ผลของการใช้ปุ๋ยหมักในการคลุมหลุมฝังกลบต่อการย่อยสลายของขยะอินทรีย์ที่ปนเปื้อนตะกั่ว

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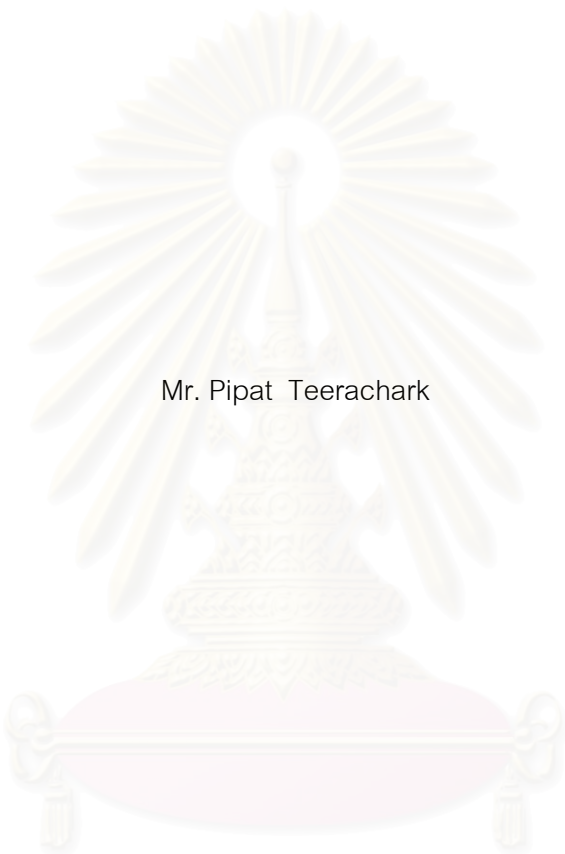
EFFECT OF COMPOST UTILIZATION ON LANDFILL MANAGEMENT OF ORGANIC WASTE

CONTAMINATED WITH LEAD

Mr. Pipat Teerachark

A Dissertation Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science in Environmental Management

(Inter-Department Program)

Graduate School

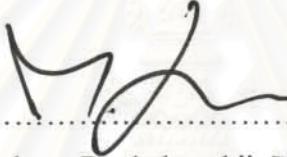Chulalongkorn University

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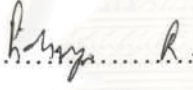
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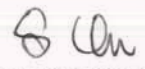
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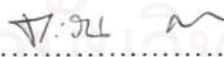
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พิพัฒน์ ธีระจักร: ผลของการใช้ปุ๋ยหมักในการคลุมหลุมฝังกลบต่อการย่อยสลายขยะอินทรีย์ที่ปนเปื้อนตะกั่ว. (EFFECT OF COMPOST UTILIZATION ON LANDFILL MANAGEMENT OF ORGANIC WASTE CONTAMINATED WITH LEAD) อ. ที่ปรึกษา: ดร. พิชญ รัชฎาวงศ์, 98 หน้า. ISBN 974-14-2443-4.

วัตถุประสงค์ของงานวิจัยนี้คือการศึกษาผลกระทบของตะกั่วต่อการย่อยสลายของขยะอินทรีย์ในหลุมฝังกลบในสภาวะไร้อากาศ กับการใช้ปุ๋ยหมักในการคลุมหลุมฝังกลบเพื่อลดผลกระทบของตะกั่ว โดยแบ่งถังหมักจำลองเป็น 4 ถัง ถังหมักแรกประกอบด้วยขยะอินทรีย์ ถังหมักที่สองประกอบด้วยขยะอินทรีย์ซึ่งถูกปนเปื้อนด้วยตะกั่วในสภาวะเป็นกรด ถังหมักที่สามประกอบด้วยขยะอินทรีย์ซึ่งถูกปนเปื้อนด้วยตะกั่วในสภาวะเป็นกรดและการใช้ปุ๋ยหมักเพื่อคลุมหัวและท้ายถังหมัก ถังหมักสุดท้ายประกอบด้วยขยะอินทรีย์และการใช้ปุ๋ยหมักเพื่อคลุมหัวและท้ายถังหมัก

ขยะอินทรีย์ถูกนำไปทำเป็นปุ๋ยหมักเป็นเวลา 21 วัน เพื่อใช้ในการคลุมหัวและท้ายของถังหมักไร้อากาศของถังที่สามและถังที่สี่ ในขณะที่ถังที่หนึ่งและถังที่สองใช้แค่เฉพาะขยะอินทรีย์จำลองในการย่อยสลาย ระยะเวลาดำเนินการหมักแบบไร้อากาศ 125 วันโดยการหมุนเวียนน้ำชะขยะและการปรับพีเอชแบบรายวันถูกดำเนินการตั้งแต่วันที่ 81 ส่วนตะกั่วถูกผสมเข้าไปในถังหมักที่สองและถังหมักที่สามในวันที่ 42 ซึ่งอยู่ในสภาวะเป็นกรดมากจึงทำให้น้ำชะขยะชะโลหะหนักออกมาได้มากถึง 201 มิลลิกรัมต่อลิตร

พบว่าตะกั่วมีความเป็นพิษต่อการเจริญเติบโตของจุลชีพในระบบการหมักแบบไร้อากาศ ทำให้เกิดการชะลอต่ออัตราการย่อยสลายของขยะ ซึ่งสังเกตได้จากปริมาณมีเทนรวมมีค่าเท่ากับ 631 มิลลิลิตร จากถังหมักที่สอง ซึ่งมีค่าน้อยที่สุดเมื่อเทียบกับถังหมักอื่นๆ และสามารถสังเกตได้จากตัวแปรต่างๆจากน้ำชะขยะและแก๊สในถังหมักที่สอง ในขณะที่การใช้ปุ๋ยหมักเพื่อคลุมหลุมฝังกลบสามารถลดผลกระทบจากพิษของตะกั่วต่อระบบย่อยสลายของขยะ ซึ่งสามารถสังเกตได้จากปริมาณความเข้มข้นของตะกั่วที่น้อยลงจากน้ำชะขยะในช่วงกรด ซึ่งมีค่าน้อยที่สุดเท่ากับ 12 มิลลิกรัมต่อลิตรในวันที่ 75 และสามารถสังเกตได้จากตัวแปรต่างๆจากน้ำชะขยะและแก๊สในถังหมักที่สาม นอกเหนือจากนี้การใช้ปุ๋ยหมักเพื่อคลุมหลุมฝังกลบไม่มีผลกระทบทางลบต่อระบบย่อยสลายของขยะ ทั้งนี้สามารถสังเกตได้จากปริมาณก๊าซมีเทนรวมมีค่าเท่ากับ 1497 มิลลิลิตร ปริมาณก๊าซชีวภาพรวมมีค่าเท่ากับ 43695 มิลลิลิตร และสารอาหารในน้ำชะขยะของถังหมักที่สี่มีค่ามากกว่าถังหมักที่หนึ่งซึ่งย่อยสลายด้วยขยะเพียงอย่างเดียว ซึ่งมีปริมาณมีเทนรวมมีค่าเท่ากับ 1230 มิลลิลิตร และปริมาณก๊าซชีวภาพรวมมีค่าเท่ากับ 34203 มิลลิลิตร ตามลำดับ

สาขาวิชา การจัดการสิ่งแวดล้อม(สหสาขาวิชา) ลายมือชื่อนิสิต................Pipat............................
ปีการศึกษา 2548   ลายมือชื่ออาจารย์ที่ปรึกษา.......Pity. R...........

PIPAT   TEERACHARK: EFFECT OF COMPOST UTILIZATION ON LANDFILL MANAGEMENT OF ORGANIC WASTE CONTAMINATED WITH LEAD. THESIS ADVISOR: PICHAYA RACHDAWONG, Ph.D., 98 pp. ISBN 974-14-2443 -4.

The objectives of this research were to study the impact of lead on degradation of organic wastes under anaerobic condition and the use of compost as daily cover to reduce lead impact. Four laboratory-scale simulating landfill bioreactors were set up: 1) Synthetic organic wastes as control reactor; 2) Organic wastes spiked with lead during acid phase; 3) Organic wastes with compost as top cover and bottom liner with lead spiked during acid phase; 4) Organic wastes with compost as top cover and bottom cover liner.

Aerobic compost was operated for 21 days for the use as top cover and bottom liner in anaerobic simulated bioreactors 3 and 4 while reactor 1 and reactor 2 were loaded only synthetic organic wastes. Anaerobic bioreactors were operated for 125 days with daily leachate recirculation and buffer neutralization since day 81. Lead was spiked in reactor 2 and reactor 3 on day 42 considered the most acidic condition with the most leaching out of lead that equals to 201 mg/l.

The results showed that lead was toxic and not suitable for the growth of microorganisms during digestion and the retardation on stabilization process could be observed as indication from the lowest cumulative methane gas that equaled to 631 ml in reactor 2 including the observation of other indications from leachate and gas parameters in reactor 2 while the use of compost could reduce the impact of lead inhibition on landfill stabilization process as indication from less concentration of lead leaching during acid phase which gave the least concentration of 12 mg/l on day 75 including the observation of other parameters from leachate and gas in reactor 3. Moreover, compost use did not retard the stabilization process since cumulative methane production that equaled to 1497 ml, biogas production that equaled to 43695 ml and leachate nutrients in reactor 4 were higher than those from reactor 1(control reactor) which had 1230 ml cumulative methane gas and 34203 ml cumulative biogas production, respectively.

Field of study Environmental management(Inter-Department) Student's signature...*Pipat.*

Academic year 2005   Advisor's signature...*P.*

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Most of all, gratitude thanks to my parents, my brother, my nephew 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

CHAPTER I

INTRODUCTION

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 is about 22 million tons of solid waste generated annually. 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.

Now, the main problem from landfill leachate migration is contamination of groundwater by heavy metals. Pollution Control Department (PCD), 1998 showed that groundwater has been significantly contaminated by heavy metals and other harmful substances in the areas around numerous waste sites in Northern and Central Thailand. This problem may be caused by inappropriate management of landfill system with respect to both design and operation, as well as no proper separation of the wastes. The contamination of household hazardous waste in municipal waste is

one cause to this problem. According to a survey conducted by Public Health Research Institute of Thailand (Public Cleaning Bangkok Metropolitan Administration (BMA), 1997), the contamination of household hazardous waste in municipal solid waste in Bangkok in 1993 was 22 tons per day and the trend would increase. The household hazardous wastes are oil tires, used oil, automobile batteries, household batteries, mobile batteries, etc.

Due to the lack of waste separation before landfilling in Thailand, all of the waste is dumped in landfill including household hazardous wastes such as computers, mobile batteries and mobile phones that are the most proportion of E-waste containing elevated toxic metal, lead and hazardous substance inside. These heavy metals are toxic and liable to produce serious problems on public health and on maintenance of the biosphere.

Alternative materials as a substitute for soil in the design of MSW landfill cover and liner is one of the emerging techniques for waste containment. The use of these materials, for examples, composted solid wastes, synthetic foams, removable geosynthetics, sludge-derived material, processed green material and man-made fabrics are currently practiced in daily cover system, since the materials offer significant space savings in a landfill cell.

Aerobic treatment by composting can be the beneficial alternative way of waste management since the quality of leachate improves significantly and more rapidly than in anaerobic conditions; offering considerable cost advantages in not requiring secondary treatment. The generation of methane reduced thus contributing to the prevention of global warming and stabilization is enhanced making it possible to return the completed landfill site another use (agriculture or leisure) in a short period of time than for conventional sites. In addition, aerobic treatment of organic waste by composting can be done for rapid stabilization of organic in order to leave only fibers for the purpose of heavy metals adsorption.

Composting is the microbial conversion of organic matter in the presence of suitable amounts of air and moisture into a humus like product (Bertoldi 1983). The compost can be used for a variety of purpose such as fertilizing landscapes, mulching, or for a daily cover at landfill. Compost has hydraulic and mechanical properties desirable of a hydraulic barrier for a landfill cover or a liner. The replacement of clayey soils that are typically used as hydraulic barriers in landfill covers with compost is motivated by several reasons. To begin with, clays are not available at a landfill and hence must be trucked to the site, a practice that is expensive and time consuming. At some sites in the United states, transportation of clay has cost $10-50 m^{-3}. If alternative materials such as compost have been used to replace clay in cover, cost reduction as well as useful function for a material considered waste will be accepted. Next, desiccation and freeze-thaw can cause cracking and increases in the hydraulic conductivity of a clay barrier (Montgomery 1990). If compost is more resistant to the effects of those, then its use in place of clay in a cover would result in less infiltration and leachate generation. Compost has the potential to be more resistant to environmental stresses than clay because it has a wider pore size distribution and fibrous structure.

Solubility of metals in leachate depends on pH, redox potential, and solubility of the deposited metal species, concentration of complexing agents (NH_3/ NH_4^+, organic acids) and ionic strength (Forstner, 1991). Metal solubilities in the leachate increase as pH decreases. The highest metal concentrations are observed during the acid formation phase of waste stabilization when pH values are low. Therefore, methanogenic conditions and neutral pH must be established within landfill site so as to form insoluble metals in the reducing atmosphere before the co-disposal commences (Greedy, 1993, Campbell, 1994). Under methanogenic conditions, soluble metals precipitate as insoluble sulfides, carbonates, hydroxides and possibly phosphates in landfills (Pohland, 1991). However, in the presence of sulfides, most of heavy metals except chromium form extremely insoluble sulfide salts (Pohland, 2000).

This research will focus on the use of anaerobic landfill to stabilize organic waste for biogas production, the impact of Lead on degradation of organic waste and the use of compost utilization as daily cover to be an alternative way for rapid stabilization of organic waste and to leave the fibers for the reduction of Lead impact.

Objectives of the study

1. To investigate the impact of Lead on landfill stabilization process.
2. To investigate the impact of organic wastes compost used as daily cover in anaerobic landfill bioreactor on Lead attenuation and landfill stabilization process as indicated by leachate and gas production parameters.

1.3 Scopes of the Study:

1. Compost organic wastes to be used as top and bottom cover in anaerobic landfill bioreactors.
2. Set up 4 bioreactors capable of running landfill simulation.

   The composition in each reactor is shown as follow. Synthetic solid wastes in reactor 1; whereas, reactor 2 contains solid wastes spiked with Lead heavy metal during acid phase. Reactor 3 is the same as reactor 2 with addition of solid wastes compost as cover. Finally, Reactor 4 is loaded with organic wastes and organic wastes compost as cover. Leachate recycling, waste shredding, sludge seeding and buffer addition are applied to all reactors to ensure that all reactors are optimized condition.

3. Assessment of the degree of leaching out for Lead during acid phase.
4. Assessment of impacts of Lead on landfill stabilization process.
5. Assessment of impacts of compost utilization as cover on Lead attenuation and landfill stabilization process.

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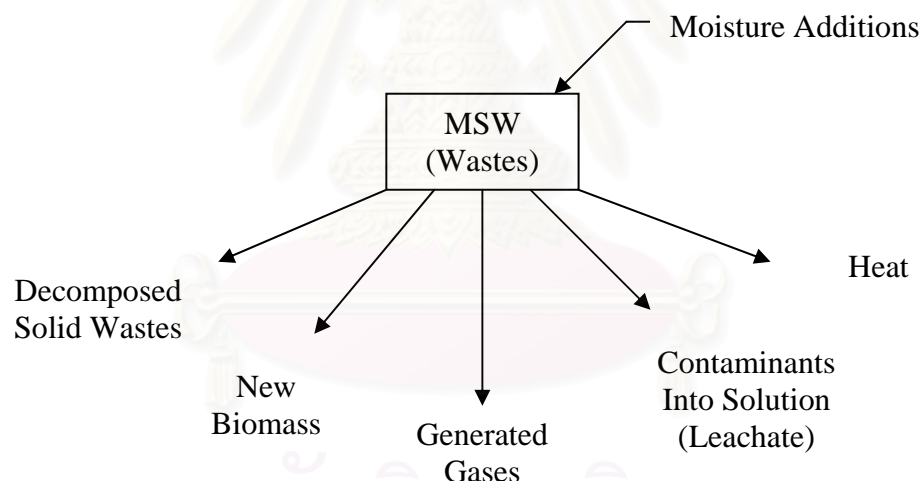
Figure 2.1 Byproducts of solid waste decomposition (Chain and DeWalle, 1997)

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,

$$CH_3 COOH \rightarrow CH_4 + CO_2$$
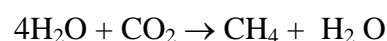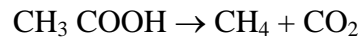
Consumption of the organic acids raises the pH of the leachate to the range of 7 to 8. Consequently, the leachate becomes less aggressive chemically and possesses a lower total organic strength. Organic acids that cannot be used directly by bacteria are converted to methane by an intermediate step. Volatile 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.

Anaerobic Processes for biogas production
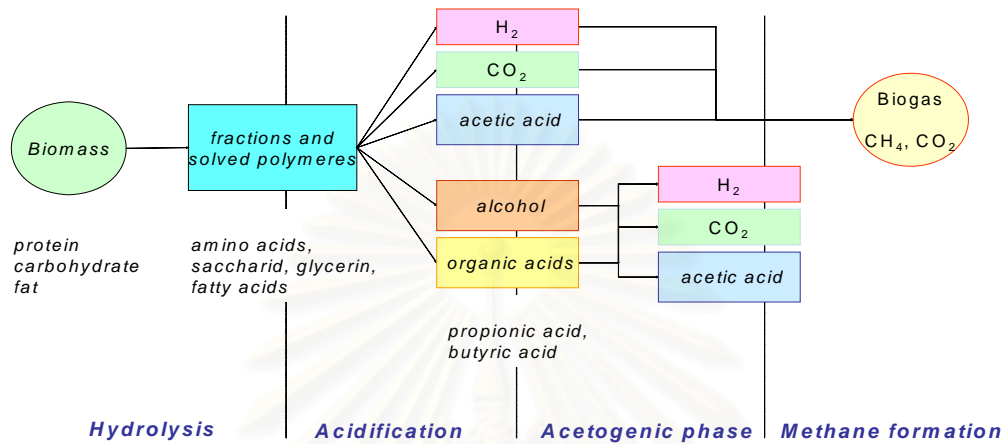
Figure 2.2 anaerobic processes in landfill body (Stegmann, 1995)

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 Meturation

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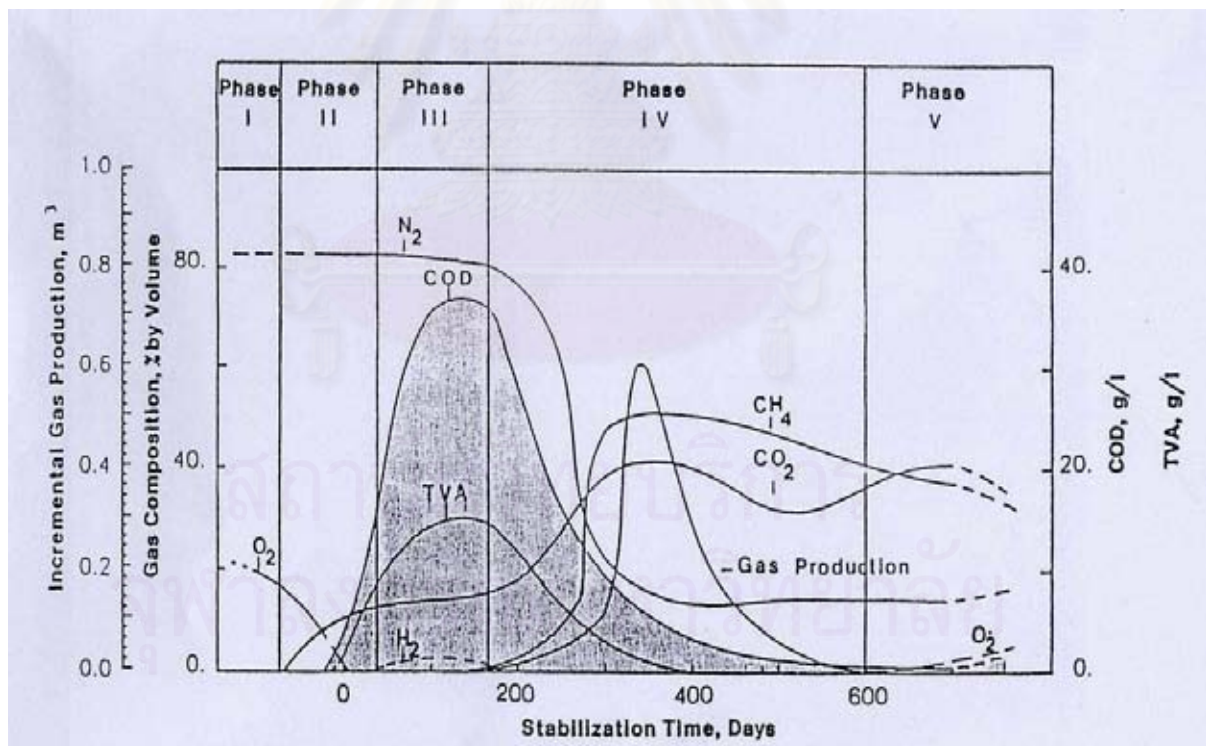
Figure 2.3 Five phases of landfill stabilization. (Adapted from Pohland and Harper, 1986

