimum. This resulted to the rise in cumulative methane generation to 4,306 ml after 73 days of operation. While the reactor 3 was turned to methane phase after 62 days operation as indicated from pH that was higher than 7; hence, the attempt of leachate volatile fatty acid loading based on daily methane gas generation has been done with the result of cumulative methane gas increase to 3,362 ml after 73 days of operation. While the cumulative methane gas on Day 73 in reactor 1 and reactor 2 was 1,794 ml and 2,194 ml, respectively. Influencing factor to methane phase was favorable after 76 and 81 day operation in reactor 1 and reactor 2, respectively. Slower degradation from reactor receiving low leachate VFA loading would be observed. Cumulative methane gas trend graph showed significant increase after all reactors were run under favorable environment and leachate volatile fatty acid to methane gas output scheme was applied. Cumulative methane gas under 123 days of operation was 5,506 ml, 6,750 ml, 8,332 ml and 8,891 ml. The result implied that daily volatile fatty acid loading more than 4,900 mg would be beneficial to the anaerobic organic waste degradation through the optimize methane gas output within shorter duration time. The result of cumulative methane gas production entire the experiment after 160 days of operation was 7,267 ml, 9,046 ml, 10,712 ml and 11,170 ml in reactor 1, 2, 3 and 4, respectively. The opportunity for methane gas promotion could be observed in reactor 3 and reactor 4.

4.4.6 Daily CH4/ Daily VFA loading



.... Application of buffer neutralization

--------- Application of leachate recirculation based on methane volume in reactor 4

--------Application of leachate recirculation based on methane volume in reactor 3

--------Application of leachate recirculation based on methane volume in reactor 2

--------Application of leachate recirculation based on methane volume in reactor 1

Figure 4.15 Daily methane gas output per daily volatile fatty acid loading input from the simulated anaerobic organic waste reactors.

Daily methane gas output per daily volatile fatty acid was analyzed to define the methane phase degradation efficiency on anaerobic organic waste stabilization and was shown in figure 4.15 and Table B-6 Appendix B.

Initially, the ratio of daily methane gas output per daily volatile fatty acid loading from all reactors was quite low which was stable in the range of 0.001- 0.040 ml CH_4/ mg VFA, since the reactor was under acid phase condition that almost volatile fatty acid was the main product during this period. In addition, the methanogenic bacteria could not grow well during this period to utilize the daily volatile fatty acid input and to generate the methane gas output which was confirmed from the parallel result of high volatile fatty acid concentration in bioreactor system. However, the daily volatile fatty acid loading could enhance the moisture content to the system and opportunity for bacteria to contact to the substrate that could enhance the degradation. In addition, the attempt of leachate neutralization has been made on Day 40 which changed the daily methane gas generation output /daily VFA loading input in reactor 4 on Day 56 to Day 71 in the range of 0.040-0.094 ml CH_4/ mg VFA. This was the highest ratio when comparing to the other reactors on those periods since the environmental condition in reactor 4 was fast to turn to be more favorable when comparing to the other bioreactors. The active of methane degradation system could be well observed on reactor 4 since almost volatile fatty acid loading could be well utilized by the bacteria in system to generate the methane gas output. In addition, the daily methane gas per daily volatile fatty acid loading was abrupt increase in reactor 3 after the leachate recirculation based on daily methane gas volume been made on Day 62 as a result the ratio was 0.107 after 74 days of operation. Daily CH4 / daily VFA loading yield in reactor 2 and reactor 1 was also increased after the pH was turned to 7 approximately 76 days and 81 days of operation, respectively. After 81 days of operation, all bioreactor could run according to the methane phase degradation scheme. So, all reactors exhibited similar daily CH_4/ daily VFA loading trend graph that ratio was high and fluctuated in the range 0.020- 0.107 daily CH4/ daily VFA loading.

4.5 Analysis of methane percentage relation during acid phase

From previous result, it could be concluded that the optimized anaerobic organic waste degradation was occurred in reactor 4 with daily 9,800 mg volatile fatty acid loading during initial phase. Hence, this part would study the degradation pattern and other criteria to determine the reasons and to define the suitable degradation for anaerobic organic waste application.

4.5.1 Methane percentage and leachate oxidation reduction potential during acid phase

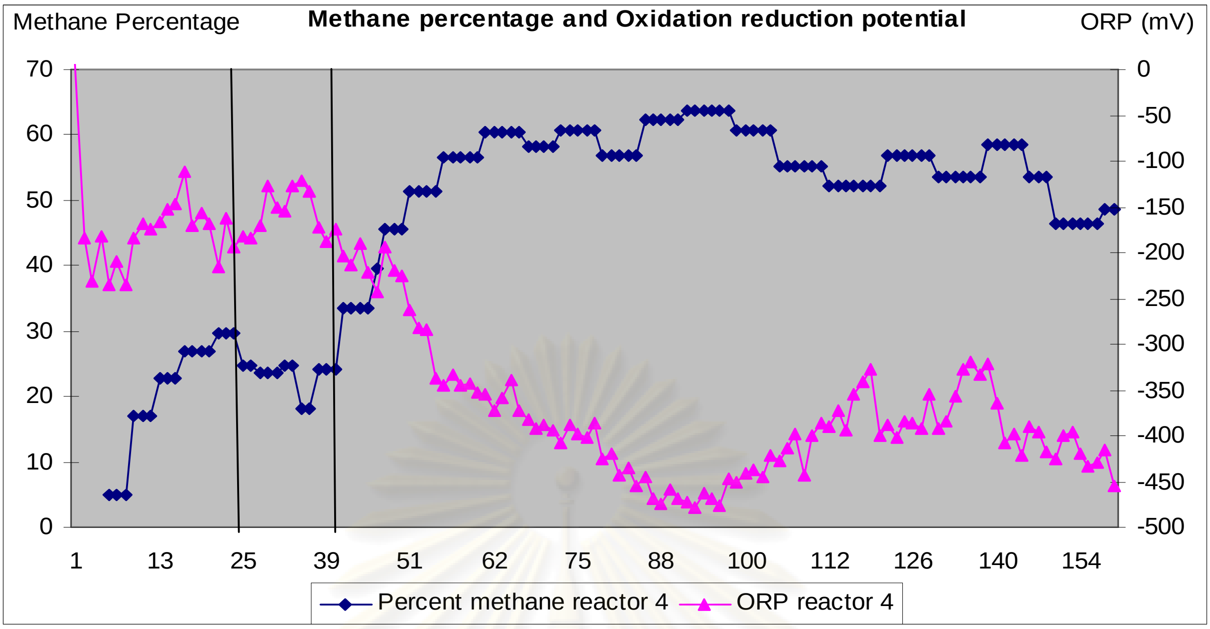


Figure 4.16 Methane percentage and leachate oxidation reduction potential during initial acid phase in simulated bioreactor 4.

Figure 4.16 explained the relationship between methane percentage and oxidation reduction potential. At first 24 days, Methane percentage in reactor 4 gradually rose from 5% to 29.54% contributed to daily 9,800 mg VFA loading. Positive result occurred during early acid phase degradation since ORP gradually dropped due to the system environmental condition that turned from aerobic to anoxic and anaerobic, respectively. Also, the initial condition was turned to reductive products. Inhibition behavior could be observed after 24 days of operation since methane percentage dropped from 29.54% to 18.12% on Day 36. ORP result rose from -194.7 mV to -134.3 mV on Day 36 that may refer to unfavorable environmental condition. The result from this study also confirmed that cumulative VFA loading, methane percentage and ORP were interrelated. After system could adapt to daily 9,800 mg VFA loading on Day 38, methane percentage rose to 51.38% on Day 51 as well as leachate ORP which dropped within the range -172.3 mV-261.8 mV. Under these criteria presented suitable methane phase degradation. From this study, ORP during the acid phase was investigated within the range of -120.9 mV to -184.6 mV.

4.5.2 Methane percentage and leachate VFA concentration during acid phase

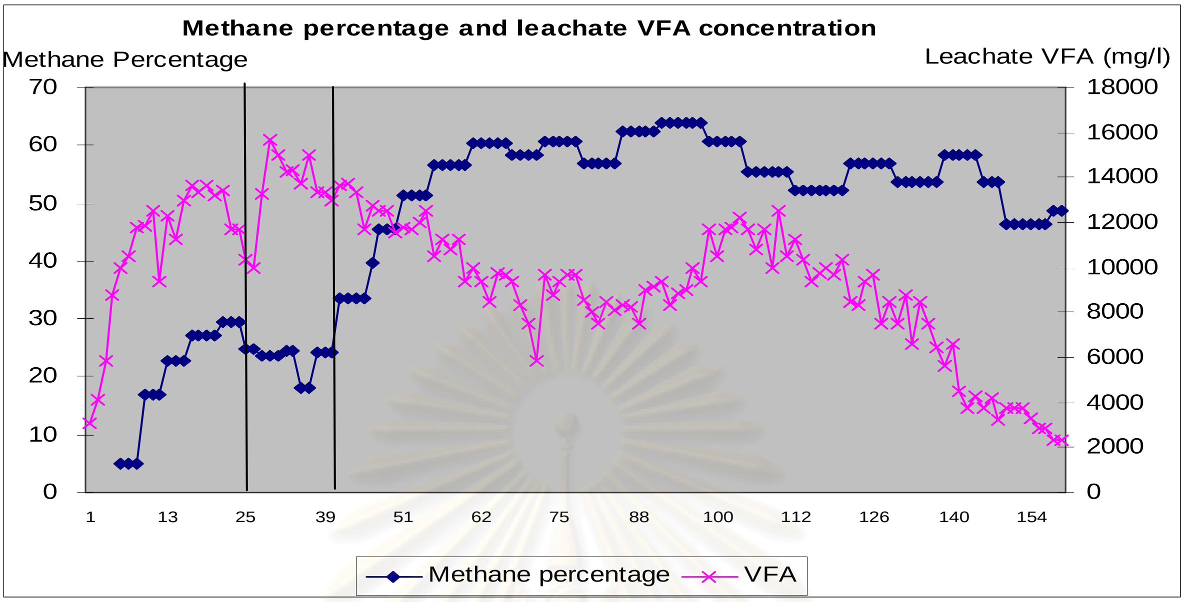


Figure 4.17 Methane percentage and leachate volatile fatty acid concentration during initial acid phase in simulated bioreactor 4.

Figure 4.17 explained the relationship between methane percentage and leachate VFA concentration in reactor 4. Leachate VFA concentration gradually raised from 3,068 mg/l on Day 1 to 13,676 mg/l on Day 16 that caused the rise of methane percentage from 5% to 29%. However, retardation was observed on Day 25 to Day 36 since methane percentage dropped from 29.54% on day 24 to 18.12% on Day 36 since leachate volatile fatty acid concentration gradually increased to approximately reach 15,000 mg/l that was highest value among the entirely study. High acid condition during this period was not suitable for methane gas generation and caused methane percentage decrease. Leachate VFA concentration exhibited lower trend graph that dropped to 11,786 mg/l on Day 51 with the result of methane percentage rise to 51.38% since leachate VFA during this period was well utilized as substrate for methane gas generation under favorable environment condition as indicated from medium pH establishment in leachate. During Day 50 to Day 150, methane percentage above 50% and leachate VFA concentration trend graph dropped explained the progress of optimum anaerobic organic waste degradation for optimized methane gas output. Leachate VFA was used as substrate and tended to be depleted on Day 160 showed the progress of organic waste stabilization since leachate VFA concentration during day 160 dropped to 2,344 mg/l even though daily leachate recirculation has been employed.

