ANAEROBIC COMPOSTING OF SOLID WASTE IN BATCH-LOADING DIGESTERS

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ANAEROBIC COMPOSTING OF SOLID WASTE IN
BATCH-LOADING DIGESTERS

Suranaree University of Technology Council has approved this thesis submitted in partial fulfillment of the requirement for Master's Degree

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การวิจัยนี้เป็นการทำปุ๋ยหมักจากเศษขยะที่เป็นสารอินทรีย์แบบไม่ใช้อากาศ สำหรับวัสดุที่ใช้ คือ เศษอาหารผสมกับฟาง และขยะที่เป็นสารอินทรีย์ (ไม่รวมเศษอาหาร) ผสมกับตะกอนจากบ่อเกรอะ ที่ค่ายทหารสุรนารี อ. เมือง จ. นครราชสีมา ซึ่งในการทดลองครั้งนี้มีถังหมักทั้งหมด 8 ถัง แต่ละถังมีขนาด 1.0 x 0.5 x 0.5 ม. โดยถังหมัก 4 ถังใช้สำหรับการหมักเศษอาหารผสมกับฟาง ส่วนอีก 4 ถังใช้สำหรับการหมักขยะที่เป็นสารอินทรีย์(ไม่รวมเศษอาหาร) ผสมกับตะกอนจากบ่อเกรอะ เศษขยะที่เป็นสารอินทรีย์ได้มาจากการคัดแยกขยะที่หลุมฝังกลบขยะของค่ายทหารสุรนารี อัตราการผสมระหว่างเศษอาหารกับฟาง คือ 1/0.4 โดยปริมาตร หรือคิดเป็น 1/4.77 โดยน้ำหนัก ส่วนอัตราการผสมระหว่างสารอินทรีย์กับตะกอนจากบ่อเกรอะ คือ 1/7.06 โดยปริมาตร หรือคิดเป็น 1/1.58 โดยน้ำหนัก การทดลองนี้ทำการทดลองทั้งหมด 4 ครั้ง ครั้งที่ 1 ใช้เวลาหมักทั้งหมด 90 วัน ส่วนอีก 3 การทดลองใช้เวลาทั้งหมด 100 วัน โดยกำหนดให้อัตราส่วนเริ่มต้นของคาร์บอน/ไนโตรเจน อยู่ระหว่าง 28-31/1 มีการวิเคราะห์ทางฟิสิกส์ ทางเคมี และการวิเคราะห์หาแบคทีเรียโคลิฟอร์มทั้งหมด (Total coliform bacteria) ตลอดการทดลอง ส่วนการสิ้นสุดการทดลองพิจารณาจากอุณหภูมิภายในถังหมักมีค่าเท่ากับอุณหภูมิบรรยากาศ, อัตราส่วนสุดท้ายของคาร์บอน/ไนโตรเจน อยู่ระหว่าง 15-20/1, วัสดุในถังหมักมีสีดำ, ของแข็งระเหยมีค่าต่ำ และมีอัตราการตายของแบคทีเรียโคลิฟอร์มทั้งหมด 99% จากการศึกษาวิจัยครั้งนี้พบว่า เศษอาหารผสมกับฟางทำให้เกิดอุณหภูมิสูงสุดภายในถังหมักเท่ากับ 52-56 °C ส่วนขยะที่เป็นสารอินทรีย์ (ไม่รวมเศษอาหาร) ผสมกับตะกอนจากบ่อเกรอะทำให้เกิดอุณหภูมิสูงสุดภายในถังหมักเท่ากับ 55-60 °C อัตราส่วนสุดท้ายของคาร์บอน/ไนโตรเจนอยู่ระหว่าง 14-19/1 อัตราการตายของแบคทีเรียโคลิฟอร์มทั้งหมดมีค่า 99.98% สำหรับเศษอาหารผสมกับฟาง และ 99.99% สำหรับขยะที่เป็นสารอินทรีย์ (ไม่รวมเศษอาหาร) ผสมกับตะกอนจากบ่อเกรอะ ซึ่งเป็นภาวะที่เหมาะสมที่สุดในการทำปุ๋ยหมักและเป็นวิธีที่ประหยัดและปลอดภัยต่อสิ่งแวดล้อม

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา..................................

ปีการศึกษา 2545 ลายมือชื่ออาจารย์ที่ปรึกษา.........................