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 Lead

Lead is a widely used material in our society. Applications include car batteries, sealant (e.g. chimney tops) in the building sector, various elements of electrical and electronic goods (e.g. solder, glass for TV tubes), weights, lead shot, (professional) fishing and other applications, among others the use in lead stabilisers in PVC. The functional applications of lead make use of the unique properties of lead like flexibility, corrosion resistance, and high density. Its flexibility and low melting point makes it easy to handle and fashion. Its high resistance to corrosion makes it suitable for weatherproofing buildings (lead sheet, lead paint) and for the equipment used in the manufacture of acids. Its high density makes it appropriate as a shield against radiation and noise. The most important use of lead today is in the use of lead-acid batteries to storage electrical power. Besides the intentional use of lead in the products lead is also present in products as a contaminant. Products may contain lead because of the natural presence of lead in ores, as is the case for example in (phosphate) fertilisers and fossil fuels, especially coal. Other contaminations of lead in products have an anthropogenic origin, such as lead in sewage sludge, manure and ashes and slags of the waste incineration and the steel industry that would be finally finished in

landfill. There are a number of technologies available for the removal of heavy metals from a wastewater. Chemical precipitation is most commonly employed for most of the metals. Common precipitants include OH^-, CO_3^{2-} and S^{2-}. Metals are precipitated as the hydroxide through the addition of lime or caustic to a pH of minimum solubility. Metals can also be precipitated as the sulfide or in some cases as the carbonate. Sulfide precipitation has several potential advantages as an alternative to hydroxide precipitation. The solubilities of metal sulfides, shown in Figure 2.4
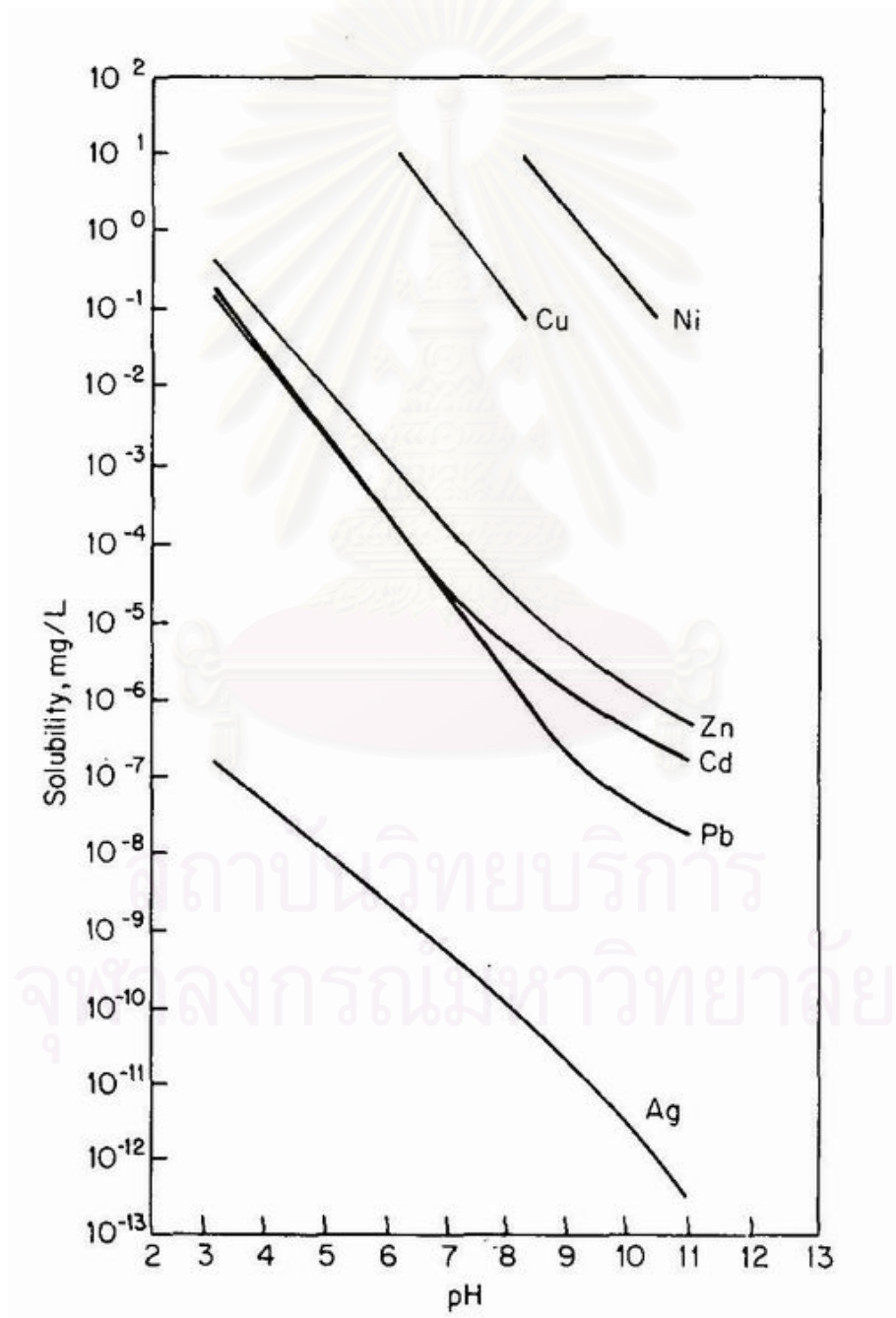
Figure 2.4 Solubilities of metal sulfides as a function of pH (Freeman, 1989)

2.7 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.

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

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

A variety of heavy metals are frequently found in landfill leachates including zinc, copper, cadmium, lead, nickel, chromium, and mercury (Lu et al.,1985). Again, these metals are either soluble components of the refuse or are products of physical processes such as corrosion and complexation. In several instances heavy metal concentrations in leachate exceed U.S. Toxicity Characteristic Leaching Procedures standards.

Heavy metal concentrations in leachate do not appear to follow patterns of organic indicators such as COD, BOD, nutrients, or major ions (Lu et al., 1985). Heavy metal releases is a function of characteristics of the leachate such as pH, flow rate, the concentration of complexing agents.

2.8 Daily cover

Daily cover is applied to the working face of landfill cell after the daily placement of solid waste as you can see in fig 2.5. Required functions of daily cover specified in federal regulations include eliminating the harboring of disease vectors, controlling windblown debris, reducing odor, limiting the potential for fire, and preventing the entry of scavenging animal. However, minimizing dust, improving site aesthetics, and providing a moisture barrier are also important.

Soil has long been used in daily cover applications. Thickness of at least six inches of soil is usually required everyday, or sometimes at more frequent intervals. When properly used, soil is a satisfactory daily cover. Unfortunately, increasing siting problems, and the relatively large volume of landfill spaces occupied by daily cover, has led to the search for alternative approaches. Moreover, unavailability of suitable earthen material and operational difficulties associated with soil has also been problematic.

Alternative daily cover materials (ADCMs) have been developed to overcome some of these problems. ADCMs encompass a variety of materials that can be separated into two main categories, indigenous and commercial. In either category, their implementation must be approved as required.

Indigenous ADCMs generally consist of materials that are conventionally disposed of as wastes at MSW landfills. They are developed by individual landfill operators and are not commercially disposed by individual landfill operators and are not commercially available. Examples of this category are ash-based materials,

compost-based materials, automobile recycling fluff, petroleum-contaminated soil, dredged materials, green wastes, and wastewater treatment plant sludge. Application of indigenous ADCMs optimize the use of available landfill space, since the materials to be disposed of as waste are disposed of as a daily cover in a planned way, thereby saving landfill space otherwise consumed by a soil or other commercial ADCMs. Special equipment, as well as labor costs associated with preparation and application of clay or commercial ACDMs, are also eliminated. Yet issues relating to sufficiency of storage facilities, climatic effects, dust generation, and potential leaching of toxic constituents from some indigenous ADCMs are of importance and, under certain circumstances, render the use of such ADCMs impractical.
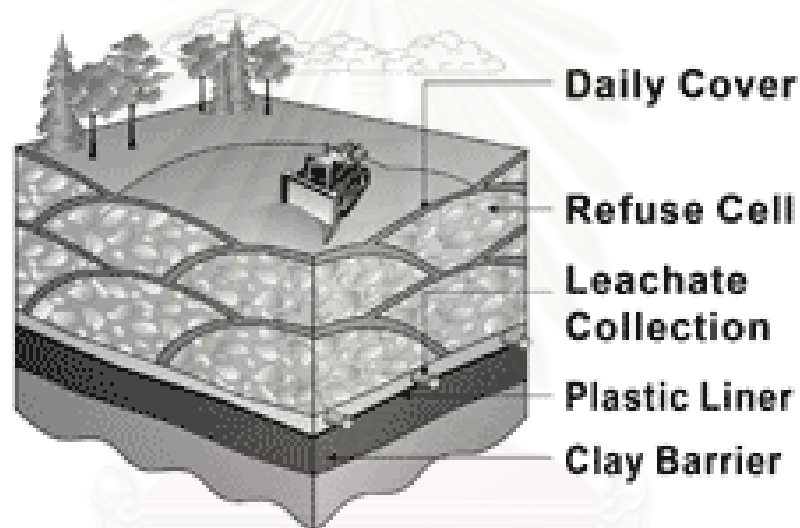
Fig 2.5 Cross-section of an active landfill (www.metrokc.gov)

2.9 Aerobic composting

Composting is a biological process based on aerobic transformation of biodegradable wastes. The result of composting is a dark, humus like material that has fertilizing and soil texture improving properties. Composting can be used on almost all types of biodegradable wastes such as food residues, yard waste, and sewage sludge. During the composting process oxygen is consumed, CO_2, H_2O and energy (heat) is produced. The overall reaction occurring during composting can in a simple manner be formulated as

Biowaste + O_2 → microbial biomass + non-degradable matter + CO_2 + H_2O + Heat
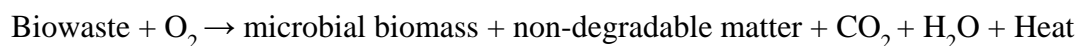
Heat production causes the temperature in the composting material to rise and increases the biological degradation rate in the early stages of the composting process. Later when the easily degradable organic material has been degraded the rate of transformation and the temperature gradually decreases to ambient levels.

2.10 Composting biology

The initial phase is the first period after initiation of the compost process where the temperature rises to about 50 ^{o}C over a period of a few days (Fig. 2.6). During this phase the population of especially bacteria increases rapidly and compounds that are easily degradable, such as sugars, starch, proteins and fats are degraded. Due to the rapid rate of degradation and oxygen consumption it is often difficult to provide enough oxygen for the biological processes and the compost will have a tendency to develop anaerobic pockets. Modest decreases in pH may be observed due to the production of organic acids by anaerobic organisms. The organisms active during the initial phase are mesophilic (optimal temperature 35 – 45 ^{o}C) and thermophilic (optimal temperature (55 – 60 ^{o}C) bacteria. If the conditions in the composting material are well maintained the composting process will normally enter the thermophilic phase next. This phase involves especially termophilic bacteria and also certain thermophilic actinomycetes and fungi. During this phase the temperature can exceed 70 ^{o}C and temperatures as high af 80-85 ^{o}C have been observed during composting of sewage sludge. The pH usually increases to about 7.5 due to the destruction of the organic acids. Near the end of the thermophilic phase when the readily degradable organic material has been removed by the microorganisms only organic materials such as hemicellulose, lignin, chitin, and similar compounds that are more difficult to degrade remain. The microbial activity especially concerning the bacteria begins to decrease and the temperature in the compost begins to fall. At this point the composting process is not yet finished and the compost is sometimes called raw compost. Upon completion of the thermophilic phase the temperature decreases to levels where the mesophilic organisms have their optimum and the composting process enters the mesophilic phase. During this phase

where the temperature ranges between 35 and 45 ^{o}C the more difficult-to-degrade components such as cellulose and lignin are decomposed. During the mesophilic phase several types of bacteria are still very active but it is especially the actinomycetes and fungi that are important during this phase. Actinomycetes and fungi are better adapted to utilize the more difficult degradable compounds compared to most of the bacteria. Some fungi can even produce penicillin that will kill some of the bacteria. The mesophilic phase can take up to several weeks to complete. At the end of the mesophilic phase the compost is often called finished compost.

The final phase of the composting process is termed the cooling phase. During this phase the temperature slowly decreases to near ambient levels during a time span of several weeks. The microbial degradation of the organic material will be almost completed when entering the cooling phase and the rate of degradation will approach that of a natural soil. The organic matter remaining consists of very complex compounds with humus like structures that are difficult to degrade. The pH during this phase will normally stay relatively constant at about 8. Towards the end of the cooling phase higher organisms such as worms and insects will often colonize the compost. The compost is now termed mature compost and the structure of the organic matter in the compost will closely resemble that of humus.
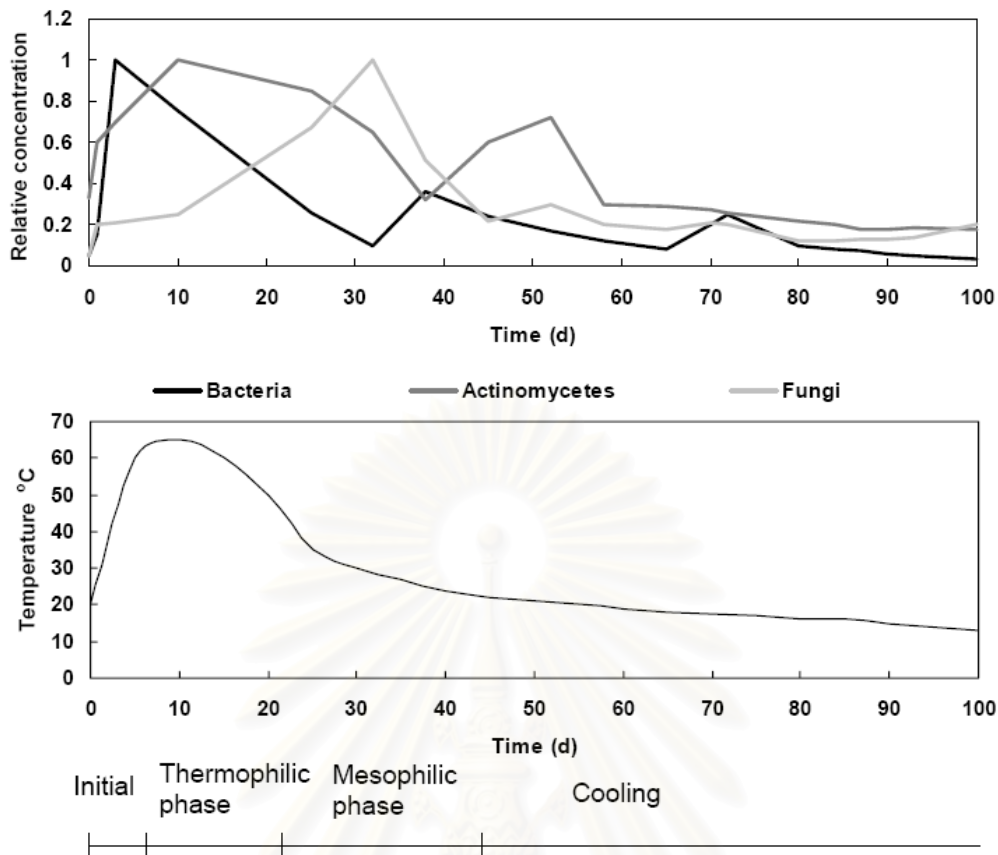
Figure 2.6 Top: Microbial succession during the composting process.

Bottom: Idealized temperature variation in the compost during the course of the composting process. (Epstein 1997)

2.11 Process parameters during composting

Temperature: The temperature controls the microbial activity and, thus, rate of the composting process. The degradation rate usually increases strongly with temperature up to about 70-80 ^{o}C. Above this temperature most microorganisms will either be killed or form spores, which is a resting stage. This prevents further increases in degradation rate and temperature of the compost. It is often important to maintain a high temperature as long as possible to ensure rapid degradation and effective use of the compost facility. High temperatures are also needed in many cases to achieve proper hygienization of the compost material. Hygienization is often required if the compost is to be used as a soil amendment on soils used in agricultural production. Hygienization reduces the concentration of pathogenic organisms and

weed seeds in the compost. Adjusting the oxygen concentration (by mixing or blowing air through the compost) and the water content (by irrigation) in the compost controls the microbial activity and, thus, the temperature. If the oxygen concentration or water content is too low the rate of degradation decreases and the temperature will fall even if there is plenty of degradable organic material available. Watering the compost if too dry or increasing the oxygen concentration if too low by turning or aeration will usually cause the microbial activity and the temperature to go back up. In cold climate regions it can be necessary to provide some type of insulation to maintain proper temperature. This may be done by covering the composting material by a layer of finished compost, or by processing the material in an enclosed space such as a building or directly in a reactor.
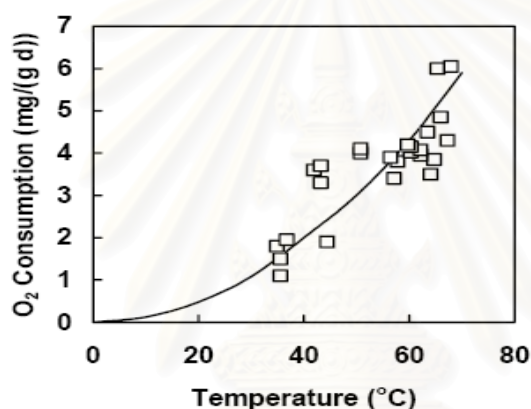
Figure 2.7 Relationship between temperature and oxygen consumption rate (degradation rate) in compost (Epstein 1997)

Water content: The water content controls both the microbial activity and the oxygen transportation in the compost material. At low water contents oxygen will be transported faster and easier because a greater amount of the pores are filled with air. This makes it easier to ensure microorganisms whose activity will cease at gravimetric water contents below 8-12 %. The optimal water content also depends on the structure of material being composted. Materials that are structurally strong can have higher permissible gravimetric water contents (70-80% for wood chips, straw, hay, etc) because the structure of the materials ensure that there will be a sufficient amount of air-filled pores. For less structured materials such as wastewater treatment sludge higher water contents will result in low air filled porosity, poor air penetration and difficulty in handling the materials, as they will become liquefied. Generally the optimal gravimetric water content for most mixtures of organic wastes containing

food residues is between 35 and 60% although practice have shown that water contents of 75% for sludge-straw-garden waste compost mixtures did not prevent successful composting. The essential issue is to maintain a volumetric air-filled porosity of 25 – 30% to ensure adequate oxygen diffusion through the compost. Poor structure and low air-filled porosity can be improved by adding a bulking agent such as straw, wood chips or paper, or by increasing the airflow through the compost to facilitate the evaporation of water. In wet climate it may be necessary to provide a roof over the compost facility to prevent high water contents from developing. Watering the compost can cure low water contents. The water content can be adjusted by mixing the waste with a material of different water content. Assuming that the waste has a water content of a (g/g), the mixing material has a water content of b (g/g) and we want a mixture water content of c (g/g) we can calculate the amount of mixing material required per kg of waste as:

$$M_{mix, water} \left(\frac{\text{kg of mixing material}}{\text{Kg of waste}} \right) = \frac{a-c}{c-d}$$

Where $M_{mix,water}$ is the amount of mixing material required per kg of waste to adjust the water content. Note that c must be between a and b otherwise it is not possible to adjust the water content.

pH: It is usually not necessary to control the pH of the compost if the composting process is well operated such as to maintain adequate levels in temperature and oxygen concentrations. In certain special types of organic material that is very easily degradable anaerobic conditions can develop in the early stages of the process resulting in overproduction of organic acids and a drop in pH. In such cases addition of lime may be necessary to maintain proper levels in pH. Such problems may be avoided altogether by adding a bulking agent such as for example straw or wood chips that is more difficult to degrade and will provide a higher air-filled porosity in the compost. At high values of pH (>9), however, nitrogen losses may become significant due to the formation of ammonia (NH_3) that will evaporate. The degradation rate depends strongly upon the pH, low pH levels are inhibitory to

most aerobic microorganisms. Degradation experiments conducted at 50 – 60 ^{o}C indicate that the degradation rate increases linearly with pH in the interval 6 – 9 (Fig 2.8 Jerris and Regan 1973).
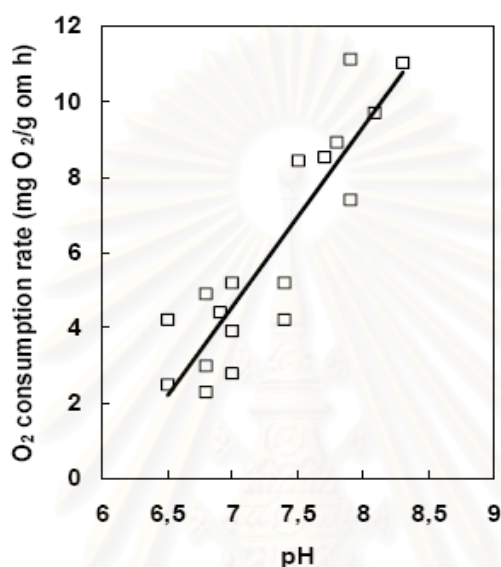
Figure 2.8 Relationship between oxygen consumption rate (degradation rate) and pH in compost (Jerris and Regan 1973)

C/N ratio: The ration of carbon (C) to nitrogen (N) of the material to be composted is important with respect to the nutritional needs of the microbial biomass. If the C/N ratio is too high, the lack of nitrogen will limit the microbial activity and thereby the degradation and transformation of the carbon. On the other hand if the ratio is too low, nitrogen will be in excess and may easily be lost in the form of ammonia (NH_3) to the atmosphere or washed out as nitrate or ammonium ions (NO_3^-, NH_4^+). The C/N ratio in living bacterial biomass is approximately 5 and in fungi approximately 7. The optimal C/N ratio in the compost is, however, much higher because a significant amount of the carbon will be mineralized to CO_2 and another large amount is not biologically accessible because it is bound in difficult-to-degrade organic compounds. The optimal C/N ratio in compost is on the order of 20 – 30

(Diaz et al. 1993, Christensen et al. 1998). The C/N ratio can easily be adjusted to a proper level by mixing materials with different C/N ratios. A list of C/N ratios for different organic materials is listed in Table 2.2

Material	C/N ratio (g/g)
Cow manure	18
Digested sewage sludge	4 - 28
Food waste	12 – 20
Garden waste	20 – 60
Grass clippings	12 – 20
Horse manure	25
Leaves	20 – 60
Night soil	6 – 10
Vegetable wastes (non-legume)	11 – 12
Paper	170 – 800
Pig urine	5 – 7
Potato tops	25
Poultry manure	15
Raw sewage sludge	10 – 15
Sawdust	200 – 500
Sheep manure	128 – 150
Straw, wheat	120 – 150
Straw, oat	48 – 50
Urine	0.8
Wood chips	400 – 500

Table 2.2 C/N ratio for different organic materials used in composting (Christensen 1998)

The procedure for calculating the amount of mixing material required for adjustment of the C/N ratio is as follows. If the waste has a carbon content of **a** (kg of C/kg of wet waste) and a nitrogen content of **b** (kg of N/kg of wet waste) and the mixing material has carbon content **c** (kg of C/kg of wet waste) and nitrogen content **d** (kg of N/kg of wet waste), we can calculate the amount of mixing material required to reach a C/N ratio of **e** (kgC/kgN):

$$M_{mix, water} \left(\frac{\text{kg of mixing material}}{\text{Kg of wet waste}} \right) = \frac{a-eb}{ed-c}$$

Where $M_{mix, C/N}$ is the amount of mixing material required to adjust the C/N ratio. Again the final C/N ratio of the mixture must be between the C/N ratios of the mixing material and the waste otherwise it is not possible to get proper adjustment. Note that the amount of mixing material that is chosen to add to the waste must satisfy both the C/N ratio and the water content requirements. This is normally done by calculating the two values of $M_{mix, water}$ corresponding to the endpoints of the water content interval (35% and 60%) and similarly calculating the values of $M_{mix, C/N}$ corresponding to the two endpoints of the C/N ratio interval (20 and 30). We now have two intervals for the mass of mixing material to be added per kg of waste. The chosen value must be within both of these intervals in order to satisfy both the constraints on water content and the C/N ratio. Normally we wish to use as little mixing material as possible due to economic reasons and we should therefore choose the smallest value of M_{mix} that satisfy both intervals. Using too much mixing material means that more energy is required for composting, as we will have to compost larger quantities. The mixing material must normally also be bought for instance from local farmers.