4.5.3 Methane percentage and leachate VFA/COD ratio during acid phase

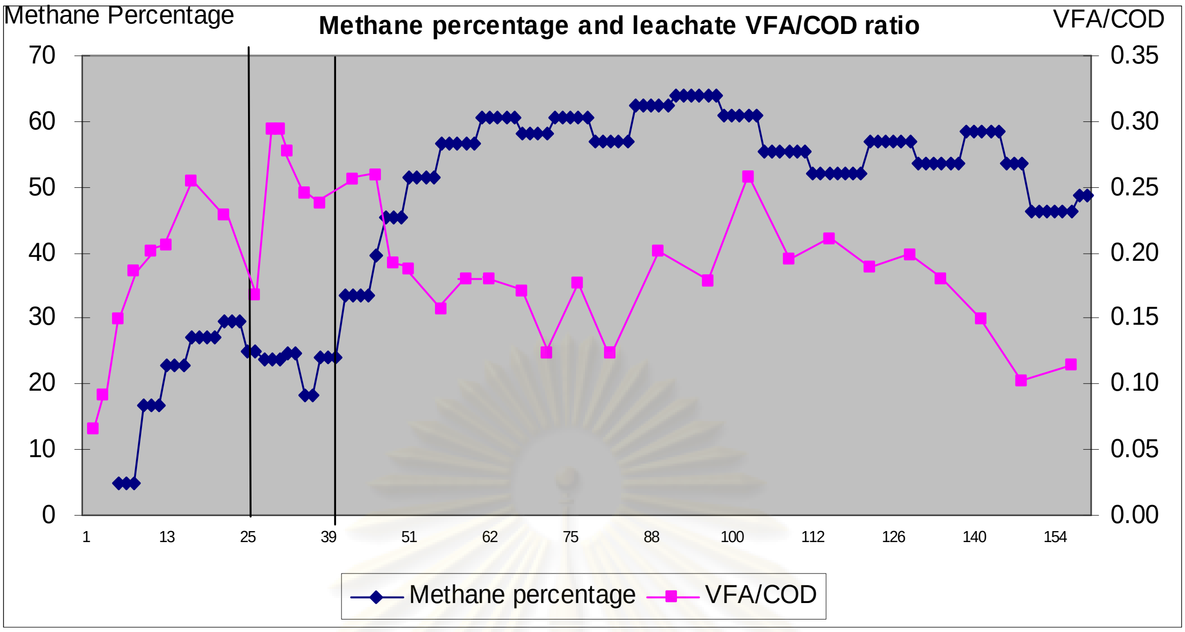


Figure 4.18 Methane percentage and the ratio of leachate VFA/COD during initial acid phase in simulated bioreactor 4.

Figure 4.18 presented the relationship between methane percentage and leachate VFA/COD ratio. On first 16 days, leachate VFA/COD ratio rose from 0.06 to 0.25 resulted to the rise of methane percentage from 5% to 27.01% since intermediate products was hydrolyzed into volatile fatty acid as substrate for methane generation. However, VFA/COD ratio dropped to 0.17 on Day 27 with the result of methane decrease to 24.82%. The result may contribute to too much daily 9,800 mg daily VFA loading while VFA could not be appropriately leached or utilized during this period. VFA/COD rose to 0.29 on Day 31 with the result of lower methane percentage to 23.64%. This was contributed to the reactor was under acid condition that excess VFA leached to the system under unfavorable for methane phase degradation as indicated from the result of highest VFA/COD ratio during this period. On Day 38, leachate VFA/COD ratio rose to 0.24 that was appropriate to rise methane percentage to 24.18%. Methane percentage gradually rose to 51.38% on Day 51 with the result of VFA/COD 0.19 since almost VFA was well utilized under favorable condition as substrate for activated methane gas generation. From this study, it could be assumed that the ratio of VFA/COD during acid phase should stay within the range of 0.2-0.25 for optimum degradation.

4.6 The application of leachate recirculation employment

Table 4.1 The comparison result of 4 simulated anaerobic bioreactors**.**

Study	Day	Length (Days)	Methane percentage	Leachate recycled loading (mg)	Methane volume/VFA mass (ml CH4/ mg VFA)
Reactor 1 (Daily 1,225 mg VFA loading)	1-80	80	2.5%-42.64%	VFA loading = 1,225 mg	0.029
	81-160	80	40.48%-52.75%	VFA loading = 786 mg- 5,482 mg	0.047
Reactor 2 (Daily 2,450 mg VFA loading)	1-75	75	2.95%-45.28%	VFA loading = 2,450 mg	0.017
	76-160	85	48.32%-58.74%	VFA loading = 941 mg- 5,315 mg	0.042
Reactor 3 (Daily 4,900 mg VFA loading)	1-61	61	3.83%-49.56%	VFA loading = 4,900 mg	0.010
	62-160	99	44.53%-63.44%	VFA loading = 882mg- 4,708 mg	0.062
Reactor 4 (Daily 9,800 mg VFA loading)	1-47	47	5%-45.5%	VFA loading = 9,800 mg	0.005
	48-160	113	46.38%-63.80%	VFA loading = 790 mg- 5,200 mg	0.055

Table 4.1 explained the data comparisons of 4 simulated bioreactors. As the variation of daily VFA employment, the result implied that daily 9,800 mg VFA loading at initial phase was fastest moving of acid to methane. The applications was converted to the ratio of daily methane volume/VFA mass loading which was 0.0289, 0.017, 0.010 and 0.005 ml CH_4/ mg VFA mass loading in reactor 1, 2, 3 and 4, respectively. Result implied that the best ratio of daily CH_4/ VFA loading to optimize degradation during initial phase was 0.005 ml CH_4/ mg VFA loading. This was the highest VFA loading employment ratio when compared to current study and also previous works (0.017 from Rachdawong (1994) and 0.011 from Teerachark (2006)).

Table 4.2 Leachate recirculation application from related studies

Previous study	Day	Length (Days)	Leachate recycled (ml)	Leachate recycled loading (mg)	Methane percentage	COD mass/ Methane volume (mg COD/ ml CH4)	VFA mass/Methane volume (mg VFA/ ml CH4)	Organic loading rate (g VFA/ liter/ day)
Rachdawong (1994)								
Organic waste (Fruit and vegetable wastes)	1-118	118	0 ml	No leachate recirculation	2.9%-18.9%	NA	NA	NA
	119-183	63	150-300 ml	COD loading = 17,523 mg- 82,985 mg	19.1-32.3%	250	59	0.148
	184-360	176	120 ml-650 ml	COD loading = 13,056 mg- 29,331 mg	28.0%-59.8%	11	4	0.070
Turajane (2001)								
Organic waste (Fruit and vegetable wastes)	1-96	96	2000 ml	COD loading = 78,271 mg	16.2%-44.6%	210	63	0.261
	97-127	31	5,000 ml	COD loading = 169,415 mg	44.7-51.1%	100	30	0.565
	128-200	73	10,000 ml	COD loading = 239,510 mg	46.8%-57.6%	115	21	0.798
San and Onay (2001)								
Organic waste (Municipal solid wastes)	1-146	146	285 ml	COD loading = 9,595 mg	4%-11%	181	54	0.044
	147-222	76	571 ml	COD loading = 16,966 mg	13%-47%	65	16	0.078
	223-275	53	1,142 ml	COD loading = 23,011 mg	30%-50%	30	6	0.071
Jaijongrak (2003)								
Organic waste (Fruit and vegetable wastes)								
-No leachate recirculation	1-195	195	0 ml	No leachate recirculation	2.3%-42.46%	NA	NA	NA
-Plan A	1-185	185	900 ml	COD loading = 30,720 mg- 95,679 mg	2.2%-42.29%	100	NA	NA
(Leachate recycle based on methane percentage)	186-195	10	2,700 ml	COD loading = 150.998 mg	46.45%-53.29%	200	NA	NA
-Plan B	1-185	185	600-2,800 ml	COD loading = 30,464 mg- 198,352 mg	5.5%-37.48%	100	NA	NA
(Leachate recycled based on daily methane volume)	186-195	10	4,000-7,000 ml	COD loading = 135,472 mg- 219,520 mg	35.69%-39.23%	100	NA	NA
Petchsri and Towprayoon (2004)								
Organic waste (Municipal solid wastes)	1-115	115	0 ml	No leachate recirculation	2.50%	NA	NA	NA
	116-402	287	150-800 ml	COD loading = 7,500 mg- 40,000 mg	5%-35%	320	80	0.227
	403-578	176	150-400 ml	COD loading = 4,500 mg- 12,000mg	34%-56%	15	9	0.056
Teerachark (2006)								
Organic waste (Fruit and vegetable wastes)	1-99	99	0-350 ml	VFA loading = 0 mg - 6,340 mg	2.3%-36.35%	200	91	0.239
	100-123	24	750 ml-1,250 ml	VFA loading = 7,241mg - 12,943 mg	34.27%-55.26%	125	48	0.301
Current study from optimized biogas in reactor 4								
Optimized acid phase with daily 9,800 mg loading	1-48	48	625 ml-1,120 ml	VFA loading = 9,800 mg	5%-45.5%	1000	200	0.784
	49-160	111	65 ml-834 ml	VFA loading = 790 mg- 5,200 mg	46.38%-63.80%	100	18	0.173

Table 4.2 explained leachate recirculation application from various studies. Organic wasted input was divided into fruit and vegetable waste from Rachdawong (1994), Turajane (2001), Jaijongrak (2003), Teerachark (2006) and current study. San and Onay (2001), Perchsri and Towprayoon (2004) utilized municipal solid waste for anaerobic degradation input. Leachate recirculation during initial phase could be investigated from methane percentage that was lower than 50% which referred to Table 3.6. Daily leachate recycle amount and daily leachate recirculation loading (mg organic) was difference which depended on its application and initial organic waste amount. Application studies was normalized and compared through loading application per their own daily methane output. Organic loading rate in term of g VFA/ liter/ day was also defined to compare between each other. The result of loading was 250, 100-210, 65-181, 100, 320, 200 and 1,000 mg COD/ ml CH_4 from Rachdawong (1994), Turajane (2001), San and Onay (2001), Jaijongrak (2003), Petchsri and Towprayoon (2004), Teerachark (2006) and current study in reactor 4, respectively. Leachate VFA mass loading/ methane volume was 59, 30-63, 16-54, 80, 91 and 200 mg VFA/ ml CH_4 from Rachdawong (1994), Turajane (2001), San and Onay (2001), Petchsri and Towprayoon (2004), Teerachark (2006) and current study in reactor 4, respectively. Study from leachate recirculation application implied that compression of acid phase could occur from high daily

organic loading input. The current loading application was 1,000 mg COD loading/ ml CH_4 or 200 mg VFA loading/ ml CH_4 and was the highest ratio comparing to other studies. In conclusion, Daily leachate organic employment could be higher than 1,000 mg COD loading/ ml CH_4 or 200 mg VFA loading/ ml CH_4. Organic loading rate could be attempted higher than 0.784 g VFA/l/day on initial degradation phase that methane percentage was lower than 50%.

4.7 Model Development

Since volatile fatty acid was considered as the major substrate for methanogenic bacteria in process to produce methane gas output, model was developed to analyze the relationship between leachate volatile fatty acid input through leachate recirculation and methane gas output. The relationship between volatile fatty acid loading and methane gas generation would describe the progress on anaerobic organic waste degradation and methane potential since various leachate recirculation would cause different methanogenic bacteria growth and methane gas product, as well. In addition, the model equation would initially exhibit the methane potential from volatile fatty acid as substrate loading as the variable on methane output as Y and leachate volatile fatty acid as X. Model equation was tested for the accuracy through R2, F test, T test and P value, respectively. Model development from leachate volatile fatty acid employment in optimized reactor 4 was described by SPSS program as following detail.