SUDTHIDA KRIENGKASEM: ANAEROBIC COMPOSTING OF SOLID WASTE IN BATCH- LOADING DIGESTERS
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ANAEROBIC/COMPOSTING/BATCH COMPOSTER/SEPTAGE/ORGANIC COMMINGLED WASTE

Pilot-scale experiments were conducted to study the anaerobic composting of food waste mixed with hay, and organic commingled waste mixed with septage. Location of this study was at the Suranaree Military Camp in Nakhon Ratchsima City in northeastern Thailand. Eight brick digesters, each with the size of 1.0 x 0.5 x 0.5 m, were used in this study. Four digesters were for composting of food waste mixed with hay and the other four were for composting of organic commingled waste (except food waste) mixed with septage. Gas outlets were provided in the lids of the digesters made with zinc. Each digester was provided with 0.02 m wide channel along the periphery, filled with water to provide a seal. Composting material was obtained by manually separating the food waste from the commingled waste that was collected and dumped daily at a site inside the military camp. Hay was mixed with the food waste in a 1/0.4 ratio by volume (1/4.77 ratio by weight), and septage was mixed with the organic commingled waste in a 1/7.06 ratio by volume (1/1.58 ratio by weight). Out of a total of four composting runs, the first run was carried out for 90 days, and the other three for 100 days each. Initial C/N ratio was kept at 28-31:1. The physical, chemical, and biological parameters were evaluated on the samples from the composting material at the beginning as well as at the end of each run. The completion of the composting period was determined by examining some characteristics of the composted material that fulfilled several criteria, e.g., temperature inside the digester to be equal to ambient temperature, and the composted material to have: brownish black color, C/N ratio between 15 – 20/1, low volatile solid content, and nearly 100% (99.99%) die-off of the total coliform bacteria. Maximum temperature during the anaerobic composting process in the four runs ranged between 52-56 °C and 55-60 °C, for food waste mixed with hay and organic commingled waste mixed with septage, respectively, and was achieved within 2 days from the start up time. C/N ratio of the end product ranged between 14-19:1 A 99.80-99.98% and 99.99% kill of total coliform bacteria was achieved for food waste mixed with hay and organic commingled waste mixed with septage, respectively. Based on the results of this study, it can be seen that anaerobic composting of the two waste combinations: food waste mixed with hay, and organic commingled waste mixed with septage, at an optimum C/N ratio can be a very appropriate low-cost, low maintenance method for safe disposal of waste.

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Sudthida Kriengkasem

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List of Abbreviations

AMB	=	Acetophilic Methanogenic Bacteria
C	=	Carbon
C_f	=	Carbon content of food waste
C_h	=	Carbon content of hay
CH_4	=	Methane
cm	=	Centimeter
C/N	=	Carbon to nitrogen ratio
$(C/N)_m$	=	C/N ratio of mixture of food waste and hay
CO_2	=	Carbondioxide
FB	=	Fermentative Bacteria
ft	=	Foot
g	=	gram
HAB	=	Homoacetogenic Bacteria
H_2O	=	water
hr	=	Hour
H_2S	=	Hidrogen sulfide
kg	=	kilogram
L	=	Liter
MB	=	Methanogenic Bacteria
mg/l	=	milligram per liter
min	=	Minute
ml	=	Milliter
µg/mL	=	microgram per milliliter
N	=	Nitrogen
N_f	=	Nitrogen content of food waste
N_h	=	Nitrogen content of hay
NH_4^+	=	Ammonia
NO_3^-	=	Nitrate
O_2	=	Oxygen
P	=	Phosphorus
p	=	Significant level
SB	=	Syntrophic Bacteria
SRB	=	Sulfate Reducing Bacteria
TKN	=	Total kjeldahl nitrogen
TS	=	Total carbon
TVS	=	Total volatile solids
VS	=	Volatile solids
V_b	=	ml of H_2SO_4 required in the blank titration
V_s	=	ml of H_2SO_4 required for the titration of sample Distillate
X	=	Normality of H_2SO_4

CHAPTER I

INTRODUCTION

1.1 Introduction

All communities have wastes. Be they wastewater, municipal solid waste, industrial or agricultural wastes, the community must deal with them. Cost to dispose wastes, particularly municipal solid wastes, are escalating. Waste generated in a community can be a valuable energy and material resource; however, past and current waste disposal and treatment practices consume energy and have led this resource to become a serious environmental burden. In many areas, landfills are approaching capacity and closing, and new sites for the disposal of solid wastes are not available.