Oxygen concentration: One of the most important process parameters is the oxygen concentration. Oxygen concentration is the limiting factor for biological degradation especially in the early stages of the composting process. If the oxygen concentration is too low, the process will proceed at a much slower rate resulting in lower temperatures in the compost. Also low oxygen concentrations are usually the cause of foul odors originating from organic acids that are produced as a result of anaerobic conditions. Proper oxygen concentrations can be maintained by turning the compost more frequently or in case forced aeration is used, by increasing the flow of air through the compost. Frequent turning or high aeration rates can, however, lead to increased evaporation of water and decreased compost temperatures. Usually proper turning or aeration levels have to be determined by trial and error.

Structure material: Structure material is usually needed when composting very wet and easily degradable material such as food waste or sewage sludge in order to maintain a proper level of air-filled porosity and to prevent liquefaction of the compost piles. Structure materials often used in composting are straw clippings, wood

chips or paper all of which have high C/N ratios (Table 2.2) and are relatively difficult to degrade. The structure materials are mixed with the wet organic material and go through the entire composting process. After the compost is finished the structure material not degraded can be recovered by sieving. If the structure material is rigid (such as wood chips) its optimal particle size is 1 – 8 cm. Larger particles do not interfere with the composting process other than making the handling more difficult. Normally it is not necessary to reduce the size of wet easily degradable materials. The amount of structure material necessary depends on the type of organic waste to be composted, the shape of the compost piles etc. For source separated organic waste from private households the optimal range is 10 – 40% structure material by weight.

Inoculum: Inoculum is material containing the microorganisms necessary for initiating the composting process. Normally an inoculum is not necessary since most types of organic waste already contain the organisms required for composting. Exemptions are special materials that are difficult to degrade such as sawdust and bark etc. that will not easily begin composting on its own. In such cases horse manure, finished compost, or a rich loamy soil can serve as inoculum as these materials all contain the necessary microorganisms. Recycling of finished compost, however, require additional space in the composting facility and can therefore be problematic in some cases.

2.12 Related studies

Wong and Cheung (1995) studied gas production and digestion efficiency of sewage sludge containing elevated toxic metals. Sludge was collected from Shantin and Taipo sewage treatment plant with more heavy metal containing in sludge from Shantin. In experiment 1, they studied the difference of digestion efficiency among sewage sludge alone and combined sewage sludge with pig manure in the ratio of 1:1. The result showed that Taipo sludge mixed with pig manure had the highest total gas yield. Shantin sludge with pig manure had a slightly higher total yield than Taipo sludge alone; where as, Shantin sludge alone had the lowest total yield. Adding of pig manure has higher gas yield because it raised the organic fraction as we can indicated from the raise of total solid, volatile solid, volatile fatty acid, BOD, COD and C:N ratio. While the Shantin sludge had the lowest gas yield due to more heavy metal

containing in Shantin sludge. In experiment 2, sludge sample collected from Taipo sewage treatment plant were fed with different heavy metal being copper, chromium, nickel and zinc with difference in concentration. The result was that the control group without addition of metals had the highest gas yield. Addition of lower levels of metal did not cause significant different from the control in term of gas production. Gas yield tends to decrease with more heavy metal added and extremely low yield with observed for the highest concentration of four metals. The degree of toxicity of the four metals was in the order of Cr > Ni > Cu > Zn.

Pohland and Gould (1986) also studied the effects of co-disposal of municipal refuse and industrial waste sludge in landfills. One column served as the control landfill and received 400 kg of municipal refuse of residential origin. The test columns (Columns 2, 3 and 4) received 400 kg of refuse plus 33.6 kg, 65.8 kg and 135.2 kg of metal plating sludge, respectively Column 2, suggesting that the lowest metal sludge loading tended to impede but not inhibit the conversion of readily available organic compounds. In contrast, both COD and VFA analysis for the leachates from Columns 3 and 4 indicated a definite inhibition of the normal progress of refuse stabilization.

Read and Morris (2004) studied the potential for a more sustainable solid waste management approach by aerobic landfilling. Their paper also reviewed that the aerobic landfills overcomes anaerobic landfills; for example, the quality of leachate improves significantly and more rapidly than in anaerobic conditions; offering considerable cost advantages in not requiring secondary treatment. The generation of methane reduced thus contributing to the prevention of global warming and stabilization is enhanced making it possible to return the completed landfill site another use(agriculture or leisure) in a short period of time than for conventional sites.

Adeyinka and Greer (2004) studied removal of metals ion from wastewater with natural wastes. Their paper reported the research of the removal of priority metals ion, such as, lead, nickel, zinc from wastewater by using tree leaves. The experiments were carried out with 2 g of 40-50 mash leaves in 200 ml synthetic wastewater containing about 50 ml/l metal ions. The result showed that the highest removal rate was 96% for lead (Pb), 61.7% for nickel (Ni), and 71.3% for zinc (Zn). The goal for

this research is to develop inexpensive, highly available, effective metal ion adsorbents from natural wastes as alternative to existing commercial adsorbents.

Shukla and Roshan (2005) studied the adsorption of Cu(II), Ni(II), Zn(II) on modified jute fibres. The potential of a lignocellulosic fibre, jute, was assessed for adsorption of heavy metal ions like Cu(II), Ni(II), Zn(II) from their aqueous solutions. The result showed that jute fibres showed metal ion uptake values of 4.23, 3.37 and 3.55 mg/g; respectively. The result also indicated that the adsorption values decreased with lowering of pH.

Pattummaart (2003) studied the impact of nickel and zinc on degradation of organic waste during acid and methane phase and the result showed that nickel and zinc added during acidogenic phase could be stayed in liquid phase for longer time and remained more toxic to microbial community in the reactor than heavy metals added during methanogenic phase.

Erses and Onay (2003) studied the in-situ heavy metal attenuation in landfills under methanogenic conditions. Two landfill simulating reactors, one with leachate recirculation and the other without, were operated in a constant room temperature at 32 ° C. these reactors were filled with shredded and compacted municipal solid waste having a typical solid waste composition of Istanbul region. After the onset of the methanogenic conditions, the selected heavy metals including iron, copper, nickel, cadmium and zinc were added according to amounts suggested for codisposal. The results of the experiments indicated that about 90% of all heavy metals were precipitated from the reactors within the first 10 days due to the establishment of highly reducing environment and the formation of sulfide from sulfate reduction, which provided heavy metal precipitation.

Hurst and Longhurst (2005) studied the ability of municipal waste compost as a daily cover material to reduce the odorous emissions. Results for the trials using landfill gas showed a 69% odour reduction (OU/m^3) through the column for compost with a bulk density of 590 kg/m^3, and a reduction of 97% using compost with a bulk density of 740 kg/m^3. Analysis showed an overall decrease in the concentration of

terpenes, and sulphurous compounds in the outlet gas from the column for both bulk densities. By using an alternative daily cover material the volume occupied by cover soil in a site could be reduced from 25% to 13% of the fill capacity, representing a significant extension of the operating life of the landfill and potentially a substantial increase in operating revenue.

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.

Related studies gave the hypothesis that heavy metal would be toxic to anaerobic system as indicated by the work of Wong (1995) and Pohland (1986). In addition, the use of ligno-cellulosic fibers from natural wastes would be beneficial through heavy metal adsorbents as indicating by the work of Greer (2004) and Roshan (2005). Moreover, heavy metals would stay in liquid phase for longer period of time and remain more toxic to microbial community during acid phase as indicated by the work of Pattummaart (2003) and Onay (2003). Finally, aerobic treatment as composting would be beneficial since useful function for a material considered waste as landfill cover would be accepted as indicated by the work of Benson (1992) and Read (2004). Those works showed promising results and led to the study on the impact of lead on degradation of organic wastes by lead spiked during acid phase and the use of compost as alternative daily covers to adsorb lead.

CHAPTER III

METHODOLOGY

3.1 Aerobic composting

15 kg of Organic waste collected from Sam-Yan market is done with aerobic composting as home composting technique. Organic waste is chosen and analyzed moisture content, structure and C/N ratio for optimum condition for composting. The composition of waste is shown in table 3.1 while waste is shredded with 0.5-1.5 inches and mixed before composting. Waste is loaded in a basket with full of holes for air inlet and leachate draining out. The fan for air blowing is put at the top of basket with 7 hours operating time per day with air flow 3 cfm. The design and operation features of the aerobic composting are shown in diagram 3.1. Waste is frequently turned approximately 3 times per week and daily detected for pH, temperature, moisture content and total organic matter while C/N ratio, cellulose and lignin are detected during the beginning and the end of operation. Methods and frequency of analytical techniques in compost is shown in table 3.2

```
┌─────────────────────────┐
│   Choose15 kg of organic │
│  wastes to be used as compost │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│  Detect compost for moisture │
│  content, structure and C/N ratio │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│  Shred organic wastes into 0.5-1.5 │
│  inches, mix and load in compost reactor │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│  Analyze cellulose and lignin in compost │
└─────────────────────────┘
             │
             ▼
┌───────────────────────────────────┐
│  Compost organic wastes for 21 days with 7 hours daily │
│  air blowing and 3 times  per week of compost turning │
└───────────────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│  Daily detect pH, temperature, moisture │
│  content and total organic matter in compost │
└─────────────────────────┘
             │
             ▼
┌─────────────────────────┐
│  Analyze C/N ratio, cellulose and lignin in │
│  compost at the end of operation │
└─────────────────────────┘
```

Diagram 3.1 Composting procedures and experiments

Type	Total weight (wet) (kg)	Percent (by weight)
Orange peel	10	67
Banana peel	5	33
Total	15	100

Table 3.1 organic waste composition during composting

Measurement	Procedure	Frequency
pH	pH meter	Everyday
Temperature	thermometer	Everyday
Water content	NREL Standard method #001	Everyday
Total organic matter	Standard method for water and wastewater # 4500 (Loss on ignition)	Every 3 days
Cellulose	TAPPI T203 om-88	Beginning and the end
Lignin	TAPPI T222 om-98	Beginning and the end
C/N ratio	Standard method for water and wastewater # 4500 (TOC analyzer and total kjeldahl method)	Beginning and the end

Table 3.2 Methods and frequency of analytical techniques in compost.

3.2 Configuration of the simulated landfill reactors

The four simulated landfill reactors were constructed using a PVC pipe. Each reactor had a diameter of 0.26 m and a height of 0.5 m with the capacity of 26 L. The columns were assembled with two 0.33 m outer diameter PVC flanges at both ends to provide support for 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 design and operation features of the simulated landfill reactor with recycling are shown in figure 3.1.

The reactors were 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, drain gas and to add liquid by using a distribution system made of PVC. The collection of the gas is connected with PE hose and 3-tee joint to trap the gas between top port of reactor, leachate containing box and inverted glass cylinder.

Four leachate containing boxes are built from plastic with capacity of 2.5 L to drain out of excess leachate.

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 cylinder 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 shown in diagram 3.2.

Figure 3.1 The design and operation features of the simulated landfill reactor

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┌─────────────────────────────────────┐
│        Construct 4 bioreactors for   │
│        anaerobic fermentation        │
└─────────────────────────────────────┘
                  │
                  ▼
┌─────────────────────────────────────────────────┐
│ Reactor1 was loaded with organic wastes; reactor 2 was │
│ loaded with organic wastes and lead spiked during acid │
│ phase; reactor 3 was the same as reactor 2 with compost │
│ as top and bottom covers; reactor 4 was the same as    │
│ reactor 1 with compost as top and bottom covers        │
└─────────────────────────────────────────────────┘
                  │
                  ▼
┌─────────────────────────────────────┐
│   All reactors were seeded with 0.5 L │
│        anaerobic sludge              │
└─────────────────────────────────────┘
                  │
                  ▼
┌─────────────────────────────────────────────┐
│    Digest organic wastes for 125 days with   │
│  lead spiked in reactor 2 and reactor 3 on   │
│        day 42 and frequent leachate          │
│  recirculation in all reactors on day 81     │
└─────────────────────────────────────────────┘
                  │
                  ▼
┌─────────────────────────────────────────────────┐
│   Leachate in every reactors were analyzed for   │
│  BOD, COD, VFA, pH, ORP, alkalinity, ortho-      │
│ phosphate, total kjeldahl nitrogen, sulfide and Pb. │
└─────────────────────────────────────────────────┘
                  │
                  ▼
┌─────────────────────────────────────────────────┐
│  Gas in every reactors were analyzed for daily gas │
│  production, cumulative gas production, percent   │
│      methane and methane production.             │
└─────────────────────────────────────────────────┘
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Diagram 3.2 Anaerobic procedures and experiments

3.3 The reactor loading

Each reactor is loaded with 5 kg of solid waste prepared, shredded and compacted solid waste mixture and 0.5 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 80% vegetables and 20% fruit by weight. Shredded refuse of composition presented in table 3.3 was shredded and mixed prior to loading. Preliminary analysis of waste samples was indicated solid waste moisture content and volatile solid. Before solid waste was loading, a 1 mm diameter holes nylon screen was placed between 2 cm diameter gravel at the bottom of each reactor. First reactor operates as control reactor loaded with 5 kg of simulated organic waste. The second reactor is loaded the same as first reactor with Lead spiked during acid phase. The third reactor is loaded with the same 5 kg of waste with 1 kg organic waste compost as top cover and 1 kg organic waste compost as bottom cover. Fourth reactor is loaded the same as third reactor with Lead spiked during acid phase. The reactor loading are shown in figure 3.2.

Type	Total weight (wet) (kg)	Percent (by weight)
White-stemmed ipomoea	1.5	30
Cabbage	0.5	10
Brassica chinensis	1	20
Water mimosa	0.5	10
Orange peel	0.5	10
Ka-Na	1	20
Total	5	100

Table 3.3 Solid waste composition loading in landfill bioreactors.

| reactor 1 | reactor 2 | reactor 3 | reactor 4 |
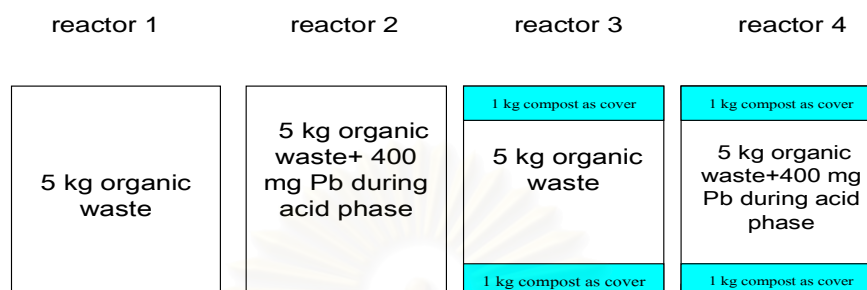
Figure 3.2 The composition in each reactor.

3.4 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 0.5 L of anaerobic digester sludge collected from Nong-Kham municipal wastewater treatment plant. Seed sludge supernatant characteristics are presented in table 3.4. This seeding procedure was initiated on the refuse loading day in all reactors.

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

Table 3.4 anaerobic digester sludge characteristics

3.5 Moisture application and management

Preliminary analyses indicated that the synthetic solid waste had approximately 98% 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.

There was no moisture addition to all reactors from day 0 to day 35 since the volume of moisture content was determined sufficient to initiate microbial activities. On day 36, 1000mL of leachate was recirculated in all reactors to make up the volume of moisture. On day 42, 1000 ml of leachate was recirculated in all reactors; however, Lead was spiked and mixed with leachate in the reactor 2 and reactor 3 according to directives of the Turkish Hazardous Waste Control Regulations. Lead selected based on two criteria:

1. general presence in municipal refuse;
2. listed as hazardous waste or toxic by RCRA;

Due to lack of standards or regulations of heavy metals from landfill leachate in Thailand, Turkish Hazardous Waste Control Regulations that were widely used for co-disposal practices, would act as the guideline of standard for unintentional co-disposal of MSW in Thailand. In addition, lead was spiked in soluble form to distribute lead contacting throughout reactors and to meet the most severe effect of lead on degradation of organic wastes.

Additions of Lead were performed to reactors 2 and reactor 3 during day 42 since that day represent high acid condition (high VFA/COD) in order to see the effects of inhibition on stabilization process and the use of compost as cover on Lead attenuation during the most impact and leaching out of Lead. The amounts introduced

followed the directives of the Turkish Hazardous Waste Control Regulations (table 3.5) since it still allows for co-disposal practice.

Table 3.5 Masses of the Lead loadings into the reactors[a].

Selected heavy metals and their salts	Metals (g)	Metal salts (g)	Regulations[c] (g/t MSW)[b]
$Pb/Pb(NO_3)_2$	0. 4	0.65	80

[a] g metal/kg wet shredded municipal solid waste

[b] MSW: municipal solid waste.

[c] allowable amount according to Turkish Hazardous waste Control Regulations.

1000mL of leachate recirculation was applied in all reactors on day 53, 60, 67 and 77 to add moisture volume and to discover the leaching of Lead during day 42 to day in reactor 2 (without compost) and reactor 3 (with compost). After that, to establish the suitable condition for methane phase, Leachate was neutralized with 6 N NaOH to bring the pH up to 7 prior to leachate introduction back to the reactor. During day 81 to the end of operation, Leachate recirculation phase shift conditions of Turajane (2001) was applied as guideline for the volume of daily leachate recirculation that is changed according to degree of waste stabilization and gas production. Leachate phase shift condition, leachate recycle volume and day of operation are shown in table 3.6 and figure 3.3

Figure 3.3 Leachate recirculation volume during the day of operation

Phase	Range % CH4	Leachate Recycle Volume	Day of operation	Leachate recycle volume (mL)
1	0-15	0% of total moisture in system		
2	16-19	5% of total moisture in system		
3	20-29	7% of total moisture in system	81-99	350
4	30-40	15% of total moisture in system	100-110	750
5	≥40	25% of total moisture in system	111-123	1250

Table 3.6 Leachate phase shift condition, leachate recycle volume and day of operation

3.6 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, sulfide, alkalinity, volatile fatty acid and Lead. 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

Measurement	Procedure	Frequency
pH	pH meter	Everyday
ORP	ORP meter	Everyday
COD BOD/COD	Standard Methods for water and wastewater Examination # 4500 (Titration Method)	Every 2 days Every 2 weeks
Total nitrogen	Standard Methods for water and wastewater Examination # 4500 (Kjeldahl Method)	Every 2 weeks
Ortho-phosphates	Standard Methods for water and wastewater Examination # 4500 (Vanadomolybophoric Acid Method)	Every 2 weeks
Alkalinity	Standard Methods for water and wastewater Examination # 4500 (Titration Method)	Every 2 weeks
Lead	Microwave digestion and AAs (Atomic absorption spectro photometry)	Everyday during acid phase
Gas production	Inverted Glass Cylinder Method	Everyday
Percent Methane	Gas Chromatography with TCD detector	Every 7 days
Water content	NREL standard method #001	Beginning and the end
VFA	Standard Methods for water and wastewater#4500 (Titration method)	Once a week
VS	Standard Methods for water and wastewater#4500 (Loss on ignition)	Beginning and the end
Sulfide	Standard Methods for water and wastewater#4500	Every 2 weeks

Table 3.7 Methods and frequency of simulated landfill leachate and gas parameters

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Composting of organic wastes

4.1.1 Temperature during composting processes
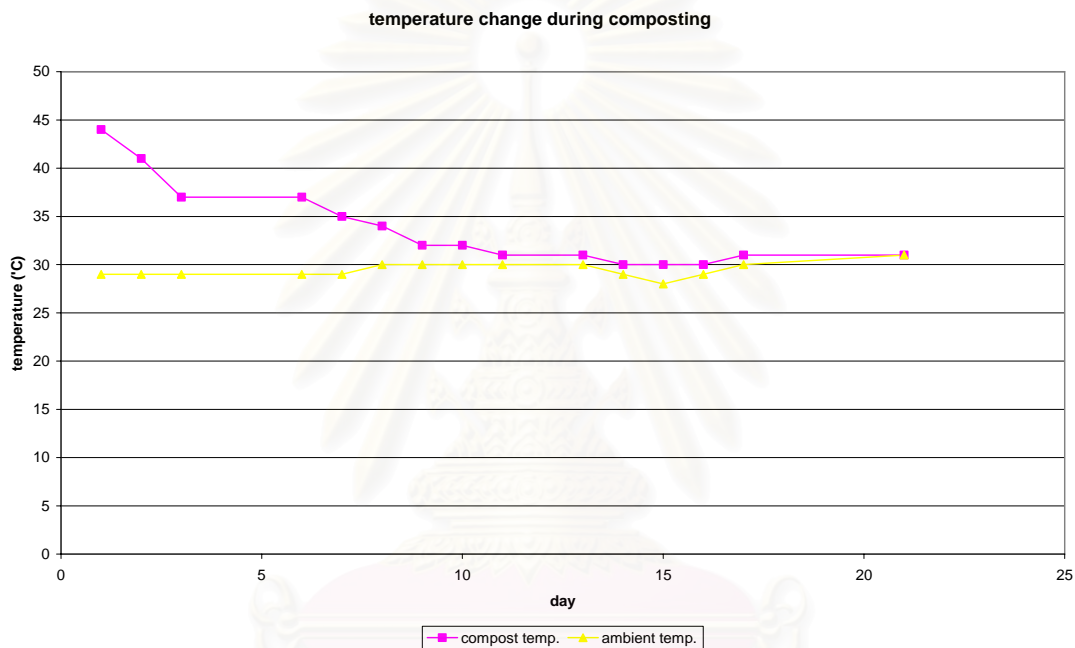
Figure 4.1 Temperature profiles in the composting. Composting temperature (rectangular line) and ambient temperature (triangular line)

The temperature regime of composting reactor was illustrated in Fig 4.1 and Table A-1 Appendix A. While composting process reached the thermophillic region and was maintained for 2 days which implied sanitation of the material. The temperature of compost reached 44° C (Fig. 4.1) on the first day of operation represented the rapid degradation of easily biodegradable organic in the synthetic waste. The temperature began to decline to 37° C on day 6, and 31°C at the end of operation. The compost temperatures on each day are higher than ambient

temperature owing to self heating from degradation of organic via oxygen respiration and appropriate moisture content.