4.7.1 Model development of daily methane gas and daily volatile fatty acid loading

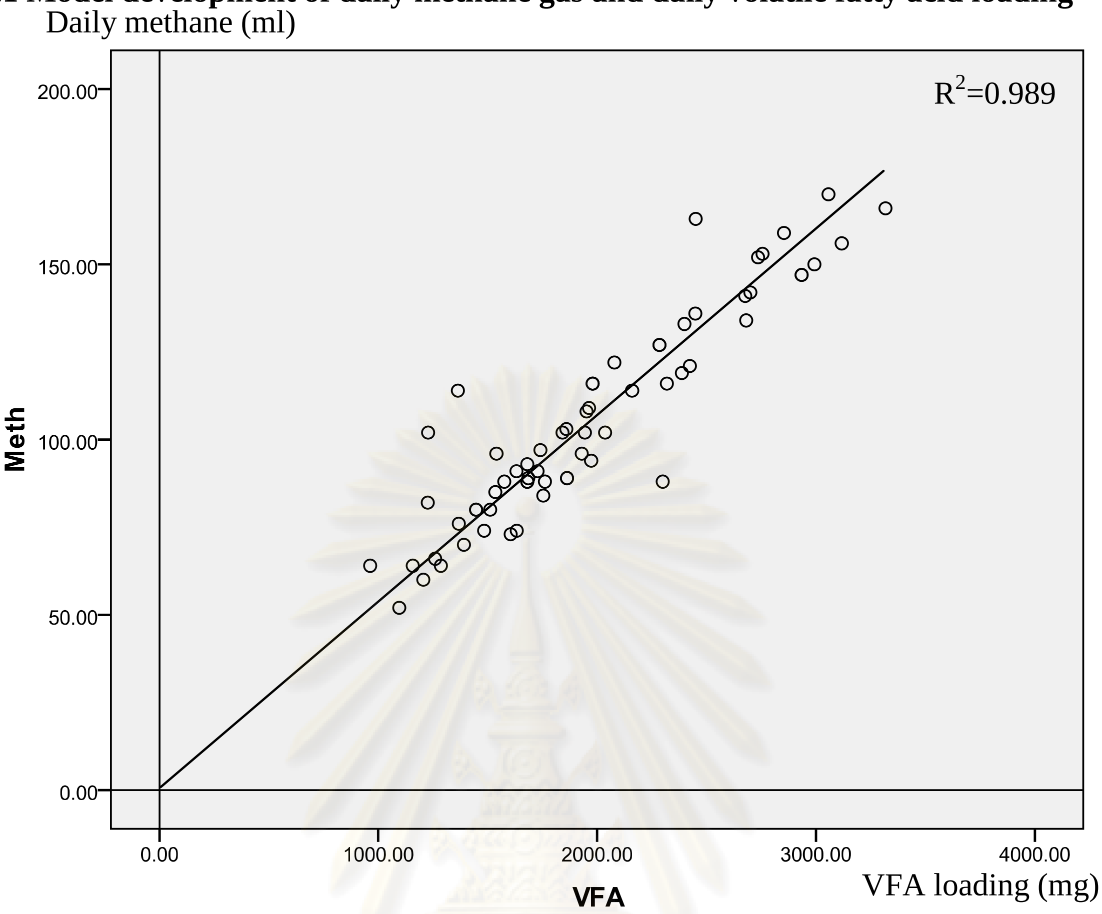


Figure 4.19 Scatter plot between daily methane gas and daily volatile fatty acid loading in reactor 4 under methane phase generation

Figure 4.19 explained the trend graph development between daily methane gas output and daily volatile fatty acid loading under methane phase generation. The trend graph showed that daily methane gas output and daily volatile fatty acid loading were related to each others in term of linear regression which daily methane gas followed to daily volatile fatty acid loading input. High daily methane gas would contribute to high daily volatile fatty acid loading input. The relationship between each others was developed by SPSS program and was described in Table 4.3.

Table 4.3 Linear regression model development between daily methane gas and daily volatile fatty acid loading in reactor 4 under methane phase generation

Model Summary[c,d]

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.994[a]	.989	.989	11.61764

ANOVA[c,d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	763875.951	1	763875.951	5659.619	.000[a]
	Residual	8638.049	64	134.970		
	Total	772514.000[b]	65			

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	VFA	.053	.001	.994	75.230	.000	.052	.055

Table 4.3 summarized the result of linear regression model of daily methane output and daily volatile fatty acid loading in reactor 4. Model proof was considered from R^2, F test and T test. Determination coefficient (R^2) was 0.989 exhibited the equation certainty. In addition, F test significant result was 0.00 that passed the statistical judgment. T test significant value from slope and constant was 0.00. The T test significant of slope was zero that could be utilized for equation development. The summary of daily methane gas and daily volatile fatty acid loading from model run was as following equation below

Daily methane output (ml) = 0.053 Daily volatile fatty acid loading (mg) R^2=0.989

4.7.2 Model development of daily biogas and daily volatile fatty acid loading

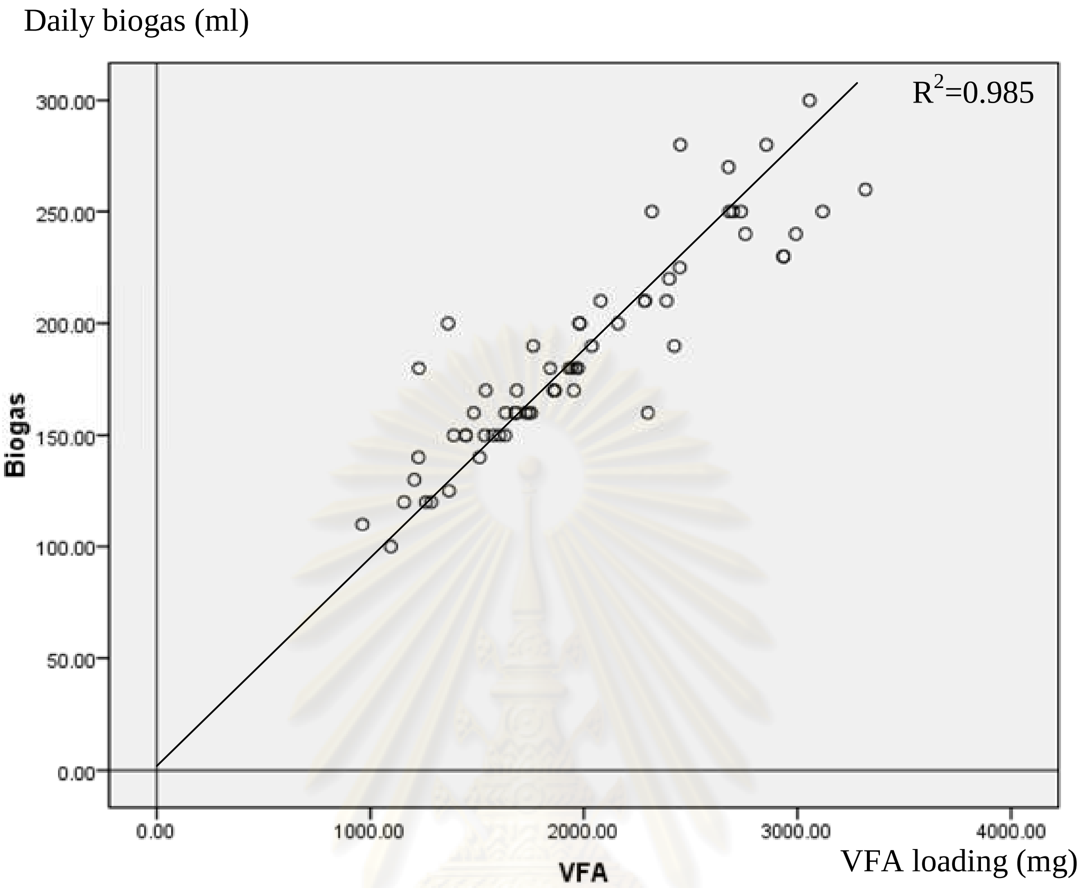


Figure 4.20 Scatter plot between daily biogas and daily volatile fatty acid loading in reactor 4 under methane phase generation

Figure 4.20 explained the trend graph development between daily biogas output and daily volatile fatty acid loading under methane phase generation. The trend graph showed that daily biogas output and daily volatile fatty acid loading were related to each others in term of linear regression which daily biogas followed to daily volatile fatty acid loading input. High daily biogas related to high daily volatile fatty acid loading input. The relationship between each others was developed by SPSS program and was described in Table 4.4.

Table 4.4 Linear regression model development between daily biogas and daily volatile fatty acid loading in reactor 4 under methane phase generation

Model Summary[c,d]

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.993[a]	.985	.985	23.22226

ANOVA[c,d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.325E+06	1	2.325E+06	4311.794	.000[a]
	Residual	34513.508	64	539.274		
	Total	2.360E+06	65			

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	VFA	.093	.001	.993	65.664	.000	.090	.096

Table 4.5 summarized the result of daily biogas and daily volatile fatty acid loading. Model was developed as linear regression model which daily biogas output was set as dependent variable (Y) and daily volatile fatty acid loading was set as independent variable (X). Model showed determination coefficient (R^2) as high as 0.985. F test significant was 0 that proved the model reliable. The coefficients of volatile fatty acid loading and constant were 0.075. Coefficient of T test significant was 0 which passed the statistical significant at 95% of interval. The summary of linear regression models from daily biogas output and daily leachate volatile fatty acid loading was shown as following equation below.

Daily biogas output (ml) = 0.093 Daily volatile fatty acid loading (mg) R^2=0.985

4.7.3 Model development of daily methane gas and daily biogas

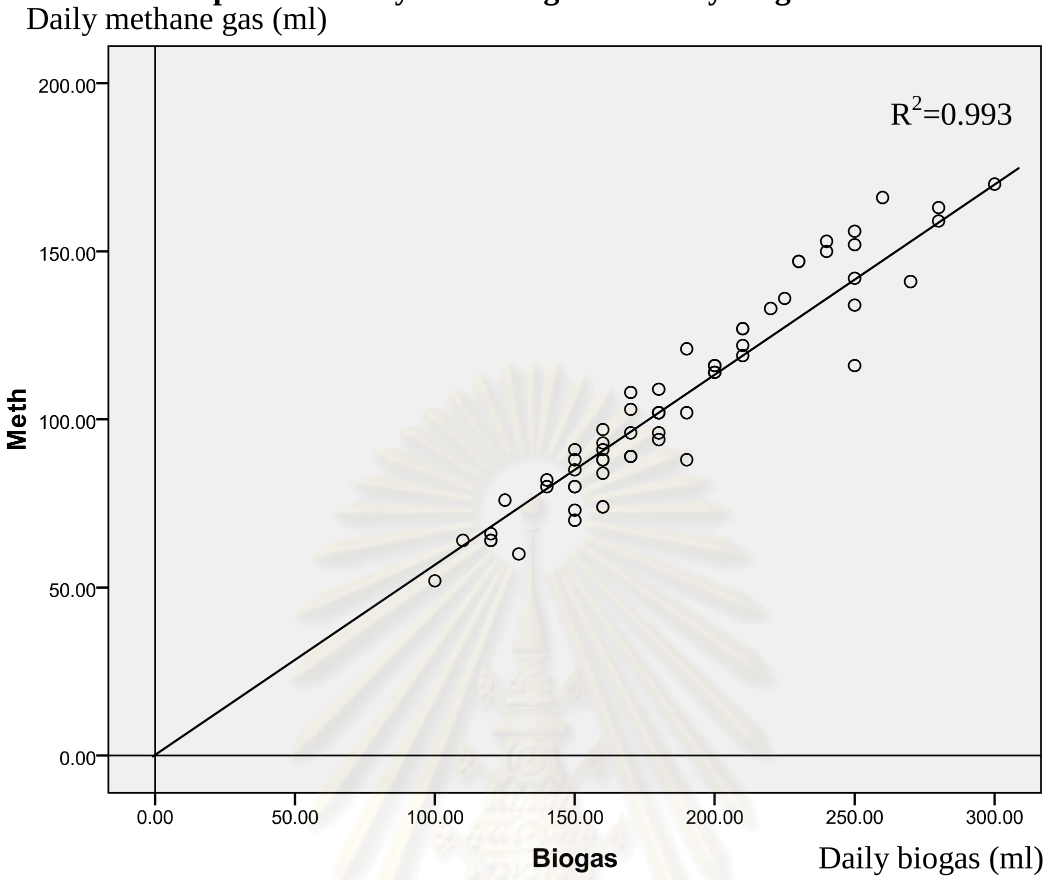


Figure 4.21 Scatter plot between daily methane gas and daily biogas in reactor 4 under methane phase generation

Figure 4.21 explained the trend graph development between daily methane gas and daily biogas under methane phase generation. The trend graph showed that both of them exhibited linear regression which daily methane gas followed daily biogas output. The relationship between each others was developed by SPSS program and was described in Table 4.5.

Table 4.5 Linear regression model development between daily methane and daily biogas in reactor 4 under methane phase generation

Model Summary[c,d]

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate
1	.997[a]	.993	.993	9.14253

ANOVA[c,d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	767164.501	1	767164.501	9178.154	.000[a]
	Residual	5349.499	64	83.586		
	Total	772514.000[b]	65			

Coefficients[a,b]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	Biogas	.570	.006	.997	95.803	.000	.558	.582

Table 4.5 summarized the result of daily methane gas and daily biogas output. Model was developed as linear regression model which daily methane gas output was set as dependent variable (Y) and daily biogas generation was set as independent variable (X). Model showed determination coefficient (R^2) as high as 0.993. F test significant was 0 that proved the model reliable. The coefficient of volatile fatty acid loading and constant was 0.570. Coefficient of T test significant was 0 which passed the statistical significant at 95% of interval. The summary of linear regression models from daily methane output and daily biogas was shown as following equation below.