At present, composting is widely used to treat wastewater sludge, processing wastes and municipal refuse. The primary benefits gained by composting these materials are stabilization of waste, reduction of the volume and moisture content of the waste, destruction of pathogens and odor producing nitrogen and sulphur containing composting compounds. Thus, it could be used to provide a marketable product as well as for ultimate safe waste disposal.

Anaerobic composting for recycling the biodegradable organic fraction of solid wastes generated is one good option for waste disposal. It is the decomposition that occurs using microorganisms that do not require oxygen. Although this is not the ultimate solution for the safe disposal of the solid wastes generated, it provides one useful end product compost.

The anaerobic microbial degradation of organic matter and conversion to methane and carbon dioxide occurs naturally in a variety of habitats such as intestinal tracts of humans and animals, and sediments. The microorganisms are exploited in the biotechnological process of anaerobic digestion both to reduce the pollution caused by organic wastes and to produce methane which can be used as a fuel. Anaerobic digestion of a waste prior to release into a natural water course, for example, offers a means of reducing the polluting effects to the waste. The economic disposal of waste and legislation designed to protect the environment from pollution necessitates simple and effective methods of waste treatment. Anaerobic digestion has the potential to be an economically attractive process (Wheatley, 1991).

The Suranaree Military Camp is situated in Nakhon Ratchasima City in the northeastern part of Thailand. The solid waste generation sources in this camp are mainly from residences for military personnel and their families, and offices located within the camp. The solid waste of this camp is so far managed by the military themselves by open dumping and burning in a large area inside the camp. Such disposal of solid waste is no doubt, highly objectionable from public health and environmental point of view. A study to investigate the potential of anaerobic composting process for the organic fraction of Suranaree Military Camp refuse would be beneficial for safe and hygienic solid waste management there.

1.2 Objectives

The main objectives of this study were:

1.2.1 To investigate the anaerobic composting process for biodegradable organic fraction of solid waste from Suranaree Military Camp.

1.2.2 To compare the rate of composting for the two waste combinations, food waste mixed with hay, and the organic commingled waste (except food waste) mixed with septage.

1.2.3 To evaluate the suitability of the end product-compost as the soil conditioner based on the bacterial die-off and change in other characteristics during the process.

1.3 Scope

1.3.1 This study involved the initial waste classification, and the physical, chemical and biological analyses on the waste samples at the beginning and the end of four sequential composting runs of the two waste combinations. The parameters included: moisture content, temperature, acid-base value (pH), carbon, nitrogen, phosphorus, and total coliform bacteria.

1.3.2 Rate of change of these parameters during the composting period was monitored for Run I by terminating the process after 20, 40, 60, and 90 days, respectively in 4 digesters filled with each waste combination at the beginning.

1.3.3 Completion of composting process for both solid waste combinations was investigated by the characteristics analyses of composted material that fulfilled the final product testing criteria.

CHAPTER II

LITERATURE REVIEW

2.1 Solid waste

Solid wastes are the wastes arising from human and animal activities that are normally solid and are discarded as useless or unwanted, waste from processes of agricultural and industrial protection such as domestic waste, industrial waste and infectious waste etc (Opartsiriwit et al, 1996).

2.2 Types of solid wastes

According to Yamcharoenwong (1988), municipal solid waste can be classified as follows:

a) Wet- solid waste means solid waste with high moisture content. Such solid waste can be biodigested for high organic content. For example food waste and manure are under this category.

b) Dry- solid waste means solid waste with low moisture content. Such solid waste can not be digested. However some types of dry solid waste can be burnt & thus reduced. It can be kept for longer period of time than wet- solid waste before disposal.

c) Animal waste is harmful as other wet-solid waste because it gives unpleasant ordor and there is a chance for disease to spread to the nearly residencial areas due to these wastes.

d) Solid waste from roads, such as, leaves, papers and soil, may block the sewage pipes.

e) Solid waste from construction site, such as, wood, concrete, bricks, stone and sand etc.

2.3 Composting

Organic materials present in solid waste can be degraded by microorganisms. The types of such waste are solid waste from households, business centers, and farming. The characteristics of the end products remaining after microbiological activity is of brown to very dark color.

Haug (1980) defined composting as the biological decomposition and stabilization of organic substrate under conditions which allow development of thermophilic temperature as a result of biologically produced heat, which a final product sufficiently stable for storage and application to land without adverse environmental effects.