4.1.2 Moisture content
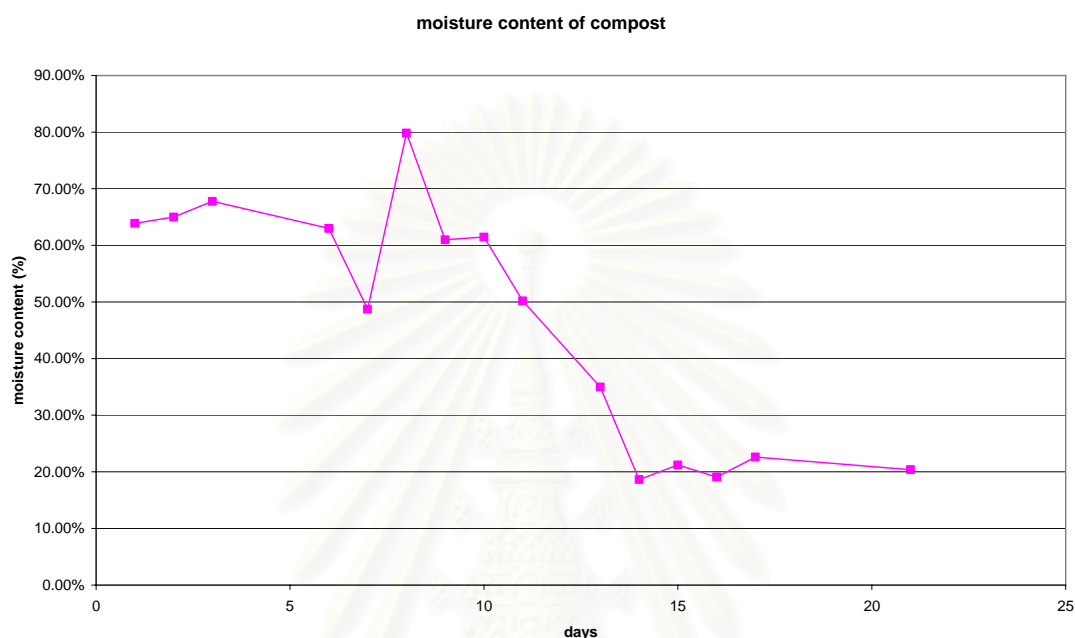
Figure 4.2 Moisture content changes during composting

Moisture content at the beginning accounted for 63.88% and was considered optimum condition for composting. The moisture content was decreased continuously during composting from 63.88% on day 1 to 50.18% on day 11 and 20.39% on day 21 (Fig. 4.2 and Table A-2 Appendix A). The sharp increasing of moisture content from day 7 to day 8 was owing to the adding of 250 mL of deionized water. The main mechanism of water removal in this composting process was the evaporation of water as a consequence of microbial heat generation including air drying from aeration. Water evaporation caused a continuous heat removal in forced and natural aeration and dried the compost material progressively. The continuous decrease in the moisture content during composting is an indication of organic matter decomposition (Miller and Finstein, 1985). The moisture content from day 1 to day 13 was in the range of 34.97%-67.78% and was considered optimum condition (40-70% is good for microbial activity Krogmann, 2000). However, to make the structure of compost to be

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used as cover, composting process were enrolled without water addition and this caused the moisture content to approximately 20% at the end of operation.

4.1.3 Total organic matter
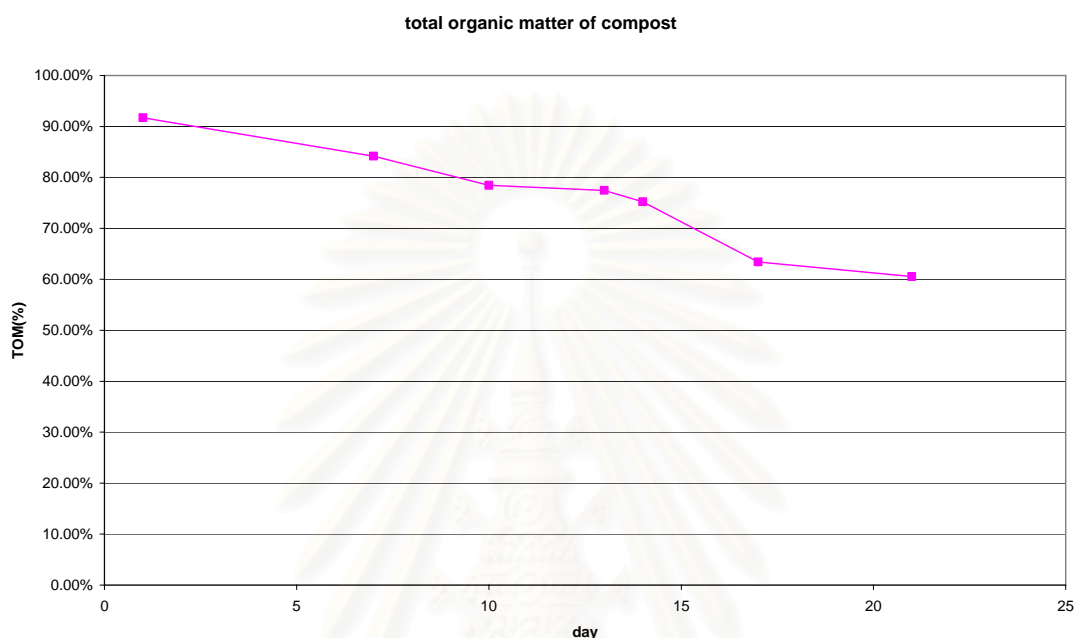
Figure 4.3 Organic matter changes during composting

The OM degradation was in relation to the OM loss, which was directly related to the microbial respiration (Paredes et al., 2002). The OM content decreased during incubation from 91.71% on day 1 to 78.45% on day 10 (Fig4.3 and Table A-3 Appendix A) and to 60.53% at the end of composting operation (day 21) The OM loss was calculated as 31.18% after 21 days operation time. Higher OM losses and higher values of biodegradability were observed during first period of operation due to the degradation of easily biodegradable compound.

It is evident from fig 4.2 and fig 4.3 that moisture and organic matter followed similar profiles. Thus, the presence of easily biodegradable compounds enhanced the temperature increase and water evaporation.

4.1.4 pH
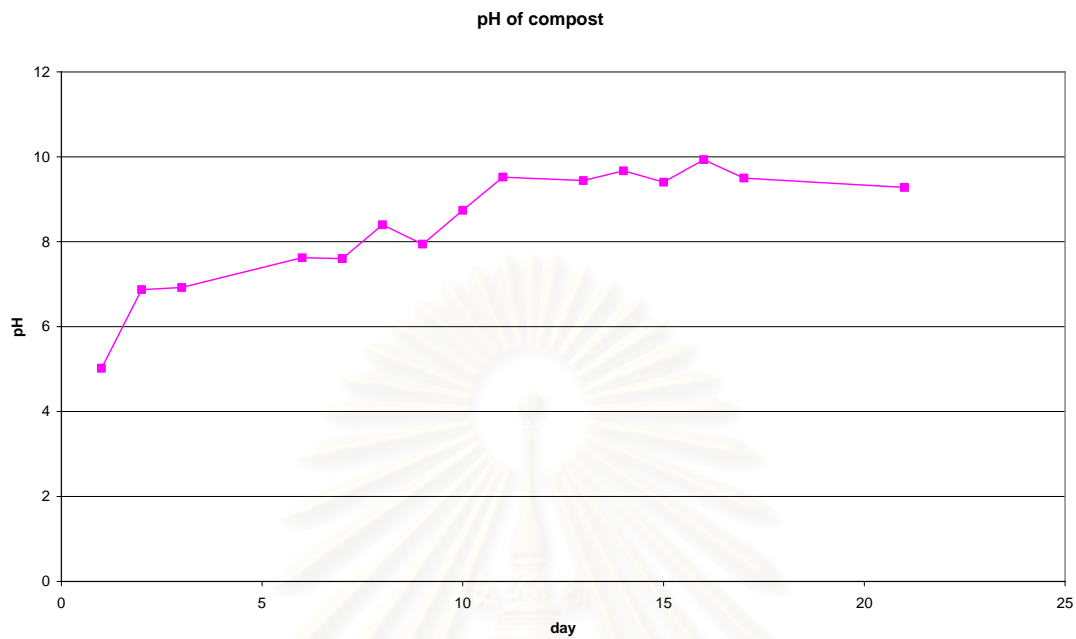
Figure 4.4 pH changes during composting

Decreases in pH may be observed during first period (5.02 on day 1 and 6.87 on day 2) due to the production of organic acids by anaerobic organisms. The increasing of pH during composting to 8.74 on day 10 and 9.28 on day 21 can be observed due to the volatilization of organic acids and formation of bases. The pH profile was shown in Figure 4.4 and Table A-4 Appendix A in the range of 5 -10 and was considered suitable condition of pH 5-12 during composting according to (Wilson, 1985).

4.1.5 Other parameters

Parameter	Initial value	Final value
Total weight (kg)	15	4
Moisture content (%)	63.88	20.39
Organic matter (%, dry matter basis)	91.71	60.53
pH	5.02	9.28
C/N ratio	40.65	30.4
Cellulose (% organic matter basis)	38.25	30.66
Lignin (% organic matter basis)	18.42	16.24

Table 4.1 Initial and final value of other parameters during composting

Other typical parameters of the composting process are present in table 4.1. The total weight of 15 kg organic waste was reduced to 4 kg at the end of operation due to the loss on moisture and degradation of organic matter. The initial parameters were shown that orange and banana peels were suitable for composting process since the moisture content was 63.88% compared with 40-70% for optimum microbial activity (Krogmann, 2000), the pH was 5.02 considered in the range of composing from 5 to 12 (Wilson, 1985), C/N ratio was 40.65 considered in the optimum range of composting 20-40:1 (Krogmann, 2000), the structure was accepted because it tended to be solid structure with no slurry or sludge addition. The moisture dropped to 20.39% at the end of operation from heat evaporation through degradation and air drying and this was suitable to be used as cover. Total organic matter was 32% dropped from 91.71% on first day to 60.53% at the end of operation. Together with the high organic matter decomposition, C/N ratio decreased significantly to reach a final value of 30.4. Cellulose and lignin were initially 38.25% and 18.42% of organic matter basis, respectively. The slightly drop of 7.59% of cellulose and 2.18% of lignin to 30.66% cellulose and 16.24% lignin can be observed during composting process. The small drop of fibers when comparing with organic matter because composting period was only 21 days of operation and bacteria can use only readily degradable organic material; whereas, more difficult to degrade such as hemicellulose, lignin, chitin, and similar compounds remained.

4.2 Anaerobic reactor experiment

4.2.1 Temperature
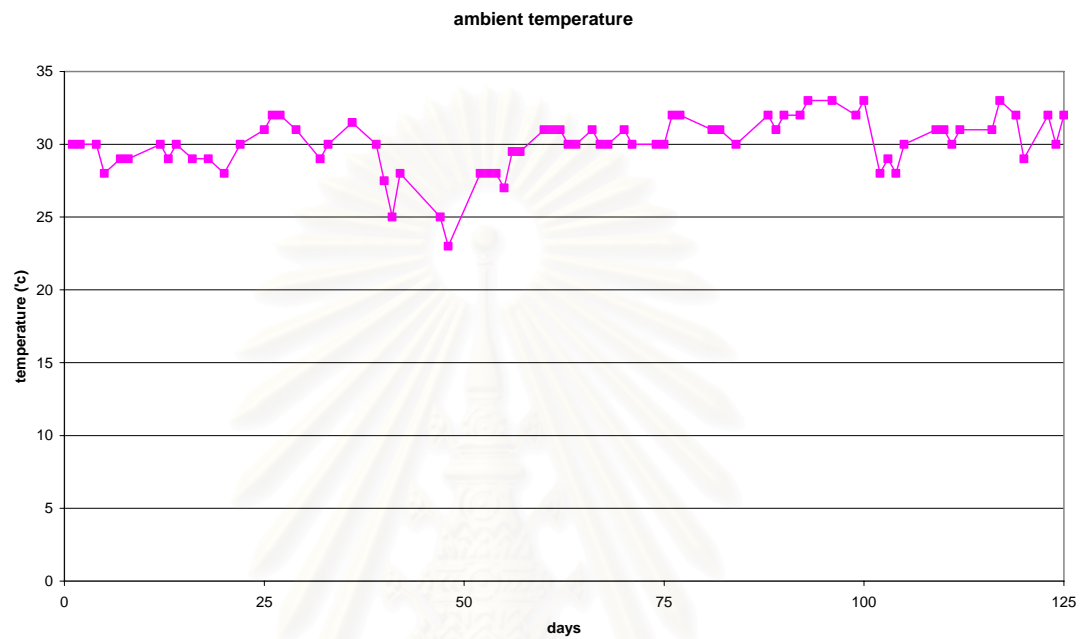
Figure 4.5 Temperature profile during anaerobic fermentation

Temperature was in the range of 23-33 ℃ throughout the experiments and was dependent on laboratory temperature fluctuations. The ambient room temperature were presented in Figure 4.5 and Table B-1 Appendix B during the majority of the experimental period, almost all of the temperature fluctuation was in the range of 29-32 ℃ 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.

4.2.2 Leachate analyses

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.

4.2.2.1 pH
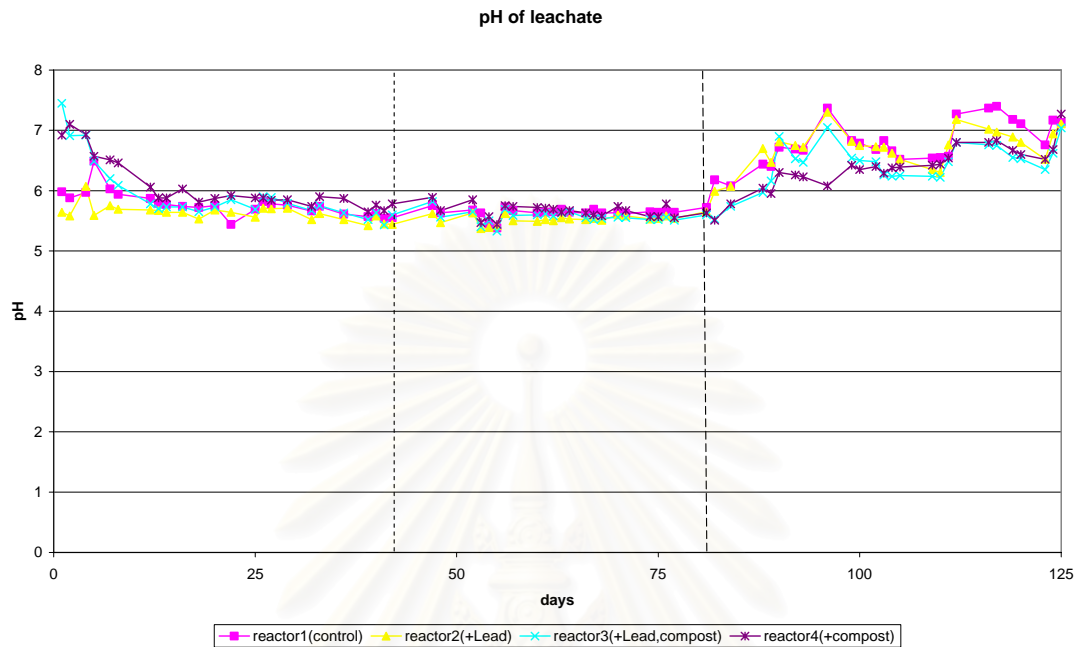
pH of leachate

- - - - - - - - Addition of lead in reactor 2 and reactor 3 (day 42)

– – – – – Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.6 pH of leachate during anaerobic digestion.

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 4.6 and Table C-1 Appendix C

Leachate pH at the beginning of anaerobic process from reactor 3 and reactor 4 were higher than those in reactor 1 and reactor 2 due to the presence of

organic compost with high pH (9.28 at the end of composting). However, leachate pH from all reactors exhibited similar decreasing tend from 5.98 on day 1 to 5.45 on day 54 in reactor1, from 5.64 on day 1 to 5.39 on day 54 in reactor 2, from 7.45 on day 1 to 5.5 on day 54 in reactor 3 and finally from 6.92 on day 1 to 5.57 on day 54 in reactor 4. This was consistent with extensive hydrolysis and acid production reactions occurring within this period, which was reflected in high concentration of volatile fatty acids present in leachate of all reactors. After that, Leachate pH from all reactors remained constant in the range of acid (5.4-5.9). Since the pH in all reactors were still not favorable for the development of a viable methanogenic population, the attempts then were made to increase the pH of leachate in all reactors by leachate neutralization with 0.6 N NaOH and frequently applying of leachate recirculation from day 81 to the end of operation. After the attempts were applied, the leachate pH from all reactors gradually rose from 5.72 , 5.65, 5.6 and 5.63 on day 81 to 7.13, 7.11, 7.04, 7.27 on day 125 in reactor1,reactor2, reactor3 and reactor 4, respectively. The pH was further increased to 7 at the end of experimental period. The pH during this period was beneficial for development of microbial populaton responsible for waste stabilization as supported by an abrupt increase in methane percentages and gas generation rates. This also emphasized the importance of maintaining pH near neutrality in enhancing waste transformation in anaerobic waste treatment processes with high volatile organic acids loadings.

4.2.2.2 Chemical oxygen demand

Leachate chemical oxygen demand (COD) was measured as an indicator of organic strength. COD data of leachate from all reactors were presented in Figure4.7 and Table C-2 Appendix C.
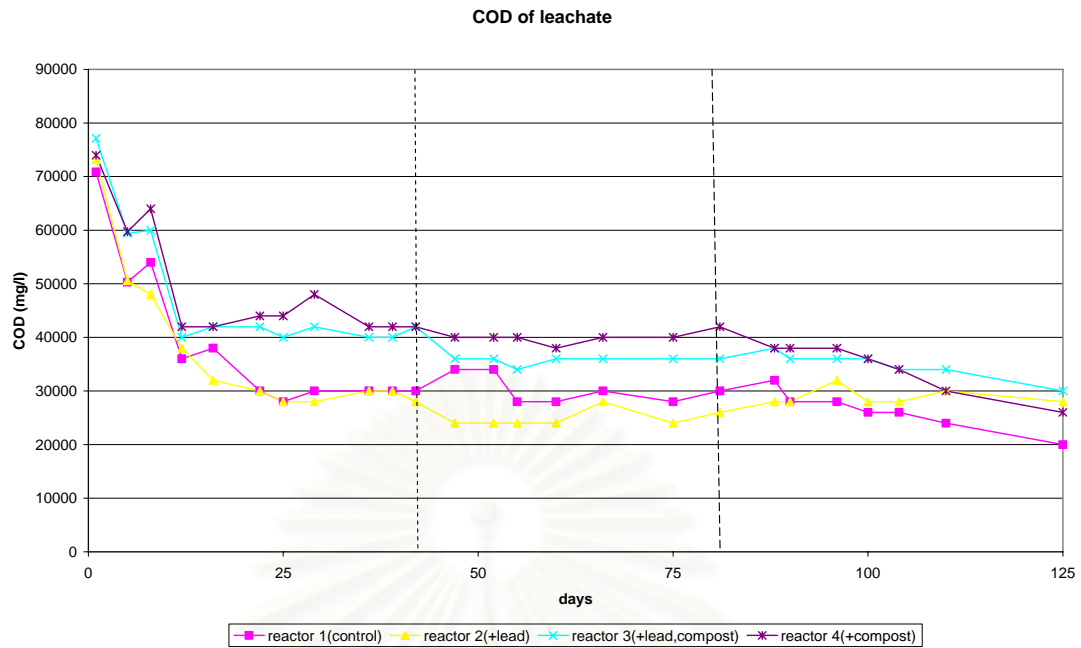
COD of leachate

Addition of lead in reactor 2 and reactor 3 (day 42)

Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.7 Daily variation of COD concentration in leachate

COD concentrations were detected by average of three dilution value at 2% 4% and 6%, respectively. The initially high leachate COD concentration in all reactors indicates that the solid waste added contained readily solubilized organic materials which were released and transformed during the period of water additions to field capacity prior to day 1. The COD concentration in leachate samples collected from the reactor 3 and 4 were higher than those of reactor 1 and reactor 2 because of higher organic matter in compost added to both reactors. The COD on day 8 of the leachate in the control reactors, reactor 2, reactor 3 and reactor 4 were 54000, 48000, 60000, and 64000 mg/L, respectively. Volatile organic acids were found to be a major contributor to the COD present during this period, since the change of COD was also reflected by a parallel change in VFA. The leachate COD in reactor1, reactor2, reactor3 and reactor 4 started to decrease to 30000, 28000, 42000 and 42000 mg/L on day 42 respectively and remained relatively consistent during day 47 to day 81 in the range of 28000-34000 mg/L in reactor1, 24000-28000 mg/L in reactor 2, 32000-36000 mg/L in reactor 3 and

38000-42000 mg/L in reactor 4. Since Lead were spiked on day 42 in reactor 2 and reactor 3, COD concentration range during day 47 to day 81 in reactor 2 was lower than that in reactor 1 and also COD concentration range in reactor 3 was lower than that in reactor 4. This can be attributed to the effect of Lead inhibition on the degradation of organic waste in reactor2 and reactor3 after Lead adding since the same profile of VFA drop related to COD drop can be observed with subsequent less biogas generation in those reactors. After daily leachate recirculation and buffer neutralization were applied to all reactors on day 88, COD concentration increased to 32000, 28000, 38000 and 38000 mg/L from reactor1, reactor2, reactor 3 and reactor 4, respectively due to the promotion of COD with leachate recirculation employing. However leachate COD on day 125 were decline to 20000 mg/L in reactor1, 30000mg/L in reactor3 and 26000 mg/L in reactor 4; where as, COD in reactor 2 remained the same 28000 mg/L. This showed the effect of leachate pH adjustment and frequently recirculation on rapid waste stabilization, which was displayed in term of declining in COD with significantly high biogas and methane gas generation. The retardation on stabilization on reactor 2 could be the effect of Lead inhibition; whereas in reactor 3, the content was covered with compost and compost could reduce the impact of Lead inhibition; consequently, the normally stabilization process could still occurred.