Daily methane gas output (ml) = 0.570 Daily biogas output (ml) R^2=0.993

Table 4.6 Various model developments between methane gas and other parameters

Model Development	R^2	Specification	References
Daily methane (ml/d) = 101.35 Acetic concentration (g/l) + 9.984	0.74	Pig manure waste	Xie et al. (2010)
Gas Production (l/d) = 0.4607 COD removal rate (g/d)	0.938	Municipal Solid wastes	He et al. (2005)
Methane (m^3) = 0.331 Volatile solids removal (kg)	-	Cauliflower stem	Gunaseelan (2004)
Methane (m^3) = 0.356 Volatile solids removal (kg)	-	Pig manure wastes	Hashimoto et al. (1981)
Methane (l) = 0.183 COD removal (g)	-	Fruit and vegetable waste	Turajane (2001)
Methane yield (l/g VS added) = 0.17 + 0.16 Carbohydrate	0.73	Fruit and vegetable waste	Gunaseelan (2006)
Daily methane (ml/d) = 0.013 Daily volatile fatty acid loading (mg/d)	0.97	Fruit and vegetable waste	Teerachark (2006)
		(pH > 7, methane 42-55%,	
		Leachate recycle as 25%	
		of moisture content)	
Daily methane (ml/d) = 0.036 Daily volatile fatty acid loading (mg/d)	0.973	Municipal solid waste	San and Onay (2001)
		(pH > 7, methane 40-50%,	
		Leachate recycle as 30 of COD	
		mass per methane volume ratio)	
Daily methane (ml/d) = 0.053 Daily volatile fatty acid loading (mg/d)	0.989	Fruit and vegetable waste	Current study in reactor 4
Daily biogas (ml/d) = 0.093 Daily volatile fatty acid loading (mg/d)	0.985	(pH > 7, methane 50-61%,	
Daily methane (ml/d) = 0.570 Daily biogas output (ml/d)	0.993	Leachate recycle as 100 of COD	
Daily methane (ml/l/d)= 0.004 Daily volatile fatty acid loading (mg/d)	0.98	mass per methane volume ratio)	

There were many studies to develop the model relationship between methane gas and other related parameters which was described in Table 4.6. The relationship of daily methane (ml/day) and acetic concentration (g/l) from pig manure waste input was studied Xie et al. (2010). Model development of gas production (l/d) and COD removal rate (g/d) from municipal solid waste was studied by He et al. (2005). Gunaseelan (2004) and Hashimoto (1981) studied relationship between methane gas and volatile solid removal from cauliflower stem and pig manure waste, respectively. Gunaseelan (2006) developed relationship model between methane yield (l/g VS added) and soluble carbohydrate content of fruit and vegetable wastes. All of those studies defined the relationship between methane gas and initial organic waste degradation such as COD removal and volatile solid removal which did not include the loading rate through leachate recycles to optimize methane gas output. Leachate recirculation technique was realized to promote more distribution of moisture and substrate throughout the refuse mass (Pohland and Harper, 1986). Based on Chapter 3, volatile fatty acid was considered the essential criteria to control biogas generation system. VFA was direct substrate for methanogenic bacteria to generate methane gas output. Leachate recirculation employed volatile fatty acid mass loading in the system to promote methane gas under methane phase of anaerobic organic waste degradation. The relationship between methane gas and volatile fatty acid loading was studied by Teerachark (2006) and San and Onay (2001). Teerachark (2006) defined the relationship between methane gas and VFA loading of fruit and vegetable waste degradation under 42-55% methane with leachate recycle as 25% of initial moisture content. Model development was as Daily methane (ml/day) = 0.013 daily volatile fatty acid loading (mg/day) (Teerachark, 2006). San and Onay (2001) defined the relationship of daily methane and daily volatile fatty acid as Daily methane (ml/day) = 0.036 Daily volatile fatty acid loading (mg/day) (San and Onay, 2001) which the condition were under municipal solid waste degradation that pH > 7, methane percentage 40-50% and leachate recycle as 30 of COD mass per methane volume ratio. Model development from current study in reactor 4 from fruit and vegetable wastes, which methane was under 50-61%, pH>7 and leachate recycle employment as 100 of COD mass per methane volume, was as Daily methane (ml/day) = 0.053 Daily volatile fatty acid loading (mg/day). Slope or daily volatile fatty acid loading coefficient was 0.013, 0.036 and 0.053 from Teerachark (2006), San and Onay (2001) and current study in reactor 4, respectively. Current study showed highest coefficient of daily volatile fatty acid loading or slope which best optimized daily methane gas output. This implied succeed of leachate recirculation from current study in reactor 4 which enhanced methane gas output and waste stabilization.

CHAPTER V
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The purpose of this research was to study the leachate recirculation based on various daily volatile fatty acid loading to optimize the anaerobic organic waste stabilization. Based on the results of this research study, the following conclusion was

1. Daily 9,800 mg leachate volatile fatty acid employment during initial phase enhanced anaerobic organic waste degradation system as indicated from cumulative methane gas production after 160 days operation was 7,267 ml, 9,046 ml, 10,712 ml and 11,170 ml in reactor 1, 2, 3 and 4 with 1,225 mg, 2450 mg, 4,900 mg and 9,800 mg daily volatile fatty acids loading, respectively.

2. There was not adverse effect from high volatile fatty acid loading on anaerobic organic waste degradation under fruit and vegetable wastes as indicated from the result of leachate environmental parameters such as pH, ORP and VFA concentration being similar during acid phase degradation.

3. Fastest degradation during acid to methane phase was established in reactor 4 with daily 9,800 mg volatile fatty acid loading since suitable environmental condition for methane phase degradation (pH >7, ORP < -250 mV, methane percentage > 50%) was occurred after 48, 62, 76 and 81 days in reactor 4, 3, 2 and 1, respectively.

4. Highest daily methane gas during day 45 to day 80 could be noticed from daily 9,800 mg VFA loading as the result of fastest VFA drop that was well utilized as substrate for highest daily methane generation, suitable environment for methane phase establishment, VFA/COD that was fastest to reach optimum and highest leachate nutrients during this period.

5. Retardation from daily 9,800 mg volatile fatty acid loading in reactor 4 was occurred during day 25 to day 36 as the result of methane percentage that dropped from

29.54% to 18.12%. This was contributed to daily 9,800 mg VFA loading was too excessive during highest acidic condition since VFA/COD was 0.29 been highest from all 160 days operation. The average ratio of daily CH_4/ daily VFA loading for daily VFA loading employment changed from 0.0053 ml CH_4/ mg VFA loading to 0.0037 ml CH_4/ mg VFA loading.

6. To enhance the degradation which compressed acid phase, the leachate recirculation during acid phase could be attempted as much as 200 mg VFA loading mass (mg VFA)/ Methane generation (ml CH_4) or organic loading rate as 0.784 g VFA/ l/day.

7. Model on optimized methane gas output was developed to study the relationship between daily methane output, daily biogas output and daily VFA loading. This was summarized as following details.

7.1 Daily methane output (ml) = 0.053 Daily volatile fatty acid loading (mg) R^2=0.989
7.2 Daily biogas output (ml) = 0.093 Daily volatile fatty acid loading (mg) R^2=0.985
7.3 Daily methane gas output (ml) = 0.57 Daily biogas output (ml) R^2=0.993

5.2 Recommendations for future work

1. Various daily volatile fatty acids loading was attempted for mixed fruit and vegetable wastes. The other wastes that had the potential for biogas generation such as manure should be studied.

2. Actual test of this work on organic wastes landfill, community anaerobic organic waste bioreactors should be further studied.

3. Correlation model development should be further developed to get highest determination coefficient (R^2)

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APPENDICES

APPENDIX A

Leachate analysis

Table A1 Daily leachate recirculation volume (ml) from the simulated anaerobic organic waste reactors

Leachaet recirculation				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
1	460	460	450	470
3	750	775	760	700
6	154	303	554	1120
7	174	277	581	980
8	150	272	452	933
9	126	233	387	832
10	128	240	449	825
11	133	218	378	784
12	123	238	424	1045
13	118	229	425	799
14	120	225	387	871
15	118	218	423	756
16	105	202	408	717
17	106	200	384	735
19	102	196	392	719
20	103	215	413	740
21	109	192	399	732
22	117	222	417	836
24	112	200	425	840
25	119	218	449	944
27	118	206	416	980
28	89	170	381	739
29	75	124	303	625
31	93	178	368	653
33	101	193	361	688
34	106	185	356	683
35	93	181	342	716
36	78	163	327	653
38	102	196	368	735
39	91	184	346	735
40	500	500	500	500
41	86	171	346	719
42	82	172	327	713
43	82	172	346	735
45	91	163	346	840
46	86	173	345	769
48	86	173	363	416
49	91	163	368	222
50	87	163	363	270
51	88	163	402	464
52	87	174	368	417
53	88	163	347	447
54	92	163	368	312
55	102	152	408	147
56	93	174	402	145
58	92	173	373	226
59	98	196	373	272
60	101	163	402	304
61	93	174	402	245
62	109	184	348	244
63	127	201	310	193
64	123	208	368	179
66	114	229	439	237
67	119	218	268	211
68	123	254	239	250
69	114	261	291	264
71	127	327	213	288
73	109	208	212	204
74	104	201	198	233
75	117	238	151	171
76	123	390	241	249
77	104	313	281	204
78	113	371	200	179
80	109	638	270	230

Leachaet recirculation				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	338	496	228	227
82	112	395	177	146
83	211	361	197	169
85	276	248	204	198
87	368	278	247	227
88	346	327	242	239
89	504	287	307	346
90	506	318	362	326
91	309	362	449	354
92	265	276	311	352
93	191	263	279	274
94	237	316	316	326
96	207	265	210	276
97	159	241	133	208
98	113	208	104	117
100	142	175	148	177
101	207	241	198	234
102	244	292	292	349
103	90	161	78	65
104	158	209	125	172
106	154	217	154	212
108	166	162	185	209
109	190	205	168	168
110	135	253	144	134
111	125	136	115	120
112	196	150	207	150
114	320	338	310	260
115	174	180	304	199
116	168	185	213	180
118	257	240	231	186
119	171	206	235	205
120	84	131	194	106
122	183	188	333	230
123	302	226	280	324
125	75	135	168	161
126	214	244	230	224
127	145	183	210	230
129	147	213	333	283
130	175	245	301	272
131	155	170	232	221
133	74	194	232	196
134	99	126	184	137
136	149	272	255	193
137	271	298	255	225
139	165	333	270	280
140	340	333	346	256
142	177	246	288	272
143	368	664	468	654
145	191	213	216	225
147	241	455	390	558
148	229	444	433	540
150	620	707	894	834
151	378	792	708	618
152	324	385	442	396
153	425	528	708	470
154	491	433	550	417
155	346	696	566	429
157	302	503	629	580
158	363	565	592	685
160	264	335	376	594

Table A2 Daily leachate volatile fatty acid loading (mg) from the simulated anaerobic organic waste reactors

Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
1	1349	1478	1534	1441
3	2737	2992	2850	2863
6	1225	2450	4900	9800
7	1225	2450	4900	9800
8	1225	2450	4900	9800
9	1225	2450	4900	9800
10	1225	2450	4900	9800
11	1225	2450	4900	9800
12	1225	2450	4900	9800
13	1225	2450	4900	9800
14	1225	2450	4900	9800
15	1225	2450	4900	9800
16	1225	2450	4900	9800
17	1225	2450	4900	9800
19	1225	2450	4900	9800
20	1225	2450	4900	9800
21	1225	2450	4900	9800
22	1225	2450	4900	9800
24	1225	2450	4900	9800
25	1225	2450	4900	9800
27	1225	2450	4900	9800
28	1225	2450	4900	9800
29	1225	2450	4900	9800
31	1225	2450	4900	9800
33	1225	2450	4900	9800
34	1225	2450	4900	9800
35	1225	2450	4900	9800
36	1225	2450	4900	9800
38	1225	2450	4900	9800
39	1225	2450	4900	9800
40	7500	7159	7500	6478
41	1225	2450	4900	9800
42	1225	2450	4900	9800
43	1225	2450	4900	9800
45	1225	2450	4900	9800
46	1225	2450	4900	9800
48	1225	2450	4900	5200
49	1225	2450	4900	2774
50	1225	2450	4900	3116
51	1225	2450	4900	5472
52	1225	2450	4900	4864
53	1225	2450	4900	5364
54	1225	2450	4900	3900
55	1225	2450	4900	1540
56	1225	2450	4900	1631
58	1225	2450	4900	2446
59	1225	2450	4900	3057
60	1225	2450	4900	2854
61	1225	2450	4900	2449
62	1225	2450	3767	2285
63	1225	2450	3202	1632
64	1225	2450	4143	1741
66	1225	2450	4708	2285
67	1225	2450	2907	1980
68	1225	2450	2388	2079
69	1225	2450	2492	1980
71	1225	2450	1366	1677
73	1225	2450	1587	1963
74	1225	2450	1700	2035
75	1225	2450	1417	1599
76	1225	4391	2211	2399
77	1225	3695	1913	1963
78	1225	4175	1688	1535

Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
80	1225	6378	2279	1842
81	3624	5315	2195	1705
82	1305	4445	1688	1228
83	2175	4059	1688	1364
85	3220	2561	1993	1646
87	4067	2784	2356	1871
88	3897	3062	2265	1796
89	5044	2940	2718	3118
90	5482	3185	2718	2993
91	2895	3489	2886	3318
92	2779	3101	2664	2935
93	2084	2714	2442	2424
94	2663	3554	2664	2935
96	2132	3231	1804	2756
97	1705	2714	1283	1952
98	1132	2431	990	1368
100	1540	2188	1484	1860
101	2446	3161	2144	2735
102	2747	4103	2741	4109
103	1057	2238	761	790
104	1923	2692	1250	2012
106	1816	2850	1539	2300
108	1709	1979	1731	2443
109	2320	2692	1731	1681
110	1465	2850	1406	1681
111	1404	1584	1082	1260
112	2095	1974	1776	1686
114	3205	3948	2842	2677
115	1887	2362	3197	1863
116	1618	2160	2131	1754
118	2696	2700	2250	1863
119	1834	2430	2013	1973
120	809	1350	1776	1096
122	1834	1760	2189	1944
123	2830	2542	2101	2700
125	786	1467	1401	1512
126	2410	2444	1970	2160
127	1572	1711	1576	1728
129	1729	1996	2183	2387
130	1973	2620	1932	2037
131	1625	1980	1739	1930
133	870	2096	1739	1286
134	1161	1531	1534	1158
136	1393	2041	1739	1447
137	2031	2232	1432	1447
139	1394	2184	1518	1576
140	2230	1872	1620	1681
142	1034	1383	1080	1226
143	1723	2490	1755	2451
145	862	1199	810	963
147	1807	2562	1626	2091
148	1506	2220	1626	2252
150	4649	3536	2874	2681
151	2834	3713	2322	2319
152	2126	2166	1659	1484
153	2834	2476	1990	1762
154	2303	2166	1548	1391
155	1949	2321	1327	1206
157	1417	1886	1769	1633
158	1700	2118	1665	1605
160	1360	941	882	1391

Table A3 Leachate VFA concentration (mg/l) from the simulated anaerobic organic waste reactors

	VFA			
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
1	2934	3214	3409	3068
3	3650	3860	3750	4090
5	5409	5769	5893	5875
6	7943	8076	8840	8750
7	7031	8824	8438	10000
8	8182	9000	10833	10500
9	9750	10500	12656	11785
10	9545	10227	10909	11875
11	9231	11250	12955	12500
12	10000	10313	11563	9375
13	10385	10714	11538	12273
14	10250	10909	12656	11250
15	10385	11250	11591	12955
16	11667	12115	12000	13676
17	11538	12273	12750	13333
19	12000	12500	12500	13636
20	11842	11400	11875	13235
21	11250	12750	12273	13393
22	10500	11029	11740	11719
24	10909	12273	11538	11667
25	10313	11250	10909	10385
27	10385	11875	11786	10000
28	13750	14375	12857	13269
29	16304	19773	16154	15682
31	13125	13750	13333	15000
33	12115	12692	13571	14250
34	11591	13217	13750	14348
35	13125	13500	14318	13696
36	15625	15000	15000	15000
38	12000	12500	13333	13333
39	13500	13333	14167	13333
40	15000	14318	15000	12955
41	14250	14286	14167	13636
42	15000	14250	15000	13750
43	15000	14250	14167	13333
45	13500	15000	14167	11667
46	14250	14167	14211	12750
48	14167	14167	13500	12500
49	13500	15000	13333	12500
50	14063	15000	13500	11538
51	14000	15000	12188	11786
52	14063	14118	13333	11667
53	14000	15000	14118	12000
54	13333	15000	13333	12500
55	12000	16071	12000	10500
56	13125	14063	12188	11250
58	13333	14167	13125	10833
59	12500	12500	13125	11250
60	12188	15000	12188	9375
61	13125	14063	12188	10000
62	11250	13333	10833	9375
63	9643	12188	10313	8438
64	10000	11786	11250	9750
66	10714	10714	10714	9643
67	10323	11250	10833	9375
68	10000	9643	10000	8333
69	10714	9375	8571	7500
71	9643	7500	6429	5833
73	11250	11786	7500	9643
74	11786	12188	8571	8750
75	10500	10313	9375	9375
76	10000	11250	9167	9643
77	11786	11786	6818	9643
78	10833	11250	8438	8571
80	11250	10000	8438	8000

VFA				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	10714	10714	9643	7500
82	11667	11250	9545	8438
83	10313	11250	8571	8071
85	11667	10313	9750	8333
87	11053	10000	9545	8250
88	11250	9375	9375	7500
89	10000	10227	8864	9000
90	10833	10000	7500	9167
91	9375	9642	6429	9375
92	10500	11250	8571	8333
93	10909	10313	8750	8864
94	11250	11250	8438	9000
96	10313	12188	8571	10000
97	10714	11250	9643	9375
98	10000	11667	9545	11667
100	10833	12500	10000	10500
101	11786	13125	10833	11667
102	11250	14063	9375	11786
103	11786	13929	9750	12188
104	12188	12857	10000	11667
106	11786	13125	10000	10833
108	10313	12188	9375	11667
109	12188	13125	10313	10000
110	10833	11250	9750	12500
111	11250	11667	9375	10500
112	10714	13125	8571	11250
114	10000	11667	9167	10313
115	10833	13125	10500	9375
116	9643	11667	10000	9750
118	10500	11250	9750	10000
119	10714	11786	8571	9643
120	9643	10313	9167	10313
122	10000	9375	6563	8438
123	9375	11250	7500	8333
125	10500	10833	8333	9375
126	11250	10000	8571	9643
127	10833	9375	7500	7500
129	11786	9375	6563	8438
130	11250	10714	6429	7500
131	10500	11667	7500	8750
133	11786	10833	7500	6563
134	11667	12188	8333	8438
136	9375	7500	6818	7500
137	7500	7500	5625	6428
139	8437	6563	5625	5625
140	6563	5625	4688	6563
142	5833	5625	3750	4500
143	4688	3750	3750	3750
145	4500	5625	3750	4286
147	7500	5625	4167	3750
148	6563	5000	3750	4167
150	7500	5000	3214	3214
151	7500	4688	3281	3750
152	6563	5625	3750	3750
153	6667	4688	2813	3750
154	4688	5000	2813	3333
155	5625	3333	2344	2813
157	4688	3750	2813	2813
158	4688	3750	2813	2344
160	5156	2813	2344	2344

Table A4 Daily variation of leachate COD concentration (mg/l) from the simulated anaerobic organic waste reactors

COD				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
3	64192	64736	63648	63104
5	64192	64192	64464	64736
7	52224	65824	69632	66912
9	59840	61472	64192	63648
11	60928	61472	63648	62016
13	58752	59296	63104	59840
16	57664	58208	52224	53856
21	48416	63104	60384	58752
27	54400	64736	63648	59840
29	52224	59296	50592	53312
31	48416	46784	46784	51136
33	47040	56000	47040	51520
35	47040	53760	49280	56000
38	51520	49280	49280	56000
42	47040	51520	49280	53760
46	53760	49280	53760	49280
49	53760	58240	53760	64960
51	51520	60480	56000	62720
55	44800	67200	64960	67200
59	58240	56000	58240	62720
62	51130	63490	57010	52080
67	43010	51130	57010	55140
71	44800	51520	61600	47040
76	49600	46400	62400	54400
81	64000	54400	64000	60800
89	44800	46400	48400	44800
96	57120	54880	67200	56000
102	53760	51520	60480	45920
109	51520	49280	57120	51440
115	51520	53760	50400	44800
122	49600	51130	42560	44800
129	52640	44800	39200	42560
134	53760	52640	45920	47040
142	34720	33600	32400	30240
150	35840	31360	29120	31360
157	32480	28000	25760	24640

Table A5 Leachate VFA/COD ratio from the simulated anaerobic organic waste reactors.

Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
3	0.06	0.06	0.06	0.06
5	0.08	0.09	0.09	0.09
7	0.13	0.13	0.12	0.15
9	0.16	0.17	0.20	0.19
11	0.15	0.18	0.20	0.20
13	0.18	0.18	0.18	0.21
16	0.20	0.21	0.23	0.25
21	0.23	0.20	0.20	0.23
27	0.19	0.18	0.19	0.17
29	0.31	0.33	0.32	0.29
31	0.27	0.29	0.28	0.29
33	0.26	0.23	0.29	0.28
35	0.28	0.25	0.29	0.24
38	0.23	0.25	0.27	0.24
42	0.32	0.28	0.30	0.26
46	0.27	0.29	0.26	0.26
49	0.25	0.26	0.25	0.19
51	0.27	0.25	0.22	0.19
55	0.27	0.24	0.18	0.16
59	0.21	0.22	0.23	0.18
62	0.22	0.21	0.19	0.18
67	0.24	0.22	0.19	0.17
71	0.22	0.15	0.10	0.12
76	0.20	0.24	0.15	0.18
81	0.17	0.20	0.15	0.12
89	0.22	0.22	0.18	0.20
96	0.18	0.22	0.13	0.18
102	0.21	0.27	0.16	0.26
109	0.24	0.27	0.18	0.19
115	0.21	0.24	0.21	0.21
122	0.20	0.18	0.15	0.19
129	0.22	0.21	0.17	0.20
134	0.22	0.23	0.18	0.18
142	0.17	0.17	0.12	0.15
150	0.21	0.16	0.11	0.10
157	0.14	0.13	0.11	0.11

Table A6 Temperature profile (Celsius) during anaerobic fermentation

Day	Temperature
1	29
3	29
5	31
6	29
7	29
8	30
9	28
10	31
11	30
12	27
13	29
14	28
15	30
16	30
17	31
19	30
20	30
21	31
22	30
24	29
25	29
27	32
28	30
29	30
31	31
33	30
34	25
35	28
36	29
38	32
39	32
40	28
41	30
42	30
43	30
45	30
46	31
48	30
49	27
50	28
51	29
52	28
53	30
54	29
55	28
56	28
58	28
59	28
60	30
61	28
62	28
63	27
64	26
66	28
67	28
68	28
69	30
71	31
73	30
74	30
75	29
76	28
77	28
78	28
80	26

Day	Temperature
81	29
82	26
83	28
85	30
87	30
88	32
89	32
90	32
91	32
92	32
93	30
94	33
96	31
97	29
98	28
100	29
101	32
102	31
103	27
104	28
106	28
108	27
109	27
110	27
111	26
112	30
114	32
115	30
116	30
118	31
119	30
120	28
122	29
123	33
125	28
126	32
127	30
129	32
130	32
131	29
133	28
134	28
136	29
137	30
139	29
140	30
142	30
143	31
145	30
147	30
148	29
150	32
151	32
152	30
153	31
154	30
155	29
157	30
158	31
160	28

Table A7 Leachate pH from the simulated anaerobic organic waste reactors.