2.3.1 Principle of composting

The organic fraction of most solid wastes can be considered to be composted of proteins, amino acid, lipids, carbohydrates, cellulose, lignin, and ash. These organic materials are digested by bacteria. The end product remaining after microbiological activity is compost or humus-like material which retains the maximum nutrient (nitrogen, phosphorous, and potassium) content. These nutrients can be used to support plant growth and as a soil conditioner.

The two principle methods of composting may be classified as aerobic decomposition and anaerobic decomposition.

a) Aerobic composting: In aerobic decomposition organic materials are decomposed by aerobic bacteria. This decomposition occurs in the presence of oxygen. The end product of the process is different from anaerobic decomposition.

$$\text{Organic Matter} + O_2 \xrightarrow{\text{Aerobic bacteria}} CO_2 + H_2O + NO_3 + SO_4^{2-}$$

As shown in the above equation, CO_2 and H_2O are produced from the conversion of the organic matter. If it has phosphorus, it changes into the phosphate. Additionally, the products in the above equation are nutrients, such as, nitrate, sulfate, nitrite etc.

Important process variables, that must be considered in the operation of composting, include total oxygen requirements, moisture content, and temperature.

The most common types of aerobic decomposition are: (i) windrow composting, (ii) high rate composting system.

(i) Windrow composting is one of the oldest methods of composting. A windrow compost system can be constructed by forming the organic material to be composted into windrows of 8 to 10 ft. high and 20 to 25 ft. wide at the base. A minimal system could use a front-end loader to turn the windrow once per years. While such a minimal system would work, it could take up to three to five years for complete degradation. Also such a system would probably emit objectionable odors, as parts of the windrow will likely be anaerobic.

(ii) A high rate composting system employs windrows with a smaller cross section, typically 6 to 7 ft. high by 14 to 16 ft. wide. The actual dimensions of the windrows depend on the type of equipment that will be used to turn the composting wastes. Before the windrows are formed, organic shredding and screening of waste is done to the size of approximately 1 to 3 inches. The moisture content is adjusted to 50 to 60 percent. High rate systems are turned up to twice per week while the temperature is maintained at or slightly above 131 °F (55 °C). Turning of the windrows is often accompanied by the release of offensive odors. Complete composting can be accomplished in three to four weeks. After the turning period, the compost is allowed to cure for an additional three to four weeks without turning. During the curing period, residual decomposable organic materials are further reduced by fungi and actinomycetes.

b) Anaerobic composting: In anaerobic decomposition organic materials are decomposed by anaerobic bacteria. This decomposition occurs in the absence of oxygen.

It should be noted that, in contrast to wastewater treatment, the terms ‘aerobic’ and ‘anaerobic’ for composting have relative meanings. They simply indicate what conditions are predominant in the process. As the compost materials are heterogeneous and bulky in character, in a compost heap there always exists ‘anaerobic’ conditions, which are little in ‘aerobic’ composting but abundant in ‘anaerobic’ composting; and vice-versa. Some composting processes, such as composting pits being practiced in China, are aerobic at first and become anaerobic during the later stages of the composting period (Polprasert, 1996).

2.3.2 Anaerobic composting process

The anaerobic digestion of organic material is biochemically a very complicated process, involving hundreds of possible intermediate compounds and reactions, each of which is catalyzed by specific enzymes or catalysts. However, the overall chemical reaction is often simplified to:

$$\text{Organic Matter} \xrightarrow{\text{Anaerobic bacteria}} CO_2 + H_2S + NH_3 + CH_4 + H_2$$

Putrefactive breakdown of organic material takes place anaerobically. Anaerobic living organisms in metabolizing nutrients break down the organic compounds by a process of reduction. As in aerobic process, the organisms use nitrogen, phosphorus, and other nutrients in developing cell protoplasm, but reduction the organic nitrogen to organic acids and ammonia. The carbon from the organics compounds which is not utilized in the cell protien is liberated mainly in the reduced from of methane, CH_4. A small portion of carbon may be respired as CO_2.

This process takes place in nature as in the decomposition of the organic muds at the bottom of marshes and in buried organic material to which oxygen does not have access. The marsh gas which rises is largely CH_4. Intensive reduction of organic matter by putrefaction is usually accompanied by disagreeable odours of hydrogen sulfide and of reduced organic compounds which contain sulfur, such as mercaptans.

Since anaerobic destruction of organic matter is a reduction process, the final product, humus, is subject to some aerobic oxidation when put on the soil. The oxidation is minor, takes place rapidly, and is of no consequence in the utilization of the material on the soil. Figure 2-1 illustrates the cycles of carbon and nitrogen in the anaerobic process of decomposition.