4.2.2.2 Volatile fatty acid

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 portion contained in leachate during the acid formation phase. The concentration of volatile fatty acid is an important parameter because of the degree of stability of anaerobic process. Leachate VFA concentrations from control reactor, reactor with Lead contamination, reactor with Lead contamination and compost cover, reactor with compost are represented in Figure 4.8 and Table C-3 Appendix C

VFA of leachate

‑ ‑ ‑ ‑ ‑ ‑ ‑ ‑Addition of lead in reactor 2 and reactor 3 (day 42)

‑ ‑ ‑ ‑ ‑ ‑Application of leachate recirculation and buffer neutralization (day 81)
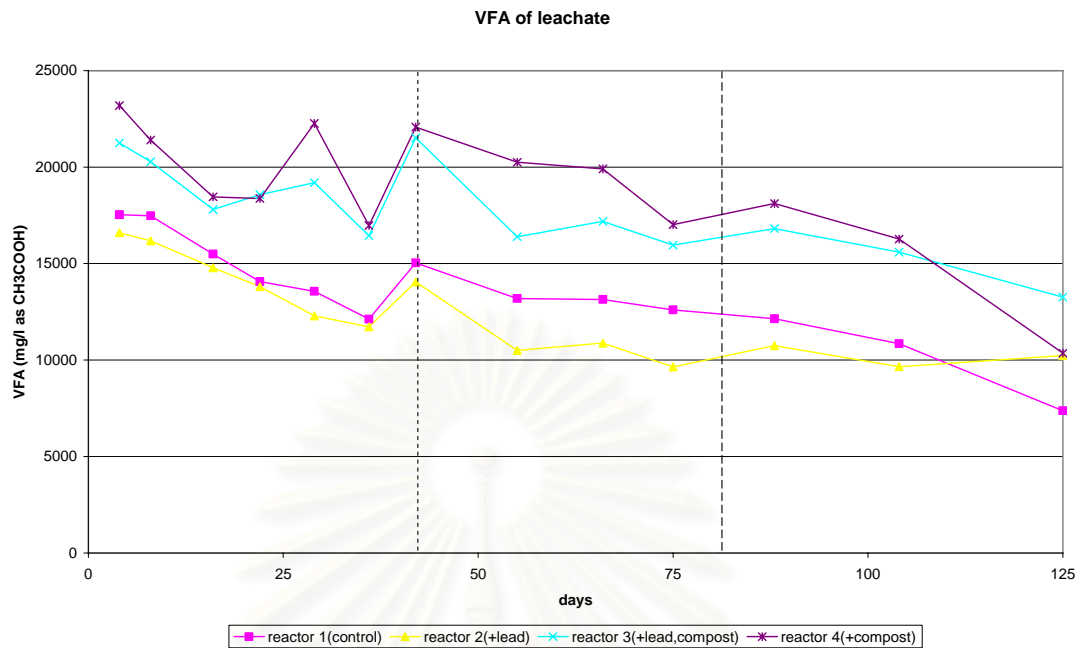
Figure 4.8 VFA variations in leachate produced from the simulated anaerobic solid waste reactor.

The concentrations of VFAs in leachate produced from all reactors exhibit similar data with COD. The initial VFA concentrations in leachate samples on day 4 were 17531, 16602, 21250 and 23183 mg/l in control, runs 2, run 3 and run 4 reactors, respectively. The VFA in leachate from reactor 3 and reactor 4 were higher than those in reactor1 and reactor 2, since it contained higher concentration of organic matter from 1 kg of compost covering in top and bottom reactors. Organic matter degradation in the initial phase of the fermentation caused high VFA concentrations. During day 4 to day 36, VFA were in similar trends and fluctuating in the range of 11500 to 17531 mg/L in rector 1 and reactor 2, 16448 to 23182 mg/L in reactor 3 and reactor 4. High VFA can be observed in all reactors on day 42 as 15042, 14045, 21513 and 22076 in run 1, 2, 3 and 4 reactors, respectively with highest VFA/COD ratio exhibiting the high acidic condition so that Lead were spiked in reactor 2 and reactor 3 on that day in order to see the most severe effect of heavy metal inhibiting

including the use of compost on heavy metal attenuation during those period. Heavy metal added during acidogenic phase could be stayed in liquid phase for longer time and remained more toxic to microbial community in the reactor than heavy metals added during other phases (Chewha, 2003). After Lead spiked, the inhibition of VFA can be observed in reactor 2 and reactor 3 as VFA dropped to 10500 and 16393 on day 55. This could be the effect of heavy metal inhibition on microorganisms through hydrolysis of organic compounds into VFA as indicated in lower VFA with lower biogas and methane yield. Where as, the drop in VFA leachate during day 42 to day 125 in ractor1 and reactor 4 were due to relatively active conversion of organics in the leachate to carbon dioxide and methane as indicated by gas compositions and gas generation rates. After leachate recirculation and buffer neutralization were applied during day 81 to day 125, the significant drop of VFA from 12136 to 7375 and from 18113 to 10354 with high biogas and methane gas generation can be observed in reactor 1 and reactor 4, respectively, while moderate drop of VFA leachate from 16813 to 13265 with moderate biogas and methane gas generation was observed in reactor 3, where as, steady VFA leachate in the range of 10235 to 10750 with low biogas and methane gas generation can observed in reactor 2. The result showed that reactor 1 and reactor 4 without Lead could be better and more rapidly stabilization than reactor 2 and reactor 3 with Lead contaminated. In addition, reactor 3 with compost covered can reduce the effect of heavy metal inhibition on stabilization process.

4.2.2.3 Alkalinity

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 4.9 and Table C-4 Appendix C.

The initial leachate alkalinity values in four reactors were 3750 mg/L as $CaCO_3$, 3450 mg/L as $CaCO_3$ and 9327 mg/L as $CaCO_3$ and 8982 mg/L as $CaCO_3$, respectively. The total alkalinity of leachate in reactor 3 and 4 were higher than total alkalinity of leachate in reactor 1 and 2 throughout the experiment. This can be due to compost addition that can generate higher alkalinity in reactors 3 and 4. Higher alkalinity in reactor 3 and reactor 4 could reduce the effect of heavy metal solubility and encourage on heavy metal precipitation. Alkalinity values during day 16 to day 66 were steady at about 7000 mg/L as $CaCO_3$ in reactor 1 and reactor 2, and about 11000 mg/L as $CaCO_3$ in reactor 3 and reactor 4. The alkalinity during this period was competitive with volatile organic acids. However, after daily adjustment of leachate pH by addition of 0.6N NaOH along with frequently leachate recirculation on day 81, the leachate alkalinity in all reactors gradually increased to 11792, 12083, 17364 and 18045 mg/L as $CaCO_3$ at the end of operation.
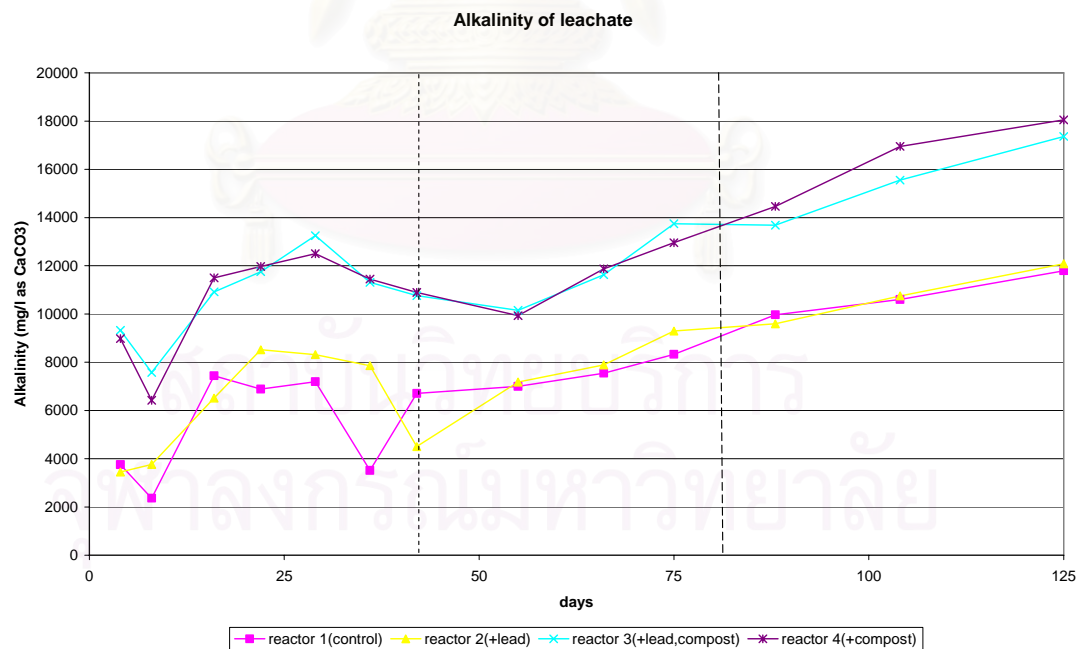
_ _ _ _ _ _ _ _ Addition of lead in reactor 2 and reactor 3 (day 42)

_ _ _ _ _ _ Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.9 Alkalinity of leachate from simulated landfill reactors

4.2.2.4 Oxidation-Reduction potential

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 4.10 and Table C-5Appendix C. 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 leachatte ORP were 108.2, 53, -147.7 and -275.5 mV for reactor1, 2, 3 and 4, respectively. The high reduction during first 14 days of operation in reactor 3 and reactor 4 with compost covered may attribute to the use of oxygen from anoxic microorganisms in compost that caused in very anaerobic or reduction condition. Leachate ORP value on day 42 decreased to -155.2, -136.1 mV in reactor 1 and reactor 2, while leachate ORP on day 42 in rector 3 and reactor 4 were -149.7 and -160.7, respectively. Due to lead contamination, the sharp increasing of leachate ORP on day 47 into – 74.7 and -110.2 could be observed in reactor 2 and reactor 3, respectively. The less negative ORP indicated that the condition suitable for methanogenic was interrupted. During day 53 to day 81 all of leachate ORP values in all reactors were steady in the range of -105 to -190. Almost all of the ORP values in reactor 2 were higher than those in reactor 1 and ORP values in reactor 3 were higher than those in reactor 4 that contribute to lead interference. Highly reducing condition, a prerequisite for proliferation of methanogens, was established or one day after the leachate recirculation program and buffer neutralization were applied. Almost all of ORP values after this day through day 125 were gradually decline in the range of -200 to – 400 as waste stabilization proceeded, and was enhanced by leachate recycle with pH adjustment.

ORP of leachate

- - - - - - - - Addition of lead in reactor 2 and reactor 3 (day 42)

– – – – – –Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.10 Oxidation-Reduction potential of leachate

4.2.2.5 Total kjedahl nitrogen

The total 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 result of analyses are expressed in mg/L of nitrogen and are presented in Figure 4.11 and Table C-6 Appendix C.

Initial total nitrogen was 1436, 1613, 1795 and 1711 mg/L in run 1, 2, 3, 4 reactor, respectively. The total nitrogen in leachate from reactor 1 was similar to that in reactor 2 and the total nitrogen in leachate from reactor 3 was similar to that in reactor 4, suggesting uniformity in refuse composition. The total nitrogen in leachate

from reactor1 and reactor 2 during 125 days of operation were in the range of 1400-2050 mg/L, while the total nitrogen in leachate from reactor 3 and reactor 4 during 125 days of operation were in the range of 1700-2600 mg/L. The total nitrogen in leachate from reactor 3 and reactor 4 were higher than that in reactor 1 and reactor throughout the experiment. This can be the benefit of compost use through adding up of necessary substrate for biological reaction.

Total Kjedahl Nitrogen

- - - - - - - - Addition of lead in reactor 2 and reactor 3 (day 42)

– – – – – –Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.11 Total Nitrogen in leachate from landfill bioreactors.

4.2.2.6 Orthophosphate

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 4.12 and Table C-7 Appendix C.

Orthophosphate in all reactors was observed to decrease with time due to orthophosphate assimilation by microorganisms. The decline in phosphorus

concentrations from day 60 to day 110 approximately 250 to 110 mg/L in reactor 1 and reactor2 and 400 to 300 mg/L from reactor 3 and reactor 4 can be observed. This behavior is in conformity with an extensive use of phosphorus and its possible precipitation. The concentrations in reactor 2 and reactor 3 with compost covered were originally higher than those in reactor 1 and reactor 2 throughout the experiment as a result of higher organic matter and adding up of nutrients from compost.
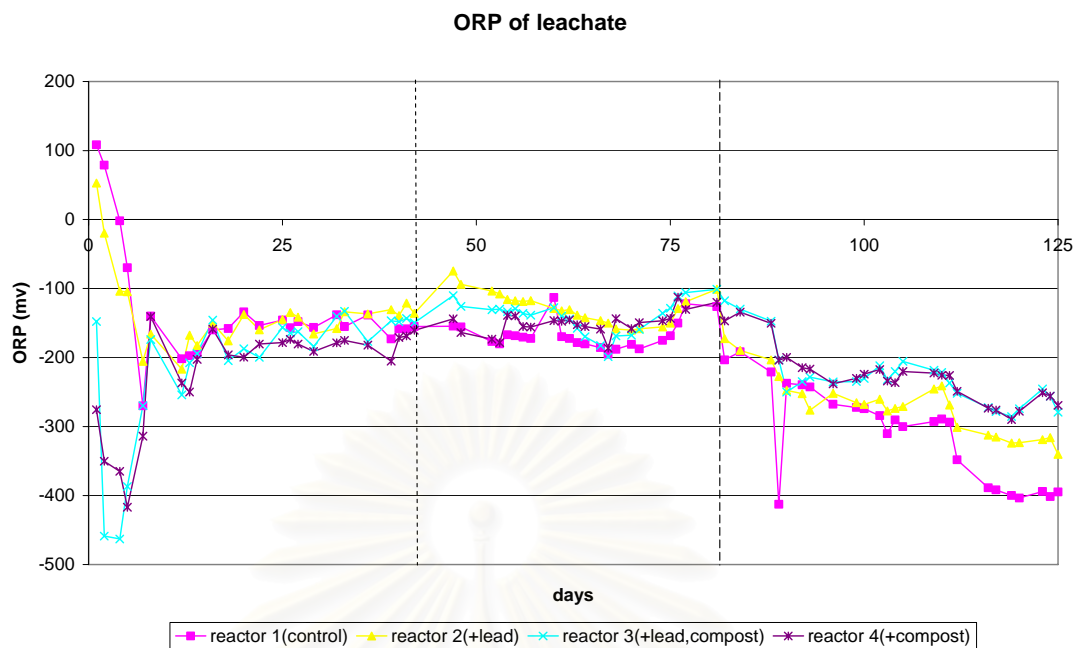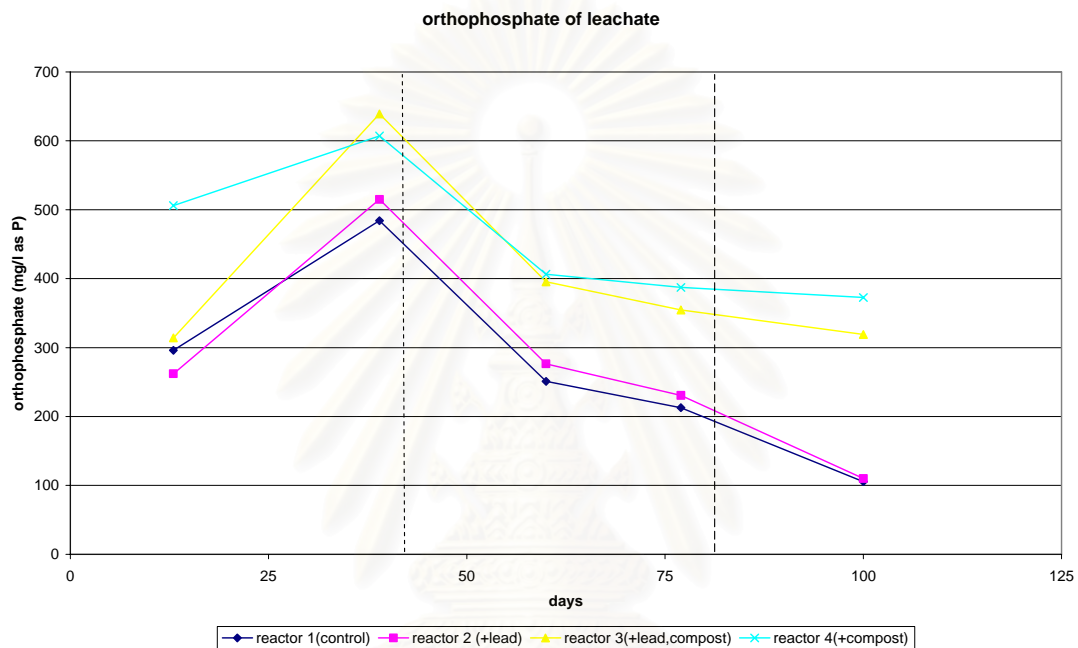
orthophosphate of leachate

- - - - - - - -Addition of lead in reactor 2 and reactor 3 (day 42)

– – – – – –Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.12 Orthophosphate in leachate from landfill bioreactors.

4.2.2.7 Sulfide

Sulfides are another indicator of the presence of reducing conditions within the landfill environment. Sulfides are produced during anaerobic decomposition from the reduction of sulfates and other sulfur-containing inorganic compounds as well as from anaerobic protein degradation. In the S^{-2} form, sulfide is a powerful precipitating agent, even at low pH values and very low sulfide concentrations. Most of the sulfide

generated is bound to heavy metals as metal sulfides in anaerobic system (Pohland, 1993). Sulfide are presented in figure 4.13 and Table C-8 Appendix C.

Sulfide in leachate on day 32 was 72, 84 136 and 108 mg/L and was 66, 52, 68 and 92 mg/L on day 55 in reactor 1, 2, 3 and 4, respectively. The drop of sulfide in reactor 2 and reactor 3 on day 55 as a result of heavy metal precipitation to form metal sulfide after Lead was spiked on day 42. Sulfide in leachate from reactor1, 2, 3 and 4 gradually increase to 192, 164, 264 and 264 mg/L on day 108 owing to sulfate reducing to sulfide in high reduction condition after leachate recirculation and buffer neutralization were applied on day 81. The result can be observed that sulfide in leachate from reactor 3 and reactor 4 with compost covered were higher in concentration than those in reactor 1 and reactor 2 throughout the experiment. Thus, the benefit from compost use can be expected through more sulfide addition to form heavy metal precipitation.
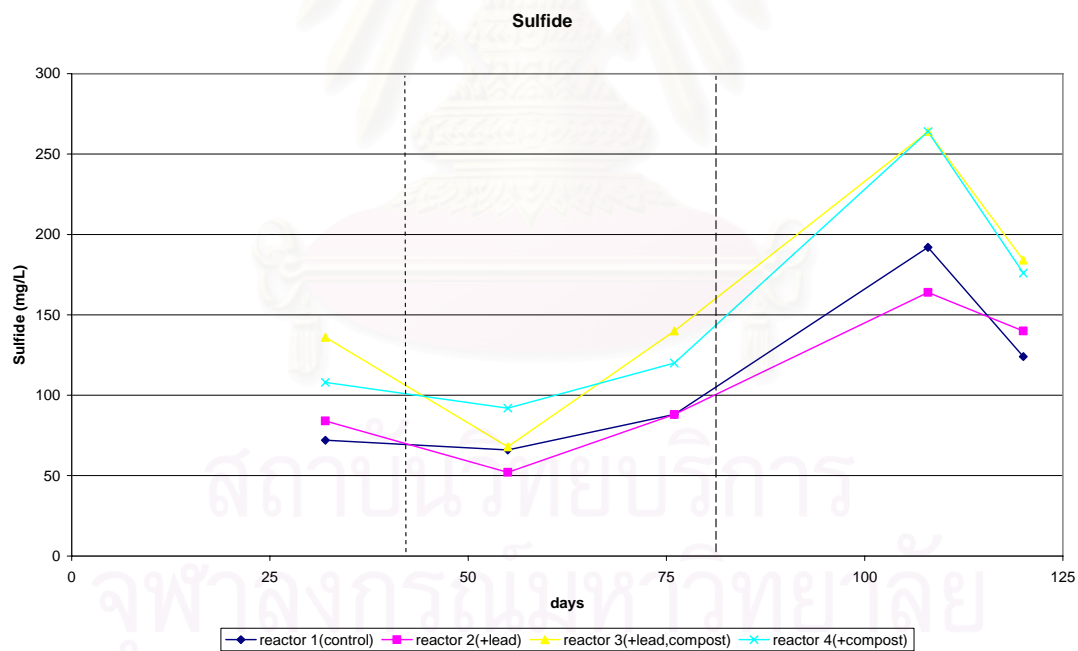
- - - - - - - - Addition of lead in reactor 2 and reactor 3 (day 42)

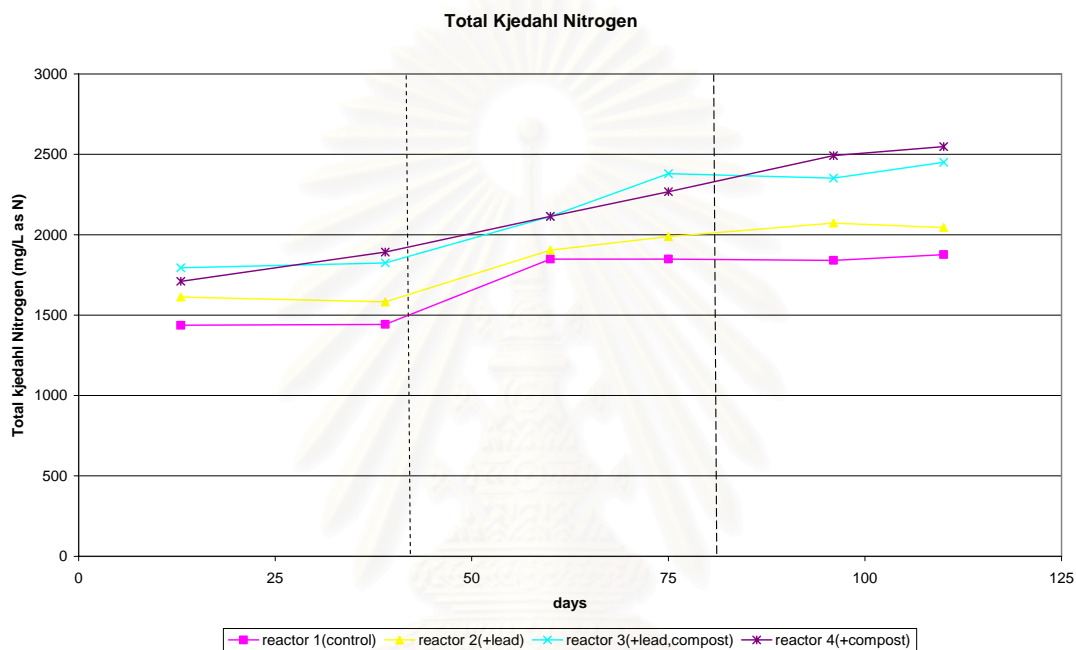- - - - - - Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.13 Sulfide concentrations in leachate from landfill bioreactors.