pH				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
1	7.21	7.62	6.67	7.49
3	6.21	6.10	5.82	5.90
5	5.64	5.52	5.60	5.47
6	5.72	5.56	5.58	5.78
7	5.59	5.61	5.69	5.58
8	5.52	5.55	5.58	5.60
9	5.43	5.54	5.51	5.62
10	5.51	5.52	5.61	5.67
11	5.74	5.89	5.75	5.87
12	5.53	5.51	5.52	5.60
13	5.68	5.73	5.67	5.71
14	5.89	5.92	5.83	5.91
15	5.81	5.74	5.77	5.80
16	5.79	5.69	5.72	5.76
17	5.61	5.69	5.67	5.71
19	5.64	5.69	5.64	5.68
20	5.71	5.73	5.69	5.70
21	5.62	5.63	5.64	5.70
22	5.57	5.51	5.62	5.59
24	5.45	5.44	5.50	5.43
25	5.62	5.64	5.68	5.57
27	5.50	5.53	5.46	5.47
28	5.76	5.83	5.77	5.75
29	5.83	5.85	5.87	5.88
31	5.74	5.74	5.76	5.82
33	5.70	5.70	5.70	5.83
34	5.48	5.47	5.51	5.59
35	5.53	5.48	5.45	5.61
36	5.86	5.77	5.79	5.99
38	5.76	5.69	5.65	5.80
39	5.87	5.80	6.00	6.13
40	5.53	5.49	5.56	5.71
41	6.32	6.22	6.13	6.44
42	5.93	5.92	5.93	6.14
43	5.98	5.90	5.88	6.22
45	5.75	5.65	5.81	6.06
46	5.96	5.90	5.91	6.22
48	6.30	6.23	6.35	6.86
49	6.35	6.25	6.29	7.21
50	6.31	6.28	6.40	7.18
51	5.91	5.62	5.67	6.94
52	6.21	6.04	6.09	7.35
53	6.24	6.24	6.45	7.63
54	6.33	6.15	6.54	7.73
55	6.32	6.22	6.53	7.81
56	6.32	6.25	6.61	8.10
58	6.37	6.31	6.48	7.72
59	6.20	6.45	6.50	7.86
60	6.21	6.15	6.75	7.59
61	6.05	6.02	6.99	7.77
62	6.17	6.21	7.04	7.82
63	6.17	5.93	7.02	7.60
64	5.77	5.80	7.13	7.15
66	6.12	5.59	7.17	7.23
67	5.98	5.81	7.33	7.32
68	6.06	5.74	7.26	7.45
69	6.18	5.68	7.04	7.21
71	6.15	5.53	6.96	7.00
73	7.04	7.00	7.86	7.84
74	7.06	7.11	7.78	7.83
75	7.24	7.35	7.80	7.76
76	7.51	7.52	7.79	7.73
77	7.46	7.30	7.76	7.81
78	7.52	7.50	7.62	7.58
80	7.74	7.72	7.75	7.90

pH				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	7.60	7.78	7.80	7.82
82	7.75	7.70	7.85	7.77
83	7.62	7.65	7.88	7.71
85	7.64	7.58	7.81	7.77
87	7.57	7.55	7.74	7.60
88	7.81	7.60	7.86	7.86
89	7.66	7.65	7.77	7.82
90	7.73	7.75	7.92	7.86
91	7.95	7.89	8.04	7.94
92	7.92	7.73	7.82	7.84
93	7.90	7.71	8.01	7.95
94	8.05	7.90	8.15	7.98
96	7.89	7.80	8.08	7.62
97	7.84	7.82	8.14	7.78
98	7.81	7.73	8.25	7.77
100	7.92	7.84	8.10	7.62
101	7.88	7.82	7.94	7.68
102	7.94	7.86	7.83	7.59
103	7.63	7.97	8.09	7.66
104	7.88	8.02	8.11	7.68
106	7.78	8.06	8.12	7.77
108	7.91	8.04	8.20	7.72
109	7.66	8.13	8.32	7.78
110	7.58	7.86	8.24	7.69
111	7.43	7.79	8.13	7.84
112	7.87	7.75	8.02	7.64
114	7.39	7.55	8.13	7.62
115	7.60	7.81	8.11	7.59
116	7.54	7.84	8.16	7.52
118	7.61	8.09	8.18	7.47
119	7.59	7.94	8.07	7.58
120	7.51	7.50	8.14	7.13
122	7.15	7.55	7.69	7.32
123	7.46	7.67	7.59	7.54
125	7.15	7.28	7.52	7.26
126	7.08	7.38	7.59	7.21
127	7.47	7.37	7.69	7.29
129	7.37	7.54	8.08	6.96
130	7.28	7.62	7.93	7.22
131	7.38	7.61	8.02	7.34
133	7.50	7.67	7.77	7.38
134	7.10	7.31	7.37	7.25
136	7.22	7.48	7.41	7.15
137	7.33	7.45	7.59	7.01
139	7.21	7.42	7.63	7.09
140	6.94	7.41	7.58	6.95
142	7.05	7.32	7.29	7.01
143	7.02	7.26	7.28	7.07
145	7.03	7.14	7.24	7.09
147	6.86	6.97	7.21	7.00
148	7.02	7.10	7.14	7.05
150	6.89	7.22	7.33	7.14
151	7.03	7.33	7.40	7.29
152	7.15	7.35	7.46	7.08
153	7.08	7.26	7.42	7.11
154	7.12	7.38	7.36	7.15
155	7.15	7.52	7.22	7.06
157	7.21	7.48	7.15	7.14
158	7.26	7.48	7.39	7.39
160	7.36	7.58	7.65	7.37

Table A8 Leachate ORP (mV) from the simulated anaerobic organic waste reactors.

	ORP			
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
1	5.2	8.4	1.8	5.6
3	-198.4	-225.2	-232.9	-184.5
5	-184.6	-198.4	-208.2	-230.5
6	-168.4	-174.6	-196.5	-182.5
7	-184.8	-179.2	-229.6	-235.1
8	-162.4	-151.8	-172.7	-210.3
9	-170.0	-139.8	-143.2	-235.3
10	-160.8	-151.6	-159.4	-185.0
11	-142.2	-133.8	-175.6	-169.3
12	-156.8	-142.6	-143.5	-174.0
13	-136.2	-151.3	-145.8	-167.4
14	-134.6	-138.0	-156.5	-152.2
15	-138.7	-125.3	-141.1	-146.8
16	-135.8	-116.7	-120.3	-112.4
17	-162.1	-157.6	-144.2	-170.3
19	-154.3	-135.9	-146.6	-156.2
20	-138.4	-144.5	-157.8	-169.3
21	-111.2	-140.6	-177.3	-215.6
22	-164.3	-159.7	-146.2	-161.8
24	-219.6	-215.3	-196.5	-194.7
25	-196.3	-186.5	-199.7	-181.9
27	-209.7	-195.3	-190.2	-184.6
28	-195.0	-145.9	-155.2	-170.5
29	-143.3	-176.8	-158.3	-128.3
31	-129.3	-138.0	-122.6	-151.8
33	-175.4	-165.7	-141.6	-155.0
34	-144.7	-141.3	-122.6	-128.1
35	-122.2	-101.0	-104.5	-120.9
36	-160.8	-142.7	-126.0	-134.3
38	-151.7	-162.4	-141.8	-172.3
39	-157.3	-179.4	-132.0	-188.2
40	-124.6	-151.0	-116.5	-174.3
41	-190.9	-184.7	-144.3	-203.8
42	-203.7	-204.0	-169.0	-214.6
43	-184.2	-184.3	-135.0	-190.6
45	-214.9	-179.7	-156.3	-221.3
46	-228.5	-197.8	-177.7	-243.6
48	-169.2	-233.4	-176.0	-194.9
49	-168.8	-188.7	-172.1	-218.9
50	-172.4	-178.6	-169.5	-225.4
51	-140.1	-189.4	-153.5	-261.8
52	-158.6	-185.6	-165.0	-282.3
53	-142.4	-182.6	-158.0	-285.2
54	-134.7	-188.2	-157.0	-337.2
55	-136.7	-206.6	-154.8	-345.8
56	-164.6	-186.2	-163.5	-332.6
58	-161.2	-195.4	-181.4	-345.8
59	-174.3	-198.7	-178.5	-342.7
60	-182.9	-204.2	-184.4	-353.8
61	-191.0	-198.1	-185.2	-355.7
62	-187.5	-201.4	-191.3	-372.6
63	-151.6	-198.0	-182.5	-358.4
64	-178.6	-159.8	-172.4	-339.1
66	-189.6	-219.8	-237.0	-372.3
67	-187.7	-217.6	-217.7	-382.5
68	-191.3	-225.6	-233.4	-391.5
69	-189.5	-219.3	-229.6	-388.7
71	-195.0	-228.3	-258.2	-394.7
73	-178.3	-240.7	-274.6	-408.6
74	-183.7	-243.0	-270.6	-388.2
75	-177.8	-254.3	-282.5	-398.6
76	-168.4	-260.6	-280.8	-402.5
77	-177.7	-252.3	-262.3	-386.5
78	-200.3	-326.5	-398.8	-425.6
80	-294.8	-412.3	-376.5	-419.5

ORP				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	-270.2	-432.5	-461.0	-442.9
82	-282.2	-440.4	-455.7	-435.4
83	-298.4	-435.2	-468.6	-455.2
85	-321.8	-441.2	-465.8	-446.0
87	-363.1	-433.6	-469.4	-468.2
88	-223.1	-440.3	-471.8	-474.3
89	-356.0	-442.9	-461.6	-459.0
90	-324.8	-447.5	-474.2	-468.6
91	-260.9	-433.0	-432.2	-473.0
92	-254.3	-438.1	-477.8	-478.5
93	-373.2	-446.5	-471.4	-462.7
94	-297.6	-440.5	-479.5	-468.3
96	-317.0	-432.4	-440.9	-476.7
97	-324.1	-429.5	-411.8	-446.4
98	-335.7	-408.6	-405.3	-451.2
100	-342.9	-410.3	-409.4	-442.1
101	-346.8	-400.3	-411.6	-437.2
102	-357.2	-392.7	-414.0	-445.5
103	-348.2	-382.6	-413.5	-422.4
104	-355.4	-384.6	-416.8	-428.1
106	-326.8	-374.0	-405.6	-413.8
108	-353.7	-351.4	-389.7	-398.9
109	-283.9	-371.3	-420.7	-442.6
110	-356.7	-366.2	-385.1	-399.5
111	-399.8	-352.0	-321.7	-386.5
112	-284.9	-325.4	-334.7	-389.9
114	-250.1	-319.3	-284.6	-372.5
115	-256.2	-338.1	-272.5	-393.7
116	-264.3	-298.6	-285.4	-354.2
118	-323.4	-271.6	-252.3	-341.2
119	-298.6	-292.5	-284.4	-328.1
120	-283.3	-363.5	-324.8	-400.8
122	-404.5	-335.4	-398.4	-388.2
123	-372.2	-299.0	-363.8	-401.3
125	-420.6	-353.4	-409.7	-385.2
126	-430.4	-359.5	-419.1	-385.7
127	-420.9	-369.4	-405.9	-392.4
129	-410.6	-327.5	-372.0	-355.2
130	-400.2	-357.4	-388.9	-392.1
131	-382.1	-358.4	-366.2	-384.5
133	-358.3	-323.8	-355.4	-356.1
134	-293.9	-286.0	-271.8	-326.9
136	-334.6	-314.8	-328.9	-319.4
137	-354.8	-308.6	-335.6	-333.8
139	-355.4	-311.3	-345.2	-321.8
140	-369.2	-291.5	-355.1	-364.3
142	-412.5	-399.6	-421.3	-408.4
143	-409.8	-386.3	-435.4	-398.6
145	-427.4	-435.8	-450.2	-421.3
147	-410.3	-419.5	-440.7	-389.6
148	-398.5	-405.6	-411.3	-395.4
150	-441.6	-411.5	-421.5	-418.3
151	-416.2	-418.7	-435.0	-425.6
152	-408.7	-416.8	-425.3	-400.2
153	-400.3	-412.6	-412.7	-395.4
154	-415.6	-430.5	-426.8	-418.7
155	-434.2	-433.6	-444.5	-432.6
157	-410.5	-435.2	-430.6	-428.7
158	-400.8	-433.2	-421.4	-416.5
160	-315.2	-400.5	-427.6	-454.9

Table A9 Leachate alkalinity from the simulated anaerobic organic waste reactors

Alkalinity				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
1	7500	7500	7727	7391
3	4545	4250	4474	4596
5	5357	6000	5417	5652
7	7500	7941	7813	7708
9	6333	8000	7188	8571
12	7500	7500	7293	6667
14	8333	6818	9063	8929
16	7222	8462	8000	8235
21	7000	7500	7727	7857
27	7308	7083	7500	7222
29	9565	10909	9615	9091
31	7917	8333	8333	9259
34	8636	8667	7917	8696
35	7083	8000	7727	7826
38	9000	8333	8333	8889
40	8500	8182	8333	8182
43	10556	9500	9445	8889
45	9000	8500	8889	7778
46	9500	8889	8421	8500
48	8889	10556	10500	10000
51	10000	10625	8750	9286
54	8571	11250	9231	9375
56	9000	10714	9000	8182
59	8333	8333	9375	8125
61	11875	10000	10000	10000
63	9286	8125	8125	7500
66	8571	6429	7143	7143
71	7143	6250	6429	6667
73	10833	12142	10714	10714
75	10714	10625	10000	8333
77	9286	10000	8182	9286
81	10714	11429	10714	10714
88	10000	10625	9375	10714
91	10625	10714	10714	11250
96	11875	11250	10000	10625
102	10625	11250	10625	13571
109	11875	11875	10625	11667
115	10000	11250	10000	12500
120	10714	10000	10714	11250
123	10000	10625	10000	10625
129	12143	8750	9375	11250
134	10625	9375	10000	11250
140	8750	8125	7500	6875
145	8750	7500	7500	6250
151	11250	11875	8750	8750
157	9375	10000	7500	8750