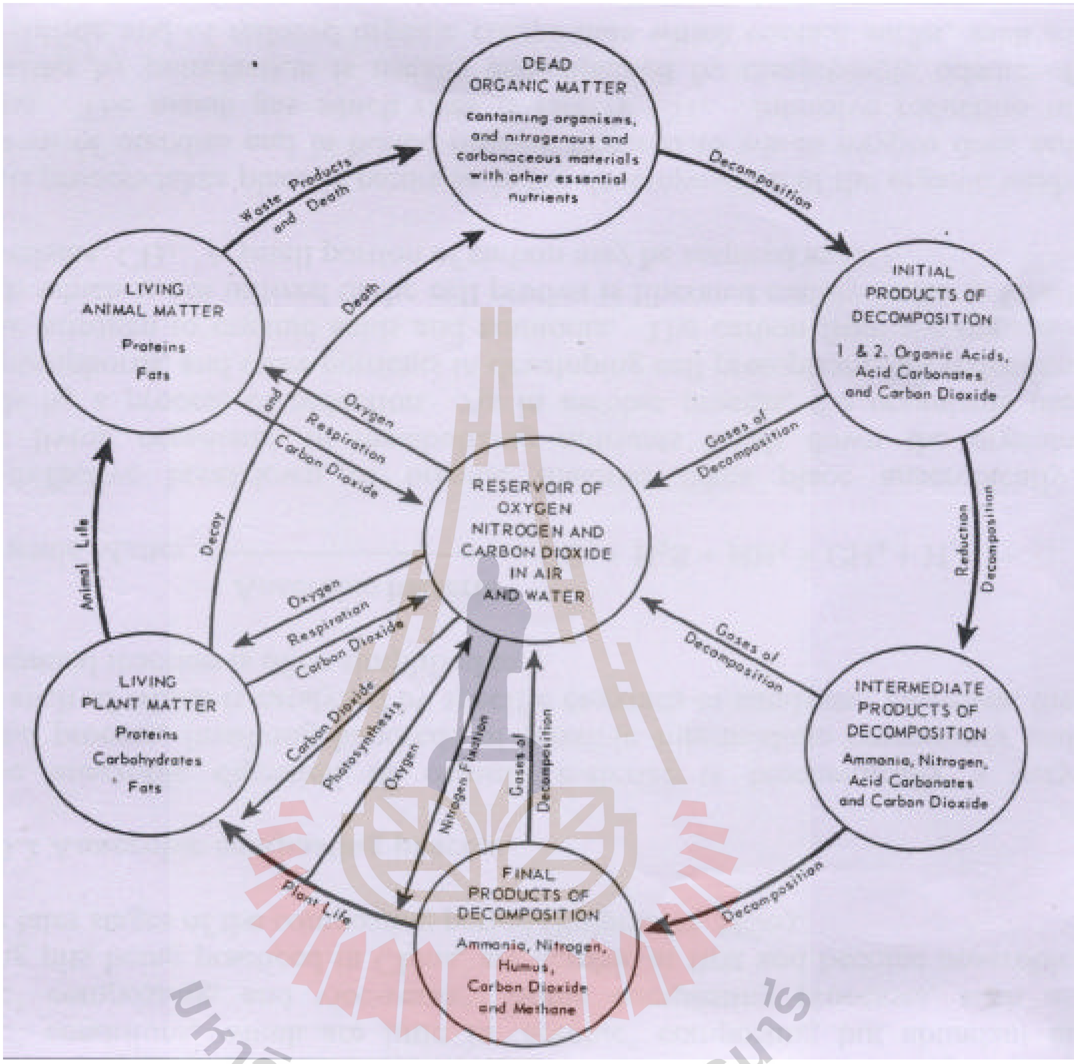


Figure 2-1. Cycle of nitrogen and carbon in anaerobic decomposition (Source: Gotass, 1956).

According to Polprasert (1996), in general, anaerobic digestion is considered to occur in the following stages:

1) liquefaction or polymer breakdown;
2) acid formation; and
3) methane formation

Stage 1: Liquefaction

In this stage these organic polymers are broken down by extracellular enzymes produced by hydrolytic bacteria, and dissolved in water. The simple, soluble, organic components (or monomers) which are formed are easily available to any acid-producing bacteria. It is difficult to distinguish this stage form what is known as stage 2 (acid- formation stage), because some molecules will be absorbed without further breakdown and can be degraded internally.