4.2.2.8 Other parameters

4.2.2.8.1 BOD_5/COD

day	reactor 1	reactor 2	reactor 3	reactor 4
25	0.70	0.66	0.71	0.66
47	0.44	0.69	0.66	0.45
66	0.42	0.52	0.47	0.44
90	0.43	0.50	0.44	0.42
125	0.36	0.46	0.41	0.33

Table 4.2 BOD_5/COD ratio in leachate from landfill bioreactors

In order to study the proportion of biodegradable organic carbon in the leachate the BOD_5/COD ratios were determined. Table 4.2 shows the computed values of BOD_5/COD ratios in the leachate samples of the all reactors. The BOI_5/COD ratio indicates the changes in the amount of biodegradable compounds in the leachate. Initially, all the reactors have high BOD_5/COD ratios of approximately 0.66-0.71 indicating the low degradability of leachate. The BOD_5/COD ratio on day 66 was 0.42, 0.52 0.47 and 0.44 in reactor 1, 2, 3, 4, respectively and at the end of operation, BOD_5/COD decreased to 0.36, 0.46, 0.41 and 0.33 in run1, 2, 3 and 4 respectively. This ratio implies a highly biodegradable leachate. In other words, this level shows the increasing biodegradability of organics due to solubilization of organic substances through methanogenesis. As the organic content biodegradation of MSW occurs, the BOD_5/COD ratio decreased. This decrease indicated that the organic waste was degraded through the fermentation phase to methane formation. At the end of operation, the BOD_5/COD ratio of reactor 4 was the lowest. This result indicated that, the organic waste in reactor 4 is converted rapidly to methane via methanogenesis; while as, BOD_5/COD ratio of reactor 2 was highest and reduction in number when compost was used in reactor 3. This indicated that, the retardation on degradation can be observed in reactor 2 owing to Lead inhibition; where as, the use of compost as cover in reactor 3 can reduce those effects.

4.2.2.8.2 VFA/COD

VFA/COD is the indicator of degradation and fermentation of organic fractions in waste materials represent a significant fraction of the biodegradable portion contained in leachate during the acid formation phase. VFA/COD ratio from all reactors was shown in table 4.3. Initial VFA/COD was 0.35, 0.33, 0.36 and 0.39 in run 1, 2, 3, 4 respectively and gradually increased due to the degradation of organic into acid products until VFA reached to the highest value on day 42 from all reactors in the range of 0.5-0.53 indicated the most acid accumulation or most acid condition during this period. Lead was spiked in reactor 2 and reactor 3 during this period to see the most severe effect of heavy metal inhibiting on the most leaching of heavy metal including the use of compost on heavy metal attenuation during those period. Heavy metal added during acidogenic phase could stay in liquid phase for longer time and remained more toxic to microbial community in the reactor than heavy metals added during other phases (Chewha 2003). After daily leachate phase shift condition and pH adjustment was applied, VFA/COD at the end of operation reduced to 0.37, 0.36, 0.44 and 0.40 in run1, 2, 3 and 4 respectively as a result of the conversion of VFA into carbon dioxide and methane.

day	reactor 1	reactor 2	rector 3	reactor 4
4	0.35	0.33	0.36	0.39
8	0.32	0.34	0.34	0.33
16	0.41	0.46	0.42	0.44
22	0.47	0.46	0.44	0.42
29	0.45	0.44	0.46	0.46
36	0.40	0.39	0.41	0.40
42	0.50	0.50	0.51	0.53
55	0.47	0.44	0.48	0.51
66	0.44	0.38	0.48	0.50
75	0.45	0.40	0.44	0.43
88	0.38	0.38	0.44	0.48
104	0.41	0.34	0.46	0.48
125	0.37	0.37	0.44	0.40

Table 4.3 VFA/COD ratio in leachate from landfill bioreactors

4.2.3 Lead analysis

Heavy metals were analyzed during experimental investigations. The most important factor in determining the presence of a metal in leachate is its solubility under the conditions prevailing within the landfill environment. Several factors influence metal solubility in leachate, including concentration of precipitant species (hydroxides, carbonate, and sulfide), presence of complexing agents (ligands), ORP, pH, ionic strength and washout effects. Lead concentration were presented in figure 4.14 and Table D-1 Appendix D.

Lead was spiked in reactor 2 and reactor 3 on day 42 considered high acid condition with the most leaching out of Lead to investigate the impact of Lead in the reactors with and without compost covered. 400 mg Lead was spiked as 650 mg Lead nitrate salt according to the amounts suggestion for co-disposal under the directives of Turkish Hazardous Waste Control Regulations. Lead concentrations from reactor 2 and reactor 3 (with and without compost covered) were shown in figure 4.14. The result of initial Lead leaching out was 201 and 174 mg in reactor 2 and reactor 3, respectively. Lead concentration in reactor 3 dropped to 14 mg/L on day 47 and remained in steady concentrations of 11-21 mg/L through the time of Lead investigation. The main mechanisms of Lead reduction from reactor 3 was the adsorption of Lead through the use of compost covered since compost had a lot of fibers such as cellulose and lignin to adsorb heavy metals. While Lead concentration in reactor 2 dropped to 91 mg/L on day 47 and fluctuated between 76 and 121 mg/L during day 48 to day 70 until it reached the final value of 37 mg/L on day 81 as a result of Lead leaching, leachate recirculation, sulfide precipitation, adsorbed onto waste particles and wash out effects. The effluent concentration was increased as a result of mobilization and complexation was found to be the principle mechanisms for increasing concentrations of Lead in the leachate; whereas, metal sulfides precipitation, adsorption onto waste particles was found to be the principle mechanisms on reduction in Lead concentrations in reactor 2. Lead concentrations in reactor 2 were higher than those in reactor 3 throughout the time of Lead investigation. Consequently, the use of compost as landfill cover would be very beneficial through the reduction of Lead concentrations and also the impact of Lead inhibition on landfill stabilization processes.

Lead concentrations
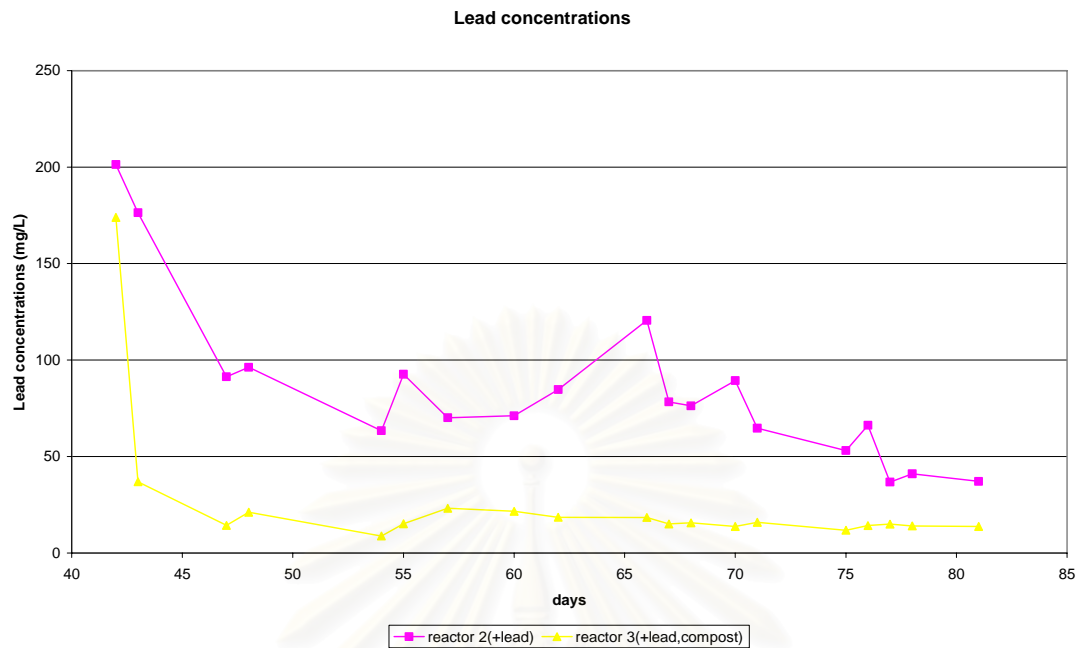
Figure 4.14 Lead concentrations in leachate during acid phase from landfill bioreactors 2 and 3 (with and without compost covered)

4.2.4 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.

4.2.4.1 Gas production

4.2.4.1.1 Daily gas production

Daily gas productions volumes were shown in figure 4.15 and Table E-1 Appendix E. Daily gas volumes in all reactors were high during day 1 to day 18 because of aerobic reaction by the use of oxygen into carbon dioxide as products. Steady gas productions were observed from all reactors in the range of 100-400 mL in reactor 1 and reactor2 and 100- 900 in reactor 3 and reactor 4 during day 18-42

until Lead was spiked on day 42 in reactor 2 and reactor 3. Lower daily gas production could be observed in those reactors especially in reactor 2 that generated only 20-140 mL biogas during day 48-90. This indicated that heavy metal was toxic and interfere the digestion system. The daily gas productions during day 42-84 were steady in the range of 60-330, 20-300 and 50- 410 mL in reactor 1, 3 and 4, respectively. After daily leachate recirculation and buffer neutralization were applied on day 81-125, higher amount of daily gas production could be observed in all reactors because leachate recirculation provided liquid, which was a substrate distribution medium, became more uniformly distributed and more available for microbial utilization after recirculation. Buffering of leachate prior to its recirculation resulted in establishing environmental conditions favored by methanogens which accelerated waste degradation and resulted in a further increase of gas production. The daily gas productions during those periods were in the range 70-410, 30-280, 40-360 and 50-420 mL from reactor 1, 2, 3 and 4 respectively.
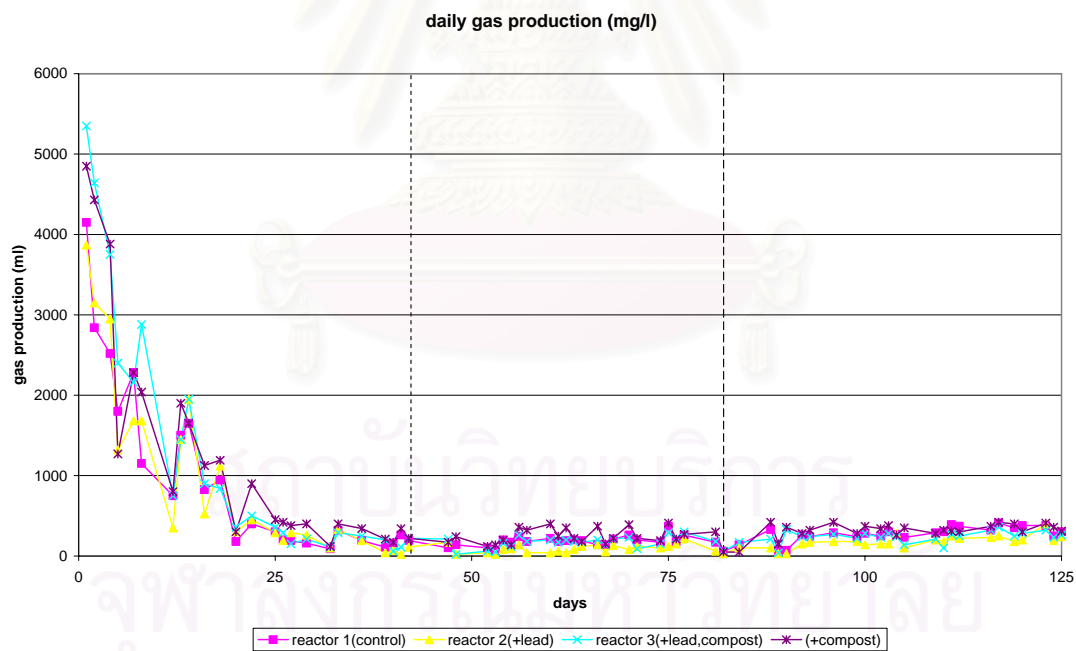
daily gas production (mg/l)

--------- Addition of lead in reactor 2 and reactor 3 (day 42)

– – – – – – Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.15 Daily gas productions in simulated landfill bioreactors

.

4.2.4.1.2 Cumulative gas production

Cumulative gas productions in reactor 3 and reactor 4 were higher than those in reactor 1 and reactor 2 due to higher organic content. Cumulative gas production from reactor 1 was in the same profile and amount as that in reactor 2 and cumulative gas production from reactor 3 was in the same profile and amount as that in reactor 4 during first 42 days of operation due to the same kinds, amount and operation between those reactors. However, after Lead was spiked on day 42, the drop of cumulative gas production in reactor 2 when comparing with reactor 1 as well as the drop of cumulative gas production in reactor 3 when comparing with reactor 4 can be observed. However, the drop of cumulative gas from reactor 3, when comparing with reactor 4, was lower than the drop of cumulative gas from reactor 1, when comparing with reactor 1. The result indicated that waste stabilization occurred more quickly and completely in non Lead reactors than in Lead contaminated reactors. In addition, Lead was toxic to the digestion system and the use of compost would reduce that impact. The cumulative gas productions at the end of operation were 34203, 29115, 39970 and 43695 mL, respectively.

Addition of lead in reactor 2 and reactor 3 (day 42)

Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.16 Cumulative gas productions in simulated landfill bioreactors

4.2.4.1.3 Gas compositions

Carbon dioxide and normalized methane percentages in all reactors were presented in figure 4.17, 4.18 and Table E-3, Table E-4, respectively

Result of the earliest phase of the simulated landfill experiment indicated a transition from aerobic condition to anaerobic condition and the majority of gas produced during this period was carbon dioxide, as oxygen was utilized and decreased in concentrations. Methanogenesis was only begining to be established, but at a very slow rate, as reflected by a gradual in methane concentrations during the period of observation. Initially, carbon dioxide was 65.14, 66.27, 70.84 and 71.72% and methane was 2.34, 2.5, 3.18 and 3.33% in reactor 1, 2, 3 and 4, respectively. Declining of carbon dioxide percentages and gradually methane percentages increasing for the gas from all reactors were in the same patterns until Lead was spiked in reactor 2 and reactor 3 on day 42. A significant drop of carbon dioxide with low methane percentage was observed in reactor 2 indicating the abnormal degradation and stabilization caused from Lead inhibition. A little Lead effect can be found in reactor 3 since methane percentage from reactor 3 was lower than methane percentages from reactor 1 (control) and reactor 4, but it was greater than reactor 2. Consequently, compost could reduce the effect of Lead inhibition since normal progress on degradation could be expected. The significant increase in methane percentage concomitant sharp decrease in normalized carbon dioxide percentage were observed in all reactors after day 81 since daily leachate recirculation with buffer neutralization provided active methanogenic activity in the system. Carbon dioxide percentage of gas at the end of operation was 40.39, 40.14, 44.21, 44.46 and methane percentage of gas was 55.26, 40.68, 45.21 and 49.32 in reactor1, 2, 3 and 4 respectively. The lowest methane percentage in reactor 2 at the end of operation also indicated that the retardation on degradation and on stabilization process would occur because system had a lower capability for enhancing growth of bacteria responsible for waste stabilization.

carbon-dioxide composition in biogas

- - - - - - - - Addition of lead in reactor 2 and reactor 3 (day 42)

- - - - - - Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.17 Carbon dioxide percentages in simulated landfill bioreactors

methane composition in biogas
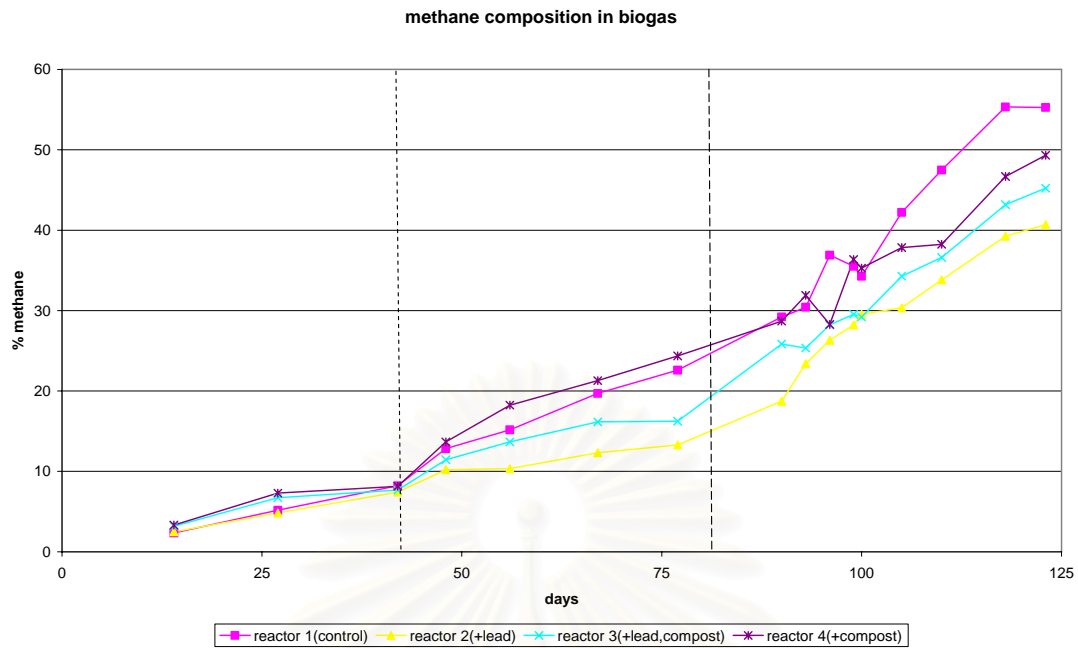
--------Addition of lead in reactor 2 and reactor 3 (day 42)

-------Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.18 Normalized methane percentages in simulated landfill bioreactors

4.2.4.1.3 Methane production

Daily methane productions and cumulative methane production was represented in figure 4.19, 4.20 and Table E-5, Table E-6, respectively

Initial daily methane gas on day 27 was 10, 14, 10 and 28 mL in run 1, 2, 3 and 4, respectively. During day 42 to day 77, daily methane gas was quite steady in the range of 16-59, 2-28, 2-49 and 17- 66 mL in reactor 1, 2, 3 and 4, respectively. Lowest daily methane production was found in reactor 2 after Lead was added on day 42 due to Lead inhibition effect. However, daily methane production was considered low due to high volatile fatty acid accumulation that caused pH unsuitable for methanogenic microorganisms. After daily leachate recirculation with pH adjustment from day 81 today 125, daily methane production on day 100-123 rose to 96-201, 30-163, 48-145 and 122-202 mL in reactor 1, 2, 3 and 4, respectively

When considering cumulative methane gas productions, all reactors had similar amount of methane accumulation before Lead was spiked. After Lead was spiked on day 42, lowest daily methane gas and cumulative methane gas from that day to the end of operation was observed in reactor 2, while the most cumulative methane production was found in reactor 4. The runner-up and the third rank of methane gas accumulation were reactor 1 and reactor 3, respectively. The result showed that Lead was toxic and not suitable for the growth of microorganisms during digestion; therefore, the inhibition on degradation from organic converting into methane gas would occur; thus, the retardation on stabilization process would be expected. In addition, the use of compost did not retard the stabilization process since cumulative methane production was higher than that in reactor 1 (control reactor). Moreover, compost use could reduce the effects of heavy metal inhibition since cumulative methane production from reactor 3 was higher than that in reactor 2.
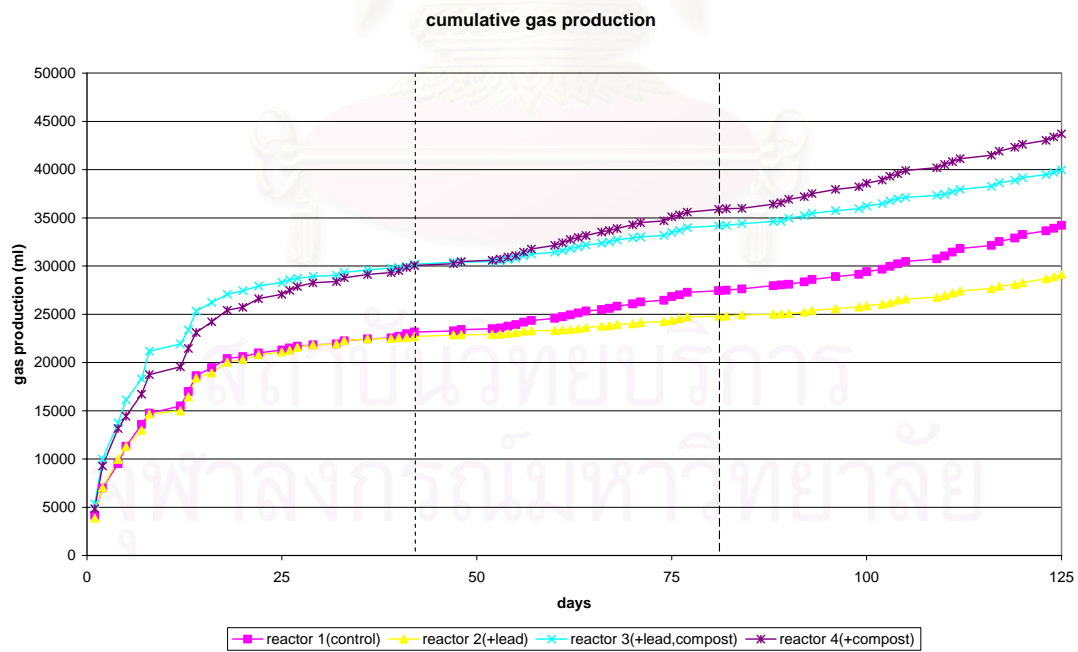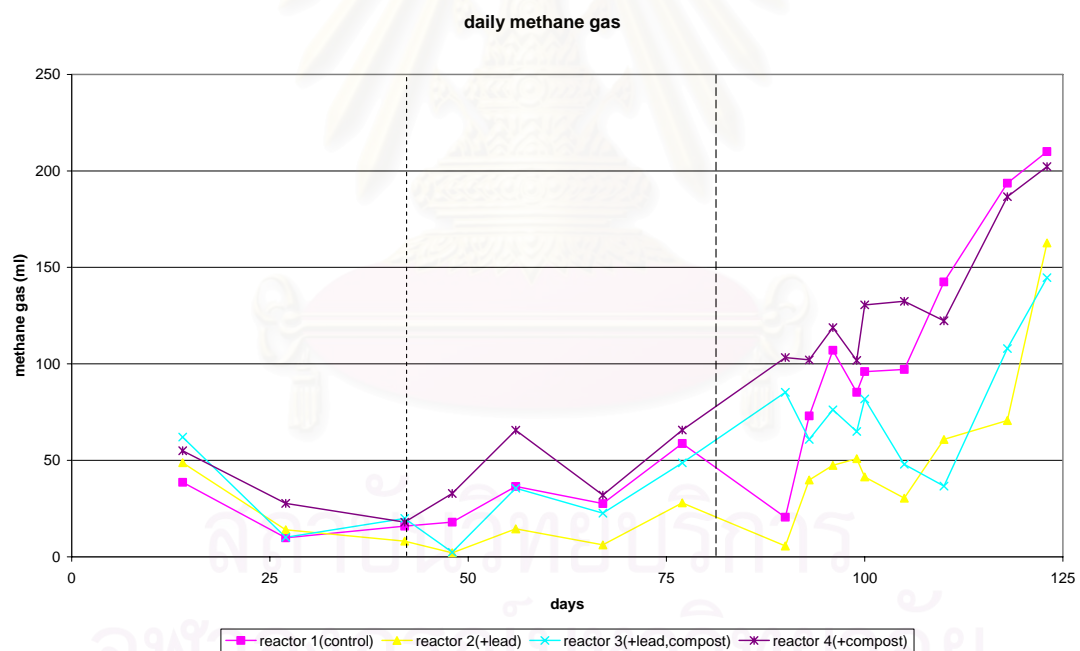