Table A10 Leachate total Kjeldahl nitrogen (mg/l) from the simulated anaerobic organic waste reactors

Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
5	1205	1386	1248	1210
21	1448	1504	1725	1810
45	1582	1644	1824	2006
66	1848	2268	2044	2416
88	1962	2080	2306	2240
109	1806	1902	2388	2150
129	1976	2008	1956	2010
157	1564	1982	1868	1806

Table A11 Leachate orthophosphate (mg/l) from the simulated anaerobic organic waste reactors

Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
5	186	196	168	188
21	256	364	348	426
45	296	312	382	440
66	322	384	392	306
88	238	315	327	280
109	232	285	276	268
129	168	194	246	230
157	215	228	196	218

Appendix B

Gas Analysis

Table B1 Daily biogas productions (ml) from the simulated anaerobic organic waste reactors

Daily Biogas				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
1	730	760	765	770
3	240	210	250	300
5	290	300	300	310
6	290	270	280	280
7	210	260	290	280
8	180	200	270	280
9	120	150	180	160
10	180	190	185	190
11	150	190	220	270
12	70	80	130	100
13	130	160	180	220
14	120	190	180	190
15	140	180	210	220
16	150	260	270	250
17	220	240	280	240
19	250	280	290	300
20	130	160	150	180
21	160	175	260	340
22	110	130	160	140
24	50	90	175	140
25	70	100	140	110
27	120	150	250	200
28	100	180	160	130
29	140	240	210	180
31	150	300	250	270
33	250	150	200	180
34	90	80	60	60
35	180	250	180	160
36	175	160	190	170
38	280	250	250	250
39	280	250	220	260
40	50	100	125	120
41	170	140	125	200
42	135	160	200	240
43	200	120	150	210
45	175	150	220	200
46	270	250	225	330
48	100	120	160	220
49	75	100	120	160
50	80	120	150	180
51	160	120	170	280
52	140	150	160	250
53	250	150	180	275
54	180	180	160	200
55	120	80	100	170
56	100	70	90	180
58	120	140	180	270
59	180	150	260	300
60	220	260	250	280
61	120	100	140	225
62	130	140	200	210
63	120	120	170	150
64	100	90	220	160
66	180	180	250	210
67	180	200	280	200
68	140	160	230	210
69	160	150	240	200
71	190	210	250	240
73	240	240	280	270
74	250	280	300	280
75	200	210	250	220
76	180	200	260	220
77	200	170	225	180
78	100	180	200	150
80	130	275	270	180

Daily Biogas				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	250	275	260	250
82	90	230	200	180
83	150	210	200	200
85	190	230	220	220
87	240	250	260	250
88	230	275	250	240
89	230	240	250	250
90	250	260	250	240
91	250	270	260	260
92	240	240	240	230
93	180	210	220	190
94	230	275	240	230
96	225	250	225	240
97	180	210	160	170
98	125	200	120	125
100	170	180	180	170
101	270	260	260	250
102	260	275	270	260
103	100	150	75	50
104	180	170	130	140
106	170	180	160	160
108	160	125	180	170
109	190	170	160	160
110	120	180	130	160
111	115	100	100	120
112	170	130	175	170
114	260	260	280	270
115	175	175	270	170
116	150	160	180	160
118	250	200	190	170
119	170	180	170	180
120	75	100	150	100
122	175	180	250	180
123	270	260	240	250
125	75	150	160	140
126	230	250	225	200
127	150	175	180	160
129	150	175	220	210
130	170	225	200	190
131	140	170	180	180
133	75	180	180	120
134	100	120	150	120
136	120	160	170	150
137	175	175	140	150
139	125	175	150	150
140	200	150	160	160
142	120	150	160	140
143	200	270	260	280
145	100	130	120	110
147	120	150	140	130
148	100	130	140	140
150	250	220	270	250
151	160	240	210	250
152	120	140	150	160
153	160	160	180	190
154	130	140	140	150
155	110	150	120	130
157	120	150	160	160
158	150	180	170	150
160	120	80	90	130

Table B2 Cumulative biogas productions (ml) from simulated anaerobic organic waste reactors

	Cumulative biogas			
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
1	730	760	765	770
3	970	970	1015	1070
5	1260	1270	1315	1380
6	1550	1540	1595	1660
7	1760	1800	1885	1940
8	1940	2000	2155	2220
9	2060	2150	2335	2380
10	2240	2340	2520	2570
11	2390	2530	2740	2840
12	2460	2610	2870	2940
13	2590	2770	3050	3160
14	2710	2960	3230	3350
15	2850	3140	3440	3570
16	3000	3400	3710	3820
17	3220	3640	3990	4060
19	3470	3920	4280	4360
20	3600	4080	4430	4540
21	3760	4255	4690	4880
22	3870	4385	4850	5020
24	3920	4475	5025	5160
25	3990	4575	5165	5270
27	4110	4725	5415	5470
28	4210	4905	5575	5600
29	4350	5145	5785	5780
31	4500	5445	6035	6050
33	4750	5595	6235	6230
34	4840	5675	6295	6290
35	5020	5925	6475	6450
36	5195	6085	6665	6620
38	5475	6335	6915	6870
39	5755	6585	7135	7130
40	5805	6685	7260	7250
41	5975	6825	7385	7450
42	6110	6985	7585	7690
43	6310	7105	7735	7900
45	6485	7255	7955	8100
46	6755	7505	8180	8430
48	6855	7625	8340	8650
49	6930	7725	8460	8810
50	7010	7845	8610	8990
51	7170	7965	8780	9270
52	7310	8115	8940	9520
53	7560	8265	9120	9795
54	7740	8445	9280	9995
55	7860	8525	9380	10165
56	7960	8595	9470	10345
58	8080	8735	9650	10615
59	8260	8885	9910	10915
60	8480	9145	10160	11195
61	8600	9245	10300	11420
62	8730	9385	10500	11630
63	8850	9505	10670	11780
64	8950	9595	10890	11940
66	9130	9775	11140	12150
67	9310	9975	11420	12350
68	9450	10135	11650	12560
69	9610	10285	11890	12760
71	9800	10495	12140	13000
73	10040	10735	12420	13270
74	10290	11015	12720	13550
75	10490	11225	12970	13770
76	10670	11425	13230	13990
77	10870	11595	13455	14170
78	10970	11775	13655	14320
80	11100	12050	13925	14500

Cumulative biogas				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	11350	12325	14185	14750
82	11440	12555	14385	14930
83	11590	12765	14585	15130
85	11780	12995	14805	15350
87	12020	13245	15065	15600
88	12250	13520	15315	15840
89	12480	13760	15565	16090
90	12730	14020	15815	16330
91	12980	14290	16075	16590
92	13220	14530	16315	16820
93	13400	14740	16535	17010
94	13630	15015	16775	17240
96	13855	15265	17000	17480
97	14035	15475	17160	17650
98	14160	15675	17280	17775
100	14330	15855	17460	17945
101	14600	16115	17720	18195
102	14860	16390	17990	18455
103	14960	16540	18065	18505
104	15140	16710	18195	18645
106	15310	16890	18355	18805
108	15470	17015	18535	18975
109	15660	17185	18695	19135
110	15780	17365	18825	19295
111	15895	17465	18925	19415
112	16065	17595	19100	19585
114	16325	17855	19380	19855
115	16500	18030	19650	20025
116	16650	18190	19830	20185
118	16900	18390	20020	20355
119	17070	18570	20190	20535
120	17145	18670	20340	20635
122	17320	18850	20590	20815
123	17590	19110	20830	21065
125	17665	19260	20990	21205
126	17895	19510	21215	21405
127	18045	19685	21395	21565
129	18195	19860	21615	21775
130	18365	20085	21815	21965
131	18505	20255	21995	22145
133	18580	20435	22175	22265
134	18680	20555	22325	22385
136	18800	20715	22495	22535
137	18975	20890	22635	22685
139	19100	21065	22785	22835
140	19300	21215	22945	22995
142	19420	21365	23105	23135
143	19620	21635	23365	23415
145	19720	21765	23485	23525
147	19840	21915	23625	23655
148	19940	22045	23765	23795
150	20190	22265	24035	24045
151	20350	22505	24245	24295
152	20470	22645	24395	24455
153	20630	22805	24575	24645
154	20760	22945	24715	24795
155	20870	23095	24835	24925
157	20990	23245	24995	25085
158	21140	23425	25165	25235
160	21260	23505	25255	25365

Table B3 Methane compositions (percentage) in biogas from the simulated anaerobic organic waste reactors

Methane Percentage				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
7	2.50	2.95	3.83	5.00
10	6.32	11.21	14.3	16.89
13	12.67	15.59	18.86	22.80
16	16.22	17.41	16.10	27.01
21	10.22	24.06	21.13	29.54
25	13.29	16.75	25.36	24.82
28	11.68	17.38	29.43	23.64
33	13.47	15.59	36.81	24.58
35	14.58	17.26	25.88	18.12
38	16.23	18.16	27.50	24.18
41	24.84	23.27	29.57	33.41
46	18.35	28.34	28.63	39.57
48	25.38	28.34	33.82	45.50
51	28.24	35.62	38.66	51.38
55	34.40	36.84	41.24	56.62
61	35.28	38.63	49.56	60.46
67	32.18	38.46	54.65	58.24
73	40.15	45.28	56.68	60.58
78	42.64	48.32	56.28	56.84
85	49.84	55.68	60.40	62.35
91	52.63	58.74	61.66	63.80
98	50.32	55.26	63.44	60.78
112	51.36	56.24	56.38	52.19
122	52.40	54.32	58.36	56.84
130	52.75	55.46	56.83	53.60
139	50.68	54.25	56.24	58.36
147	44.28	50.23	48.38	53.62
151	42.18	48.35	50.26	46.38
158	40.48	45.26	44.53	48.65

Table B4 Daily Methane gas (ml) in biogas from the simulated anaerobic organic waste reactors

Daily Methane gas				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
7	5	8	11	14
8	5	6	10	14
9	3	4	7	8
10	11	21	26	32
11	9	21	31	46
12	4	9	19	17
13	16	25	34	50
14	15	30	34	43
15	18	28	40	50
16	24	45	43	68
17	36	42	45	65
19	41	49	47	81
20	21	28	24	49
21	16	42	55	100
22	11	31	34	41
24	5	22	37	41
25	9	17	36	27
27	16	25	63	50
28	12	31	47	31
29	16	42	62	43
31	18	52	74	64
33	34	23	74	44
34	12	12	22	15
35	26	43	47	29
36	26	28	49	31
38	45	45	69	60
39	45	45	61	63
40	8	18	34	29
41	42	33	37	67
42	34	37	59	80
43	50	28	44	70
45	43	35	65	67
46	50	71	64	131
48	25	34	54	100
49	19	28	41	73
50	20	34	51	82
51	45	43	66	144
52	40	53	62	128
53	71	53	70	141
54	51	64	62	103
55	41	29	41	96
56	34	26	37	102
58	41	52	74	153
59	62	55	107	170
60	76	96	103	159
61	42	39	69	136
62	46	54	99	127
63	42	46	84	91
64	35	35	109	97
66	64	70	124	127
67	58	77	153	116
68	45	62	126	122
69	51	58	131	116
71	61	81	137	140
73	96	109	159	164
74	100	127	170	170
75	80	95	142	133
76	72	91	147	133
77	80	77	128	109
78	43	87	113	85
80	55	133	152	102

Daily Methane gas				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	107	133	146	142
82	38	111	113	102
83	64	101	113	114
85	95	128	133	137
87	120	139	157	156
88	115	153	151	150
89	115	134	151	156
90	125	145	151	150
91	132	159	160	166
92	126	141	148	147
93	95	123	136	121
94	121	162	148	147
96	118	147	139	153
97	95	123	99	108
98	63	111	76	76
100	86	99	114	103
101	136	144	165	152
102	131	152	171	158
103	50	83	48	30
104	92	100	78	77
106	86	106	96	88
108	81	73	108	94
109	97	100	96	88
110	61	106	78	88
111	59	59	60	66
112	87	73	99	89
114	134	146	158	141
115	90	98	152	89
116	77	90	101	84
118	128	112	107	89
119	87	101	96	94
120	39	56	85	52
122	92	98	146	102
123	141	141	140	142
125	39	81	93	80
126	121	136	131	114
127	79	95	105	91
129	79	95	128	119
130	90	125	114	102
131	74	94	102	96
133	40	100	102	64
134	53	67	85	64
136	63	89	97	80
137	92	97	80	80
139	63	95	84	88
140	101	81	90	93
142	61	81	90	82
143	101	146	146	163
145	51	71	67	64
147	53	75	68	70
148	44	65	68	75
150	111	111	131	134
151	67	116	106	116
152	51	68	75	74
153	67	77	90	88
154	55	68	70	70
155	46	73	60	60
157	51	73	80	74
158	61	81	76	73
160	49	36	40	63