- - - - - - - - Addition of lead in reactor 2 and reactor 3 (day 42)

- - - - - - Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.19 Daily methane productions from simulated landfill bioreactors
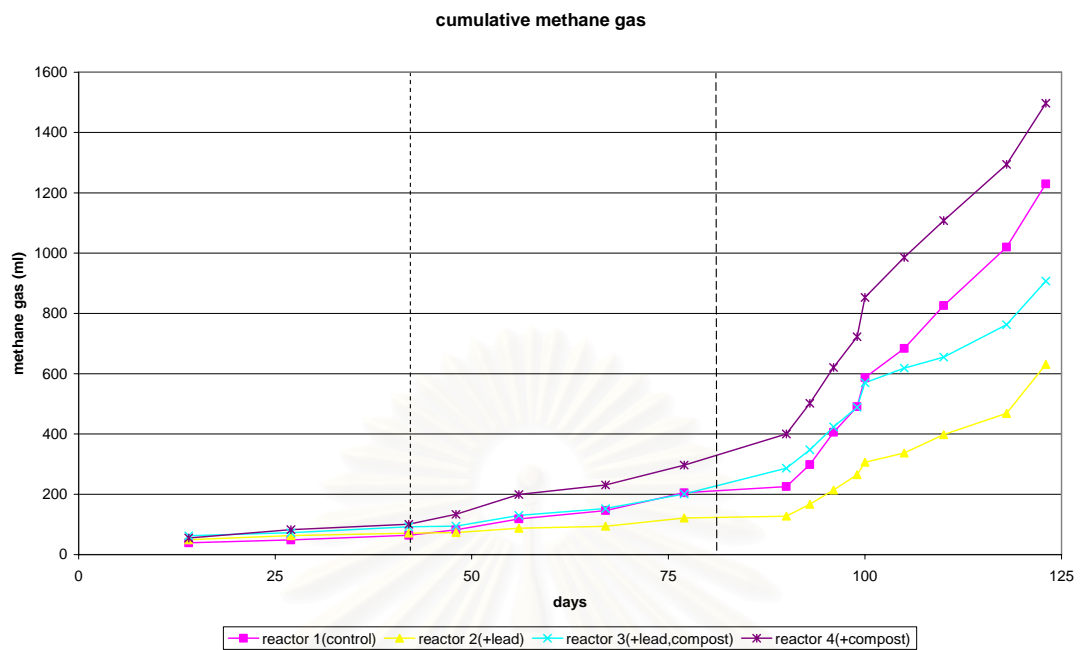
cumulative methane gas

- - - - - - - - Addition of lead in reactor 2 and reactor 3 (day 42)
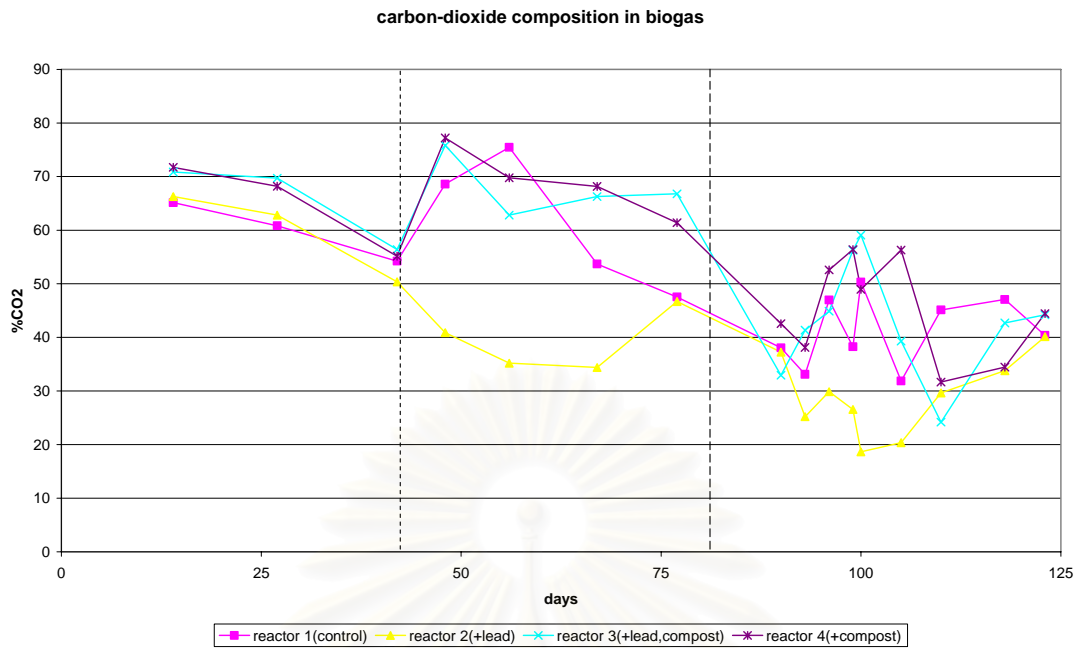
– – – – – –Application of leachate recirculation and buffer neutralization (day 81)

Figure 4.20 Cumulative methane productions from simulated landfill bioreactors

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The purpose of this research investigate was to study the impacts of Lead on degradation of organic waste and the use of compost as daily covered on both degradation of organic waste and the reduction of Lead impact. Based on the results of this research study, the following conclusion was

1. Lead was toxic and not suitable for the growth of microorganisms during digestion; therefore, the inhibition on degradation from organic converting into methane gas would occur; thus, the retardation on stabilization process would be expected as indicated by leachate and gas parameters.

2. Compost could reduce the impact of Lead inhibition on stabilization process in landfill bioreactor as indicated by fewer amounts of Lead concentrations from leaching out of leachate during acid phase and other parameters from leachate and gas in reactor 3.

3. The use of compost did not retard the stabilization process since cumulative methane production, biogas production, nutrients and organic content in reactor 4 were higher than that from control reactor while the abnormally stabilization process did not occur.

4. Leachate recirculation management strategy offers opportunities for more rapid waste stabilization, provides more favorable environmental conditions for microbiological growth and proliferation while he utilization of pH adjustment was effective in establishing a viable methane forming population with a concomitant production of additional intermediates and their collective conversion to CH_4 and CO_2.

5.2 Recommendation for future work

1. At real site, there are a large number of various heavy metals in landfill. Consequently, determining other heavy metals impact on landfill stabilizations is crucial.

2. Since the work reported here did not attempt to investigate the underlying mechanisms, the possible explanations given are conjecture. There could be complicated mechanisms for attenuation of heavy metals; therefore, future studies are needed to investigate to the relationships among pathway and removal mechanisms.

3. Investigate various organic wastes with various fiber contents in compost to be used as landfill cover relative to amount of heavy metal attenuation and on stabilization process in landfill bioreactor.

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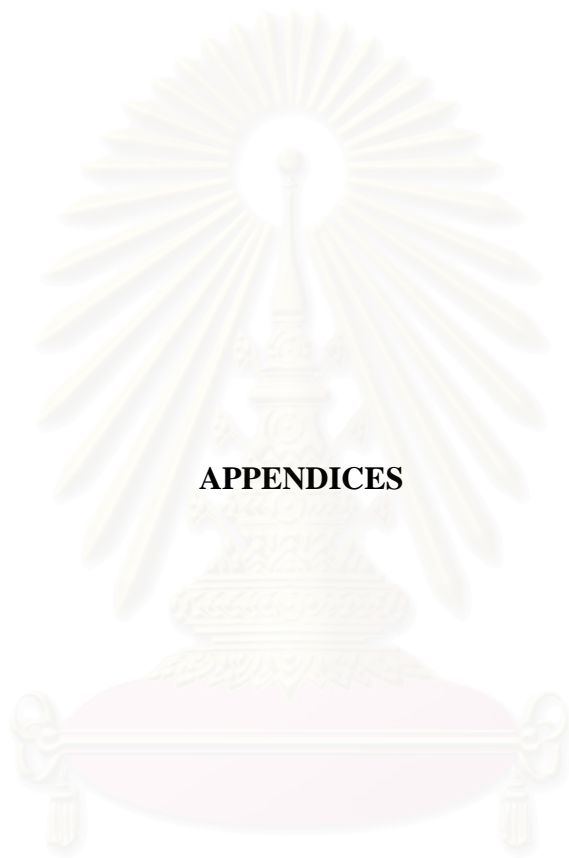
APPENDICES
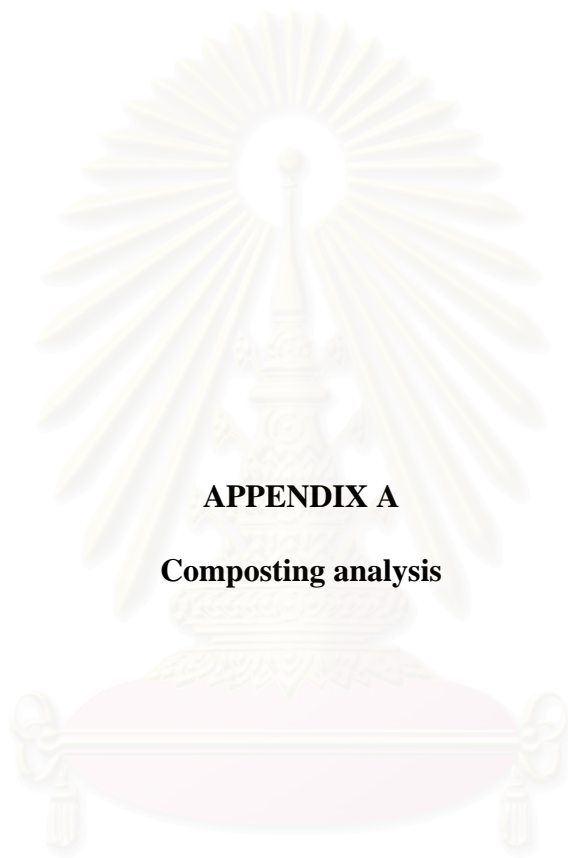
APPENDIX A

Composting analysis

Table A-1 Temperature during composting processes (C)

day	compost temp.	ambient temp.
1	44	29
2	41	29
3	37	29
6	37	29
7	35	29
8	34	30
9	32	30
10	32	30
11	31	30
13	31	30
14	30	29
15	30	28
16	30	29
17	31	30
21	31	31

Table A-2 Moisture content during composting processes

day	moisture content
1	63.88%
2	64.99%
3	67.78%
6	63.00%
7	48.72%
8	79.84%
9	60.99%
10	61.48%
11	50.18%
13	34.97%
14	18.64%
15	21.20%
16	19.08%
17	22.60%
21	20.39%

Table A-3 Total organic matter during composting processes

day	TOM
1	91.71%
7	84.20%
10	78.45%
13	77.45%
14	75.24%
17	63.41%
21	60.53%

Table A-4 pH during composting processes

day	PH
1	5.02
2	6.87
3	6.92
6	7.62
7	7.60
8	8.40
9	7.94
10	8.74
11	9.52
13	9.44
14	9.67
15	9.40
16	9.93
17	9.50
21	9.28
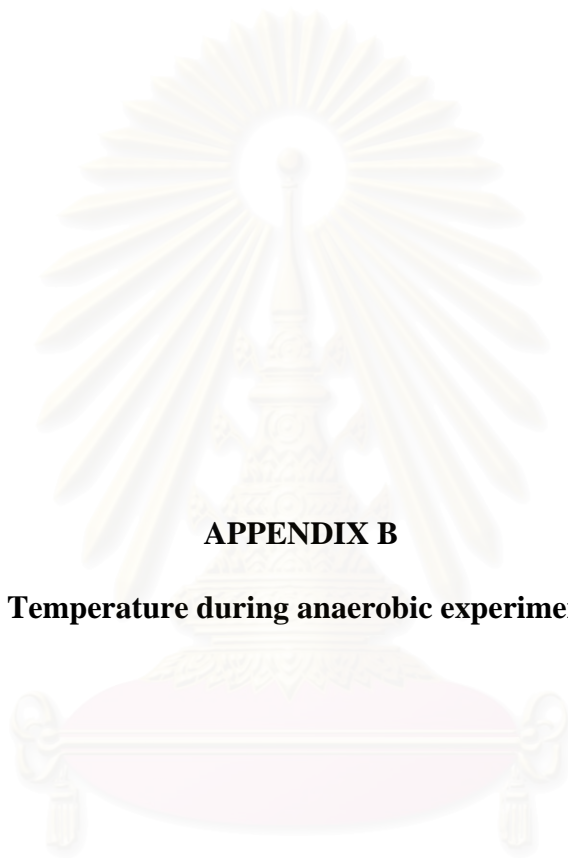
APPENDIX B

Temperature during anaerobic experiment

Table B-1 Temperature during fermentation (C)

Day	temperature
77	32
81	30
82	30
84	30
5	28
7	29
8	29
12	30
13	29
14	30
16	29
18	29
20	28
22	30
25	31
26	32
27	32
29	31
32	29
33	30
36	31
39	30
40	27
41	25
42	28
47	25
48	23
52	28
53	28
54	28
55	27
56	29
57	29
60	31
61	31
62	31
63	30
64	30
66	31
67	30
68	30
70	31
71	30
74	30
75	30
76	32

Day	temperature
88	32
89	31
90	32
92	32
93	33
96	33
99	32
100	33
102	28
103	29
104	28
105	30
109	31
110	31
111	30
112	31
116	31
117	33
119	32
120	29
123	32
124	30
125	32

APPENDIX C

Leachate analysis data from the simulated landfill reactors

Table C-1 pH of leachate in simulated landfill bioreactors

day	reactor1	reactor2	reactor3	reactor4	day	reactor1	reactor2	reactor3	reactor4
1	5.98	5.64	7.45	6.92	84	6.08	6.07	5.74	5.78
2	5.88	5.58	6.91	7.1	88	6.44	6.7	5.97	6.04
4	5.97	6.07	6.92	6.93	89	6.4	6.47	6.16	5.95
5	6.49	5.59	6.49	6.57	90	6.72	6.81	6.9	6.3
7	6.03	5.75	6.2	6.51	92	6.69	6.75	6.53	6.26
8	5.94	5.69	6.09	6.46	93	6.67	6.72	6.47	6.23
12	5.87	5.68	5.78	6.06	96	7.37	7.3	7.05	6.08
13	5.79	5.67	5.7	5.88	99	6.83	6.82	6.54	6.42
14	5.77	5.64	5.73	5.88	100	6.79	6.75	6.5	6.35
16	5.74	5.64	5.73	6.03	102	6.68	6.73	6.48	6.4
18	5.72	5.53	5.65	5.81	103	6.83	6.72	6.26	6.29
20	5.75	5.68	5.73	5.87	104	6.66	6.62	6.24	6.38
22	5.44	5.64	5.85	5.92	105	6.52	6.52	6.25	6.39
25	5.69	5.56	5.69	5.88	109	6.54	6.35	6.24	6.42
26	5.82	5.71	5.9	5.88	110	6.55	6.3	6.22	6.44
27	5.78	5.7	5.89	5.84	111	6.57	6.76	6.48	6.54
29	5.76	5.71	5.79	5.85	112	7.27	7.18	6.8	6.8
32	5.66	5.52	5.67	5.74	116	7.37	7.02	6.76	6.8
33	5.74	5.62	5.75	5.9	117	7.4	6.97	6.75	6.83
36	5.61	5.52	5.63	5.87	119	7.18	6.89	6.55	6.67
39	5.57	5.42	5.52	5.65	120	7.11	6.8	6.53	6.6
40	5.62	5.58	5.63	5.76	123	6.76	6.52	6.35	6.52
41	5.54	5.45	5.43	5.67	124	7.17	6.94	6.62	6.68
42	5.55	5.44	5.6	5.78	125	7.13	7.11	7.04	7.27
47	5.75	5.62	5.82	5.89					
48	5.63	5.47	5.56	5.67					
52	5.68	5.63	5.65	5.85					
53	5.63	5.37	5.4	5.47					
54	5.45	5.39	5.5	5.57					
55	5.38	5.42	5.33	5.44					
56	5.73	5.62	5.69	5.75					
57	5.67	5.5	5.59	5.74					
60	5.63	5.49	5.6	5.72					
61	5.64	5.52	5.62	5.71					
62	5.65	5.5	5.58	5.69					
63	5.69	5.55	5.63	5.64					
64	5.64	5.53	5.65	5.67					
66	5.63	5.52	5.55	5.63					
67	5.69	5.54	5.52	5.6					
68	5.63	5.51	5.54	5.58					
70	5.63	5.6	5.56	5.74					
71	5.62	5.58	5.55	5.67					
74	5.65	5.53	5.52	5.57					
75	5.64	5.54	5.52	5.57					
76	5.65	5.58	5.56	5.78					
77	5.64	5.54	5.51	5.55					
81	5.72	5.65	5.6	5.63					
82	6.18	5.99	5.53	5.51					

Table C-2 COD of leachate in simulated landfill bioreactors (mg/L)

day	reactor 1	reactor 2	reactor 3	reactor 4
1	70857	73143	77142	74000
5	50286	50571	59428	59714
8	54000	48000	60000	64000
12	36000	38000	40000	42000
16	38000	32000	42000	42000
22	30000	30000	42000	44000
25	28000	28000	40000	44000
29	30000	28000	42000	48000
36	30000	30000	40000	42000
39	30000	30000	40000	42000
42	30000	28000	42000	42000
47	34000	24000	36000	40000
52	34000	24000	36000	40000
55	28000	24000	34000	40000
60	28000	24000	36000	38000
66	30000	28000	36000	40000
75	28000	24000	36000	40000
81	30000	26000	36000	42000
88	32000	28000	38000	38000
90	28000	28000	36000	38000
96	28000	32000	36000	38000
100	26000	28000	36000	36000
104	26000	28000	34000	34000
110	24000	30000	34000	30000
125	20000	28000	30000	26000

Table C-4 VFA of leachate in simulated landfill bioreactors (mg/L)

day	reactor 1	reactor 2	rector 3	reactor 4
4	17531.11	16602.25	21250	23182.69
8	17481.25	16175	20281.25	21400
16	15500	14781.25	17804.62	18456.25
22	14062.5	13800	18566.67	18375
29	13562.5	12291.66	19196.43	22261.36
36	12125	11720.58	16448.27	16968.75
42	15041.66	14045.45	21513.16	22076
55	13187.5	10500	16392.86	20250
66	13141.3	10875	17187.5	19906.25
75	12593.75	9641.3	15956.52	17021.74
88	12136.36	10750	16812.5	18113.63
104	10850	9654.7	15587.23	16272.72
125	7375	10235.4	13265.44	10354.47

Table C-5 Alkalinity of leachate in simulated landfill bioreactors (mg/L)

day	reactor 1	reactor 2	rector 3	reactor 4
4	3750	3450	9327	8982
8	2362.5	3757.5	7575	6425
16	7437.5	6513.89	10912.5	11500
22	6887	8512.5	11750	11966.67
29	7194.44	8312.5	13250	12500
36	3514.7	7861.1	11312.5	11448.27
42	6704.54	4500	10760.87	10894.74
55	7000	7175	10156.25	9928.57
66	7545.45	7891.3	11625	11875
75	8326.08	9291.66	13739.13	12956.52
88	9966.66	9590.91	13681.82	14458.33
104	10600	10750	15550	16950
125	11791.66	12083.33	17363.64	18045.45

Table C-6 ORP of leachate in simulated landfill bioreactors (mV)

day	reactor 1	reactor 2	reactor 3	reactor 4
1	108.2	53	-147.7	-275.5
2	78.8	-19.7	-458.8	-350.4
4	-2.04	-103.8	-463	-364.9
5	-69.9	-104.7	-386.9	-416.8
7	-270	-205.6	-269.9	-313.9
8	-140	-166	-173.8	-140.8
12	-201.9	-216.7	-254	-236.9
13	-197.3	-167.7	-207.7	-250
14	-195.2	-182.6	-194.2	-202.6
16	-160	-150.3	-145.6	-158.8
18	-158	-175.7	-204.6	-196.2
20	-134	-137.7	-187.2	-199.6
22	-153.6	-159.8	-199.7	-180.5
25	-145.8	-144.9	-156.3	-178.4
26	-157	-134.6	-164.5	-173.7
27	-148.1	-141.5	-162.5	-180.4
29	-156.3	-165.8	-184.2	-191.1
32	-138.1	-158.1	-140.1	-178.5
33	-155	-133.7	-132.9	-175.2
36	-138.5	-136.7	-176.9	-182
39	-173.2	-130.5	-146.8	-205.29
40	-158.4	-139.1	-148	-171.1
41	-158.4	-121.1	-143.3	-168.6
42	-155.2	-136.1	-149.7	-160.7
47	-154.5	-74.7	-110.2	-143.9
48	-155.5	-94	-125.8	-163.6
52	-176.7	-103.6	-130.7	-173.3
53	-180.1	-107.7	-129.8	-178.3
54	-167.1	-115.9	-133.6	-139
55	-168.5	-117.8	-129.1	-139.6
56	-170.5	-118.7	-136.1	-155.1
57	-172.3	-117.4	-138.7	-156
60	-113.1	-129	-127.7	-146.4
61	-169.7	-132.4	-140	-147.5
62	-172.4	-130.5	-144.2	-145.3
63	-178.3	-138.7	-157.8	-152.4
64	-180.1	-142.4	-169.7	-155
66	-185.7	-146.6	-182.6	-158.7
67	-195.3	-150.2	-198.7	-186.5
68	-188	-158.6	-168.8	-143.7
70	-181	-160.2	-167.7	-157.9
71	-187.5	-158.2	-159.4	-149.4
74	-175.2	-155.5	-135.7	-146.7
75	-168.3	-150.2	-128.4	-143.3
76	-150.1	-128.9	-110.7	-112.5
77	-122.3	-119	-106.1	-130.4
81	-126.1	-101	-101.1	-120
82	-203.5	-172.7	-117.8	-146.9

Day	Reactor 1	Reactor 2	Reactor 3	Reactor
84	-191.6	-189.5	-129.7	-134.2
88	-220.9	-203.4	-147.3	-150.3
89	-412.6	-227.5	-203.4	-203.9
90	-237.4	-247.5	-250	-199.7
92	-239.4	-252.3	-234.7	-214.8
93	-242.7	-276.3	-228.3	-216.7
96	-267.7	-251.7	-235.4	-238.1
99	-272.3	-265.4	-234.8	-230.2
100	-274.2	-268.1	-230.3	-224
102	-284.2	-260.4	-211.9	-217.2
103	-310.4	-277.5	-232.2	-234
104	-290.4	-273.6	-220.1	-236.4
105	-300.1	-270.8	-205.6	-220.2
109	-292.7	-245.4	-218.3	-222.6
110	-289.2	-241.1	-221.4	-225.6
111	-293.5	-268.8	-237	-225.8
112	-348.3	-301.1	-251.8	-249
116	-388.7	-312.4	-272.5	-273.4
117	-391.9	-315.2	-278.5	-276
119	-399.9	-323.8	-285.4	-290
120	-403.7	-323.4	-274.2	-277.8
123	-394.3	-318.8	-245.5	-251.1
124	-401.6	-316	-255.9	-255.9
125	-394.6	-340.3	-279.1	-269.2

Table C-7 Total nitrogen of leachate in simulated landfill bioreactors (mg/L)

day	reactor 1	reactor 2	reactor 3	reactor 4
13	1436.4	1612.8	1794.8	1710.8
39	1442	1582	1825	1892
60	1848	1904	2114	2114
75	1848	1988	2380	2268
96	1840	2072	2352	2492
110	1876	2044	2450	2548

Table C-8 Orthophosphate of leachate in simulated landfill bioreactors (mg/L)

day	reactor 1	reactor 2	reactor 3	reactor 4
13	296	262	314	506
39	484	515	639	607
60	250	276	395	406
77	212	230	354	387
100	105	110	319	372

Table C-9 Sulfide of leachate in simulated landfill bioreactors (mg/L)

day	reactor 1	reactor 2	reactor 3	reactor 4
32	72	84	136	108
55	66	52	68	92
76	88	88	140	120
108	192	164	264	264
120	124	140	184	176
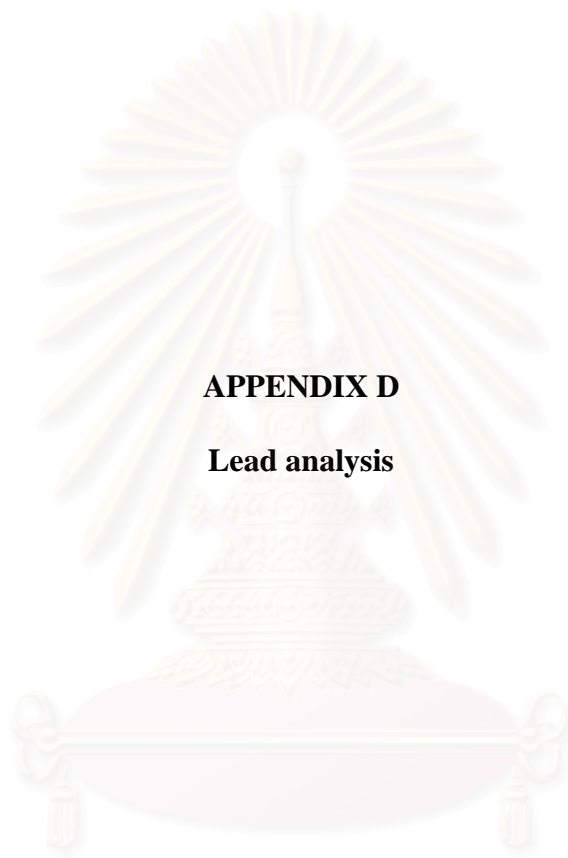
APPENDIX D

Lead analysis

Table D-1 Lead leaching in landfill bioreactors with and without compost covered (mg)

day	reactor2	reactor3
42	201.31	173.90
43	176.35	36.89
47	91.35	14.28
48	96.30	21.09
54	63.40	8.83
55	92.60	15.16
57	70.05	23.18
60	71.10	21.56
62	84.65	18.55
66	120.60	18.39
67	78.30	15.03
68	76.25	15.63
70	89.30	13.74
71	64.70	15.91
75	53.10	11.81
76	66.20	14.25
77	36.70	14.91
78	41.05	14.01
81	37.10	13.75
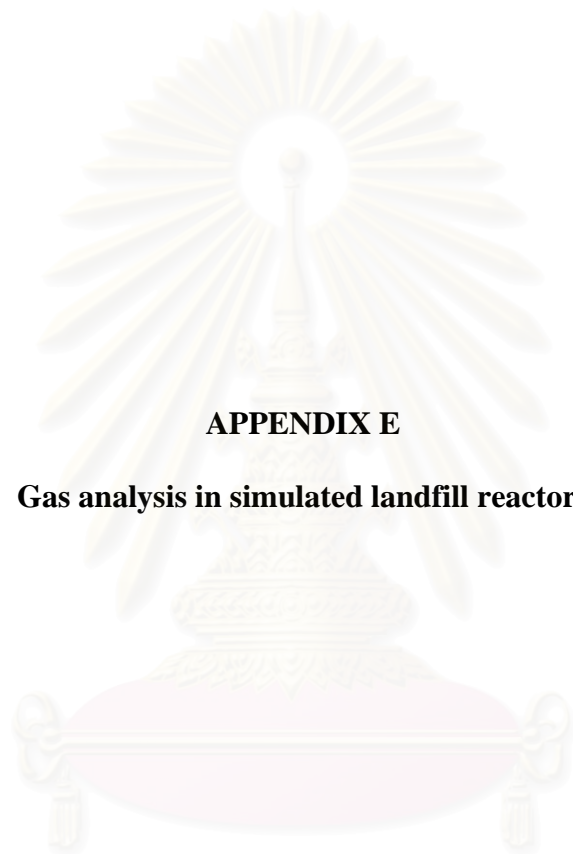
APPENDIX E

Gas analysis in simulated landfill reactors

Table E-1 Daily gas production in simulated landfill bioreactors (mL)

day	reactor1	reactor2	reactor3	reactor4
1	4150	3870	5350	4850
2	2840	3150	4640	4430
4	2520	2950	3750	3880
5	1800	1320	2400	1270
7	2280	1680	2160	2280
8	1150	1680	2880	2040
12	750	350	750	800
13	1500	1450	1450	1900
14	1650	1950	1950	1650
16	825	525	900	1125
18	945	1120	840	1190
20	180	300	360	300
22	400	450	500	900
25	300	290	360	450
26	200	190	290	420
27	190	290	150	380
29	160	260	210	400
32	90	100	110	120
33	320	330	290	400
36	190	190	250	340
39	110	40	200	210
40	160	70	60	170
41	260	20	110	340
42	193	110	220	220
47	100	170	210	170
48	140	20	20	240
52	100	40	60	120
53	60	20	50	140
54	200	80	160	200
55	170	90	120	140
56	240	140	260	360
57	180	40	180	320
60	220	40	200	400
61	180	60	170	250
62	190	40	200	350
63	200	80	180	220
64	190	120	170	180
66	140	140	200	370
67	140	50	140	150
68	210	130	210	220
70	260	80	230	390
71	200	120	90	220
74	170	100	150	190
75	370	120	290	410
76	180	150	220	210
77	260	210	300	270
81	170	60	180	300

day	Reactor1	Reactor2	Reactor4	Reactor4
82	60	30	60	50
84	140	100	170	50
88	330	100	210	420
89	70	30	40	150
90	70	30	*330*	360
92	260	150	240	280
93	240	170	240	320
96	290	180	270	420
99	240	180	220	280
100	280	140	280	370
102	250	150	230	340
103	300	150	280	380
104	270	280	240	260
105	230	100	140	350
109	290	200	210	280
110	300	180	100	320
111	390	250	270	310
112	370	220	250	300
116	320	230	320	370
117	410	250	360	420
119	350	180	250	400
120	380	200	280	300
123	380	400	320	410
124	250	190	230	360
125	300	240	260	310

Table E-2 Cumulative gas production in simulated landfill bioreactors (mL)

day	reactor1	reactor2	reactor3	reactor4
1	4150	3870	5350	4850
2	6990	7020	9990	9280
4	9510	9970	13740	13160
5	11310	11290	16140	14430
7	13590	12970	18300	16710
8	14740	14650	21180	18750
12	15490	15000	21930	19550
13	16990	16450	23380	21450
14	18640	18400	25330	23100
16	19465	18925	26230	24225
18	20410	20045	27070	25415
20	20590	20345	27430	25715
22	20990	20795	27930	26615
25	21290	21085	28290	27065
26	21490	21275	28580	27485
27	21680	21565	28730	27865
29	21840	21825	28940	28265
32	21930	21925	29050	28385
33	22250	22255	29340	28785
36	22440	22445	29590	29125
39	22550	22485	29790	29335
40	22710	22555	29850	29505
41	22970	22575	29960	29845
42	23163	22685	30180	30065
47	23263	22855	30390	30235
48	23403	22875	30410	30475
52	23503	22915	30470	30595
53	23563	22935	30520	30735
54	23763	23015	30680	30935
55	23933	23105	30800	31075
56	24173	23245	31060	31435
57	24353	23285	31240	31755
60	24573	23325	31440	32155
61	24753	23385	31610	32405
62	24943	23425	31810	32755
63	25143	23505	31990	32975
64	25333	23625	32160	33155
66	25473	23765	32360	33525
67	25613	23815	32500	33675
68	25823	23945	32710	33895
70	26083	24025	32940	34285
71	26283	24145	33030	34505
74	26453	24245	33180	34695
75	26823	24365	33470	35105
76	27003	24515	33690	35315
77	27263	24725	33990	35585
81	27433	24785	34170	35885
82	27493	24815	34230	35935

day	Reactor1	Reactor2	Reactor3	Reactor4
84	27633	24915	34400	35985
88	27963	25015	34610	36405
89	28033	25045	34650	36555
90	28103	25075	34980	36915
92	28363	25225	35220	37195
93	28603	25395	35460	37515
96	28893	25575	35730	37935
99	29133	25755	35950	38215
100	29413	25895	36230	38585
102	29663	26045	36460	38925
103	29963	26195	36740	39305
104	30233	26475	36980	39565
105	30463	26575	37120	39915
109	30753	26775	37330	40195
110	31053	26955	37430	40515
111	31443	27205	37700	40825
112	31813	27425	37950	41125
116	32133	27655	38270	41495
117	32543	27905	38630	41915
119	32893	28085	38880	42315
120	33273	28285	39160	42615
123	33653	28685	39480	43025
124	33903	28875	39710	43385
125	34203	29115	39970	43695

Table E-3 Carbon dioxide percentages in simulated landfill bioreactors

days	reactor1	reactor2	reactor3	reactor4
14	65.14	66.27	70.84	71.72
27	60.84	62.81	69.72	68.2
42	54.25	50.38	56.4	55.14
48	68.59	40.88	75.8	77.23
56	75.46	35.18	62.83	69.77
67	53.71	34.39	66.27	68.17
77	47.54	46.69	66.8	61.4
90	38.04	37.23	32.94	42.56
93	33.1	25.21	41.35	38.12
96	46.98	29.86	44.88	52.6
99	38.24	26.53	56.25	56.4
100	50.33	18.64	59.09	48.97
105	31.87	20.37	39.31	56.3
110	45.13	29.63	24.19	31.65
118	47.06	33.77	42.68	34.45
123	40.39	40.14	44.21	44.46

Table E-4 Methane percentages in simulated landfill bioreactors

days	reactor 1	reactor 2	reactor 3	reactor 4
14	2.34	2.5	3.18	3.33
27	5.17	4.83	6.74	7.29
42	8.21	7.43	7.68	8.15
48	12.82	10.2	11.44	13.67
56	15.17	10.34	13.66	18.23
67	19.7	12.32	16.16	21.29
77	22.59	13.3	16.23	24.35
90	29.21	18.72	25.84	28.68
93	30.41	23.4	25.35	31.9
96	36.9	26.31	28.22	28.29
99	35.5	28.22	29.53	36.35
100	34.27	29.55	29.21	35.29
105	42.21	30.34	34.27	37.83
110	47.49	33.82	36.61	38.24
118	55.34	39.25	43.17	46.67
123	55.26	40.68	45.21	49.32

Table E-5 Daily methane productions in simulated landfill bioreactors (mL)

days	reactor 1	reactor 2	reactor 3	reactor 4
14	38.61	48.75	62.01	54.95
27	9.82	14.01	10.11	27.70
42	15.85	8.17	19.9	17.93
48	17.95	2.04	2.29	32.81
56	36.41	14.48	35.52	65.63
67	27.58	6.16	22.624	31.94
77	58.73	27.93	48.69	65.75
90	20.45	5.616	85.27	103.248
93	72.98	39.78	60.84	102.08
96	107.01	47.36	76.19	118.82
99	85.2	50.8	64.97	101.78
100	95.96	41.37	81.79	130.57
105	97.08	30.34	47.98	132.405
110	142.47	60.88	36.61	122.37
118	193.69	70.65	107.93	186.68
123	209.99	162.72	144.67	202.21

Table E-6 Cumulative methane productions in simulated landfill bioreactors (mL)

days	reactor 1	reactor 2	reactor 3	reactor 4
14	38.61	48.75	62.01	54.95
27	48.43	62.76	72.12	82.65
42	64.28	70.933	92.02	100.58
48	82.22	72.973	94.31	133.39
56	118.63	87.45	129.83	199.01
67	146.21	93.61	152.45	230.95
77	204.95	121.54	201.14	296.69
90	225.39	127.16	286.41	399.94
93	298.38	166.94	347.25	502.02
96	405.39	214.30	423.44	620.84
99	490.59	265.10	488.41	722.62
100	586.55	306.47	570.20	853.19
105	683.63	336.81	618.18	985.60
110	826.10	397.69	654.79	1107.97
118	1019.79	468.34	762.71	1294.65
123	1229.78	631.06	907.39	1496.86
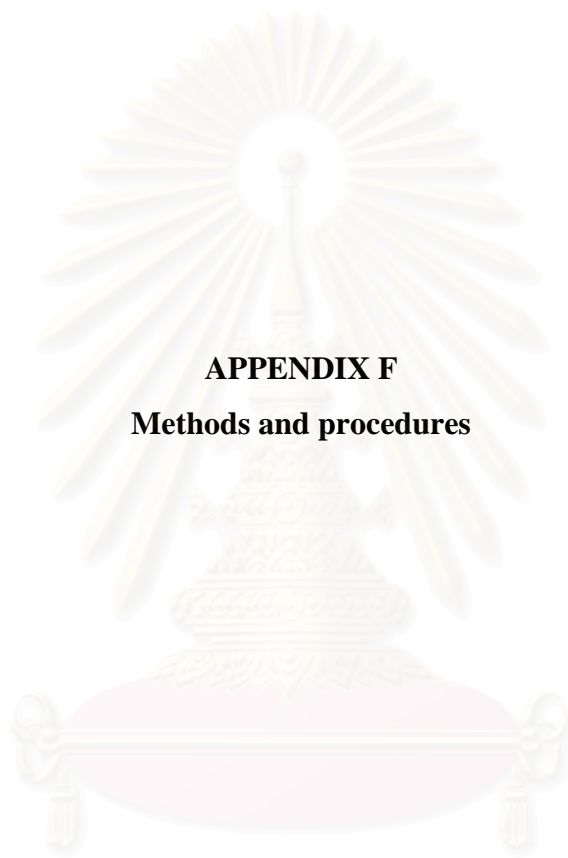
APPENDIX F

Methods and procedures

Acid chlorite method by Browing for holo-cellulose analytical method

1. Weight 3 g sample into 250 ml flask.
2. Put 160 ml deionized water, 0.5 ml acetic acid and 1.5 sodium chloride in the flask.
3. Incubate sample in water bath at 70-80°C for 1 hour.
4. After 1 hour incubation, put 0.5 ml acetic acid and 1.5 g sodium chloride.
5. Do the same as procedure 4 until the sample reach 4 hours incubation.
6. Put flask in ice tank for 30 minutes
7. Filter sample with sinter glass crucible#3, wash sample with cold water and acetone.
8. Incubate sample at 105°C.
9. Calculate holo-cellulose percentage from

$$\% \text{ cellulose} = \frac{\text{Weight of holo-cellulose}}{\text{Weight of sample}} * 100$$

TAPPI T 203 om-88 analytical method for cellulose

1. Weight 1.5 g of sample analyzed for holo-cellulose and put in 400 ml beaker
2. Put 75 ml of 17.5% NaOH into sample, Adjust sample temperature to 2.5°C.
3. Shake sample until solvent is totally mixed.
4. Put 2.5 ml of 17.5% NaOH, shake and incubate at temperature 2.5°C for 30 minutes.
5. Put 100 ml deionized water, shake and leave for 30 minutes.
6. Filter sample with sinter glass crucible#3
7. Wash sample with deionized water and 40 ml of 10% acetic acid
8. Incubate sample at 105°C.
9. Calculate cellulose percentage from

$$\% \text{ cellulose} = \frac{\text{Weight of cellulose}}{\text{Weight of sample}} * 100$$

TAPPI T 203 om-98 analytical method for lignin

1. Weight 1 g sample into 15 ml beaker
2. Put beaker into ice tank, add 15 ml 72% H_2SO_4, shake sample every 15 minutes.
3. Put beaker into water bath at temperature 20°C for 2 hours, shake sample every 15 minutes.
4. Add 400 ml deionized water and sample into 1000 ml flask, reflux sample for 4 hours and leave sample for 1 day.
5. Filter sample with sinter glass crucible#3, rinse sample with hot water.
6. Incubate sample at 105°C for 6 hours.
7. Calculate lignin percentage from

$$\% \text{ lignin} = A100/W$$

A= weight of lignin (g)

W= weight of sample (g)

Digestion Procedure for Metal in Leachate by Ethos Sel Installation

This method provides for the acid digestion of the Wastewater II in a closed vessel device using temperature control microwave heating for the metal determination by spectroscopic methods.

Microwave Equipment

Milestone ETHOS PLUS labstation with HPR-1000/10S high pressure segmented rotor.

Sample Amount Up to 1000 Watt

5 grams

Reagents

6 mL of HNO3 65%, 3 ml of HCL 36% and 0.25 Ml of H_2O_2 30%.

Procedure

1. Place a TFM vessel on the balance plate, tare it and weigh 5 grams of sample.

2. Introduce the THM vessel into the HTC safety shield.

3. Add the acids; if part of the sample stays on the inner wall of the TFM vessel, wet it by adding acids drop by drop, then gently swirl the solution to homogenize the sample with the acids.

4. Close the vessel and introduce it into the rotor segment, then tighten by using the torque wrench.

5. Insert the segment into the microwave cavity and connect the temperature sensor.

6. Run the microwave program to completion.

7. Cool the rotor by air or by water until the solution reaches room temperature.

8. Open the vessel and transfer the solution to a marked flask.

Microwave Program

Step	Time	Temperature	Microwave power
1	10 minutes	200°C	Up to 1000 Watt
2	20 minute	200°C	Up to 1000 Watt

Organic Matter analysis in compost, procedures and methods (loss on ignition method)

Number porcelain crucibles with wax pencil. Weigh crucibles to 4 decimal places. Scoop dried and ground samples into crucibles using 5 g soil scoop. Put crucibles plus samples on tray in furnace. Set temperature to 105 degrees C. Ash at this temperature for 2 h. (It takes 15 minutes for the furnace to reach this temp, so set the dial at 105 for a total of 2 h and 15 min.)

1. Remove samples from furnace with tongs, place in desiccator, and weigh to 4 decimal places immediately while still warm so moisture won't be absorbed. Replace crucibles plus samples in furnace. Turn dial up to 360 degrees C.

2. Ash at this temp for 2 hours. (It takes ½ hour for the furnace to reach this temperature, so set the dial at 360 for a total of 2½ hour.) Turn furnace off and open door. Place samples in desiccator with tongs and allow samples to cool. Weigh samples to 4 decimal places.

3. Calculate OM% and record on data sheet with one decimal.
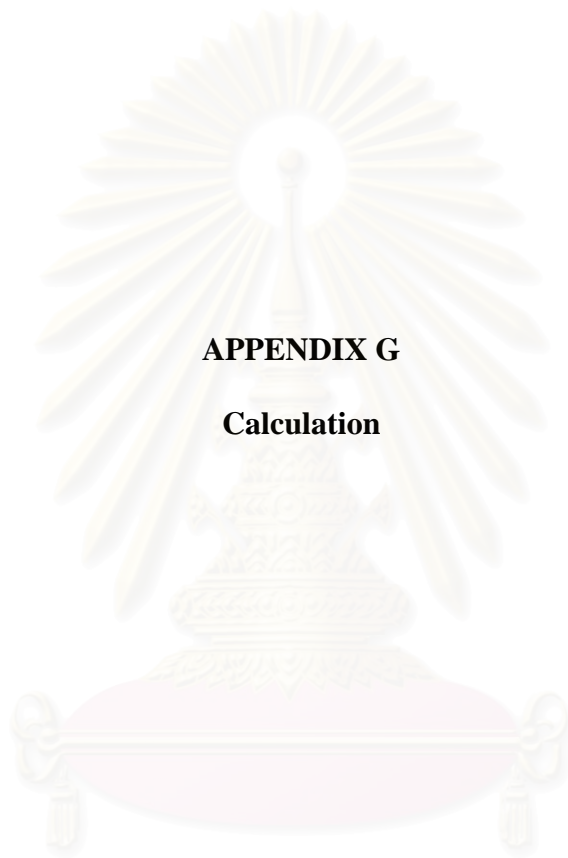
Crucible wt = a
Crucible wt + sample wt after 105 heating = b
Crucible wt + sample wt after 360 heating = c

%OM = ((b-a)-(c-a))(100)/(b-a)

APPENDIX G

Calculation

Amount of compost before and after composting

Before, total weight 15 kg, moisture content 63.88%, and organic matter 91.71%

Volume of water =15 * 63.88/100= 9.58 L

Dry weight = 15-9.58 = 5.42 kg

Organic matter 5.42* 91.71/100 = 4.97 kg

After, moisture content 20.39% and organic matter 60.53%

Moisture loss =63.88%-20.39% = 43.49%

Organic loss = 91.71%-60.53% = 31.18%

Volume of water loss 15* 43.49/100= 6.52 L

Organic matter loss 5.42 * 31.18/100= 1.69 kg

Weight of compost after composting 15-6.52-1.69 = 6.79 kg

Masses of selected heavy metals loading into reactors

Allowable amount according to Turkish Hazardous waste Control Regulations = 80 g/t MSW (lead)

Weight of solid waste = 5 kg

$\therefore$ Allowable amount of heavy metals in system = 0.4 g

Atomic weight of Pb = 207.2

Atomic weight of $Pb(NO_3)_2$ = 331.2

Allowable amount of heavy metals in system = 0.4 g

$\therefore$ $Pb(NO_3)_2$ will be spiked in reactor = (331.2/207.2)×0.4

$$= 0.64 \text{ g}$$

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, Chulalongkorn University, Bangkok, Thailand in May 2004. He finished his Master Degree of Science in Environment Management in May 2006.