Table B5 Cumulative methane gas (ml) from the simulated anaerobic organic waste reactors

Cumulative Methane Gas				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
7	5	8	11	14
8	10	14	21	28
9	13	18	28	36
10	24	39	55	68
11	34	61	86	114
12	38	70	105	131
13	55	95	139	181
14	70	124	173	224
15	87	152	212	274
16	112	197	256	342
17	147	239	301	407
19	188	288	348	488
20	209	316	372	536
21	225	358	427	637
22	237	389	460	678
24	242	411	497	719
25	251	428	533	747
27	267	453	596	796
28	279	484	643	827
29	295	526	705	870
31	313	578	779	933
33	346	601	852	978
34	358	614	875	992
35	385	657	921	1021
36	410	685	970	1052
38	456	730	1039	1113
39	501	775	1100	1176
40	509	793	1134	1205
41	551	826	1171	1271
42	585	863	1230	1352
43	635	891	1274	1422
45	678	926	1339	1489
46	728	997	1404	1619
48	753	1031	1458	1719
49	772	1059	1499	1792
50	792	1093	1549	1874
51	838	1136	1615	2018
52	877	1189	1677	2146
53	948	1243	1746	2288
54	998	1307	1808	2390
55	1040	1337	1850	2487
56	1074	1362	1887	2588
58	1115	1414	1961	2741
59	1177	1469	2068	2911
60	1253	1565	2171	3070
61	1295	1604	2241	3206
62	1341	1658	2340	3333
63	1384	1704	2424	3423
64	1419	1739	2533	3520
66	1482	1808	2657	3647
67	1540	1885	2810	3764
68	1585	1947	2936	3886
69	1637	2004	3067	4002
71	1698	2085	3203	4142
73	1794	2194	3362	4306
74	1895	2321	3532	4475
75	1975	2416	3674	4609
76	2047	2506	3821	4742
77	2128	2583	3949	4851
78	2170	2670	4061	4936
80	2226	2803	4213	5039

Cumulative Methane Gas				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	2332	2936	4360	5181
82	2371	3047	4472	5283
83	2435	3149	4585	5397
85	2529	3277	4718	5534
87	2649	3416	4875	5690
88	2764	3569	5026	5839
89	2878	3703	5177	5995
90	3003	3847	5328	6145
91	3134	4006	5488	6311
92	3261	4147	5636	6457
93	3355	4270	5772	6579
94	3476	4432	5920	6725
96	3595	4579	6058	6879
97	3690	4702	6157	6987
98	3752	4813	6233	7063
100	3838	4912	6347	7166
101	3974	5056	6512	7318
102	4105	5208	6683	7476
103	4155	5291	6731	7507
104	4247	5390	6809	7584
106	4333	5496	6905	7672
108	4414	5569	7014	7766
109	4511	5669	7110	7855
110	4572	5774	7188	7943
111	4631	5833	7248	8010
112	4718	5906	7347	8098
114	4852	6052	7504	8239
115	4941	6151	7657	8328
116	5018	6241	7758	8412
118	5147	6353	7865	8500
119	5234	6455	7961	8594
120	5273	6511	8046	8646
122	5364	6609	8192	8749
123	5506	6750	8332	8891
125	5545	6831	8425	8970
126	5666	6967	8556	9084
127	5744	7062	8661	9175
129	5823	7157	8790	9294
130	5913	7282	8903	9396
131	5986	7376	9006	9493
133	6026	7476	9108	9557
134	6079	7543	9193	9621
136	6142	7631	9290	9702
137	6234	7728	9369	9782
139	6298	7823	9454	9870
140	6399	7905	9544	9963
142	6460	7986	9634	10045
143	6561	8133	9780	10208
145	6612	8203	9847	10272
147	6665	8278	9915	10342
148	6709	8344	9983	10417
150	6820	8454	10114	10551
151	6887	8570	10219	10667
152	6938	8638	10295	10741
153	7006	8715	10385	10829
154	7060	8783	10455	10899
155	7107	8856	10516	10959
157	7157	8928	10596	11034
158	7218	9010	10672	11107
160	7267	9046	10712	11170

Table B6 Daily methane gas output per daily volatile fatty acid loading input (ml CH4/ mg VFA loading) from the simulated anaerobic organic waste reactors

Daily CH4/Daily VFA loading				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
7	0.004	0.003	0.002	0.001
8	0.004	0.002	0.002	0.001
9	0.002	0.002	0.001	0.001
10	0.009	0.009	0.005	0.003
11	0.008	0.009	0.006	0.005
12	0.004	0.004	0.004	0.002
13	0.013	0.010	0.007	0.005
14	0.012	0.012	0.007	0.004
15	0.014	0.011	0.008	0.005
16	0.020	0.018	0.009	0.007
17	0.029	0.017	0.009	0.007
19	0.033	0.020	0.010	0.008
20	0.017	0.011	0.005	0.005
21	0.013	0.017	0.011	0.010
22	0.009	0.013	0.007	0.004
24	0.004	0.009	0.008	0.004
25	0.008	0.007	0.007	0.003
27	0.013	0.010	0.013	0.005
28	0.010	0.013	0.010	0.003
29	0.013	0.017	0.013	0.004
31	0.014	0.021	0.015	0.007
33	0.027	0.010	0.015	0.005
34	0.010	0.005	0.005	0.002
35	0.021	0.018	0.010	0.003
36	0.021	0.011	0.010	0.003
38	0.037	0.019	0.014	0.006
39	0.037	0.019	0.012	0.006
40	0.007	0.007	0.007	0.003
41	0.006	0.005	0.005	0.010
42	0.027	0.015	0.012	0.008
43	0.041	0.011	0.009	0.007
45	0.035	0.014	0.013	0.007
46	0.040	0.029	0.013	0.013
48	0.021	0.014	0.011	0.010
49	0.016	0.012	0.008	0.014
50	0.017	0.014	0.010	0.030
51	0.037	0.017	0.013	0.046
52	0.032	0.022	0.013	0.023
53	0.058	0.022	0.014	0.029
54	0.041	0.026	0.013	0.019
55	0.034	0.012	0.008	0.025
56	0.028	0.011	0.008	0.066
58	0.034	0.021	0.015	0.094
59	0.051	0.023	0.022	0.069
60	0.062	0.039	0.021	0.052
61	0.035	0.016	0.014	0.048
62	0.037	0.022	0.020	0.052
63	0.035	0.019	0.022	0.040
64	0.029	0.014	0.034	0.059
66	0.052	0.028	0.030	0.073
67	0.047	0.031	0.033	0.051
68	0.037	0.025	0.043	0.062
69	0.042	0.024	0.055	0.056
71	0.050	0.033	0.055	0.071
73	0.079	0.044	0.061	0.069
74	0.082	0.052	0.107	0.086
75	0.066	0.039	0.083	0.065
76	0.059	0.037	0.104	0.083
77	0.066	0.018	0.058	0.045
78	0.035	0.024	0.059	0.043
80	0.045	0.032	0.090	0.067

Daily CH4/Daily VFA loading				
Day	Reactor 1	Reactor 2	Reactor 3	Reactor 4
81	0.087	0.021	0.064	0.077
82	0.011	0.021	0.051	0.060
83	0.049	0.023	0.067	0.093
85	0.044	0.032	0.079	0.101
87	0.037	0.054	0.079	0.095
88	0.028	0.055	0.064	0.080
89	0.029	0.044	0.067	0.087
90	0.025	0.049	0.056	0.048
91	0.024	0.050	0.059	0.055
92	0.044	0.040	0.051	0.044
93	0.034	0.040	0.051	0.041
94	0.058	0.060	0.061	0.061
96	0.044	0.041	0.052	0.052
97	0.044	0.038	0.055	0.039
98	0.037	0.041	0.059	0.039
100	0.076	0.041	0.115	0.076
101	0.088	0.066	0.111	0.082
102	0.053	0.048	0.080	0.058
103	0.018	0.020	0.017	0.007
104	0.087	0.045	0.103	0.098
106	0.045	0.039	0.077	0.044
108	0.045	0.026	0.070	0.041
109	0.057	0.050	0.056	0.036
110	0.026	0.039	0.045	0.053
111	0.040	0.021	0.043	0.039
112	0.062	0.046	0.091	0.070
114	0.064	0.074	0.089	0.084
115	0.028	0.025	0.054	0.033
116	0.041	0.038	0.032	0.045
118	0.079	0.052	0.050	0.051
119	0.032	0.038	0.043	0.050
120	0.021	0.023	0.042	0.026
122	0.113	0.072	0.082	0.093
123	0.077	0.080	0.064	0.073
125	0.014	0.032	0.044	0.029
126	0.153	0.093	0.094	0.075
127	0.033	0.039	0.053	0.042
129	0.050	0.056	0.081	0.069
130	0.052	0.063	0.052	0.043
131	0.037	0.036	0.053	0.047
133	0.024	0.050	0.059	0.033
134	0.061	0.032	0.049	0.050
136	0.055	0.058	0.063	0.069
137	0.066	0.048	0.046	0.056
139	0.031	0.043	0.059	0.060
140	0.073	0.037	0.059	0.059
142	0.027	0.043	0.056	0.049
143	0.098	0.106	0.135	0.133
145	0.029	0.028	0.038	0.026
147	0.062	0.063	0.084	0.072
148	0.025	0.025	0.042	0.036
150	0.074	0.050	0.080	0.060
151	0.015	0.033	0.037	0.043
152	0.018	0.018	0.032	0.032
153	0.032	0.036	0.055	0.059
154	0.019	0.027	0.035	0.039
155	0.020	0.033	0.039	0.043
157	0.026	0.031	0.061	0.062
158	0.043	0.043	0.043	0.045
160	0.029	0.017	0.024	0.039

APPENDIX C

Calculation

Amount of leachate volatile fatty acid loading on initial phase

Before, total weight 2.5 kg, moisture content =88%

Mass of water =2.5 * 88/100= 2.2 kg

Volume of water = M/D = 2.2 kg / 1000 kg/m^3 = 0.0022 m3 = 2.2 Liter

Based on Jaijongrak plan A leachate reirculation volume (Jaijongrak, 2003) = 5% of initial moisture in system

Leachate recirculation volume = 0.05 * 2.2 Liter = 0.11 Liter

Based on Teerachark study (Teerachark, 2006); average leachate volatile fatty acid on initial phase from vegetable wastes equaled to 11,136 mg/l

Consequently, leachate volatile fatty acid loading base on plan A Jaijongrak study equaled to 0.11 liter * 11,136 mg/l = 1,224.96 mg

Amount of leachate volatile fatty acid loading on methane phase

CH_4 Range	Volume of methane/ COD mass
0-15%	0
16-30%	0.002
30-50%	0.005
> 50%	0.010

At methane phase generation, methane percentage was investigated over 50%

The daily loading employment was as 0.010 of volume methane/ COD mass

For example, Daily methane output = 119 ml

0.010 = 119 ml / COD mass loading

COD mass loading = 119/ 0.01 = 11,900 mg

On that day the ratio of VFA/COD = 0.20   VFA/ 11,900 mg =0.20

VFA loading = 2,380 mg

On that day, Leachae VFA concentration = 8,438 mg/l

Leachate recycled = 2,380/ 8,438 = 282 ml

BIOGRAPHY

Mr. Pipat Teerachark was born on March 29, 1983 in Bangkok Province, Thailand. He graduated secondary course from Assumption College, Bangkok in 2000. He received his Bachelor’s Degree in environmental engineering from Chulalongkorn University in 2004. He pursued his Master Degree study in the International Postgraduate Programs in Environmental Management, Inter-Department of Environmental Management, Graduate School, Chulalongkorn University, Bangkok, Thailand in May 2004. He finished his Master‘s Degree of Science in Environment Management in May 2006. He enrolled his Philosophy’s Degree study in the International Postgraduate Programs in Environmental Management, Inter-Department of Environmental Management, Graduate School, Chulalongkorn University, Bangkok, Thailand in May 2006. He finished his Doctoral Degree of Science in Environment Management in May 2011.