Stage 2: Acid formation

The monomeric components released by the hydrolytic breakdown due to bacterial action in stage 1 are further converted to acetic acid (acetates), H_2 and CO_2 by the acidogenic bacteria. Volatile fatty acids are produced as the end- products of bacterial metabolism of protein, fat, and carbohydrate; in which acetic, propionic, and lactic acids are the major products. Carbon dioxide and hydrogen gas is also liberated during carbohydrate catabolism, with methanol, and other simple alcohols, being other possible by- products of carbohydrate breakdown. The proportion of these different substrates produced depends on the flora present, as well as on the environmental condition.

Stage 3: Methane formation

The products of stage 2 are finally converted to CH_4 and other end- products by a group of bacteria called methanogens. Methanogenic bacteria are obligate anaerobes whose growth rate is generally slower than the bacteria in stages 1 and 2.

The methanogenic bacteria use acetic acid, or carbon dioxide and hydrogen gas to produce methane. Acetic acid or acetate is the single most important substrate for methane formation, which approximately 70 percent of the methane produced form acetic acid. The remaining methane comes form carbon dioxide and hydrogen. A few other substrates can also be used, such as formic acid, but these are not important, as they are not usually present in anaerobic fermentation. The methanogenic bacteria are also dependent on the stage 1 and stage 2 bacteria to provide nutrients in a usable form.

2.3.3 Microbiology of anaerobic digesters

The metabolic stages involved in the production of methane from wastes as shown in Figure 2-2 are hydrolysis, acidogenesis, acetogenesis and methanogenesis (Bryant, 1979; Kirsop 1984). Schemes for the metabolic conversions in methanogenesis are extremely complicated but even so are not yet a complete description of the process. Often the complexity only serves to hide the essential features. Nevertheless, in terms of the controlling reactions in anaerobic digestion the scheme in Figure 2-2 can be simplified further to become a balance between the production and removal of electrons (e.g. as H_2 or formate) and H^+.

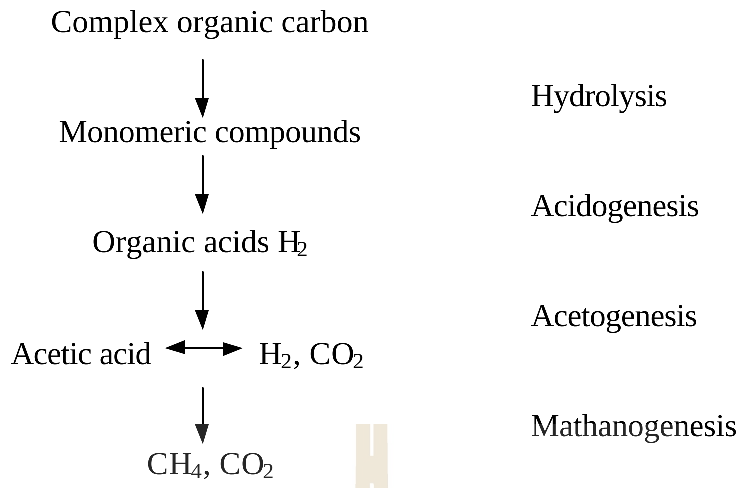


Figure 2-2. Metabolic stages in the anaerobic digestion of wastes. (Source: Wheatley, 1991)

Presently, a general pattern accounting for the formation of methane by anaerobic fermentation, applicable to all methanogenic environments, has been established (Figure 2-3). Some modifications of this scheme must be done. For example, when considering the rumen where volatile fatty acids are mainly absorbed through the intestine wall and not converted to methane. On other hand, in underwater sediments, methane oxidation can occur (Bruce et al, 1986).

According to Bruce et al (1986), the current scheme represents a three-stage process in which three groups of bacteria are involved.

These three groups are:

a) Hydrolytic and acidogenic bacteria,
b) Acetogenic bacteria,
c) Methanogenic bacteria

As it can been seen, the three groups of bacteria include a great variety of microorganisms. This diversity reflects the great number of substrates and intermediary metabolites involved. The main impediment in this field arises from the difficulty encountered in assessing the in vivo importance of the different groups of bacteria (Hobson et al, 1974; Bryant, 1979; Siebert et al, 1968). It is also difficult to establish the actual importance of the biological interactions developed between the different population. However, a general sketch of metabolic pathways and bacterial groups implicated in anaerobic digestion has been proposed as shown in Figure 2-4.

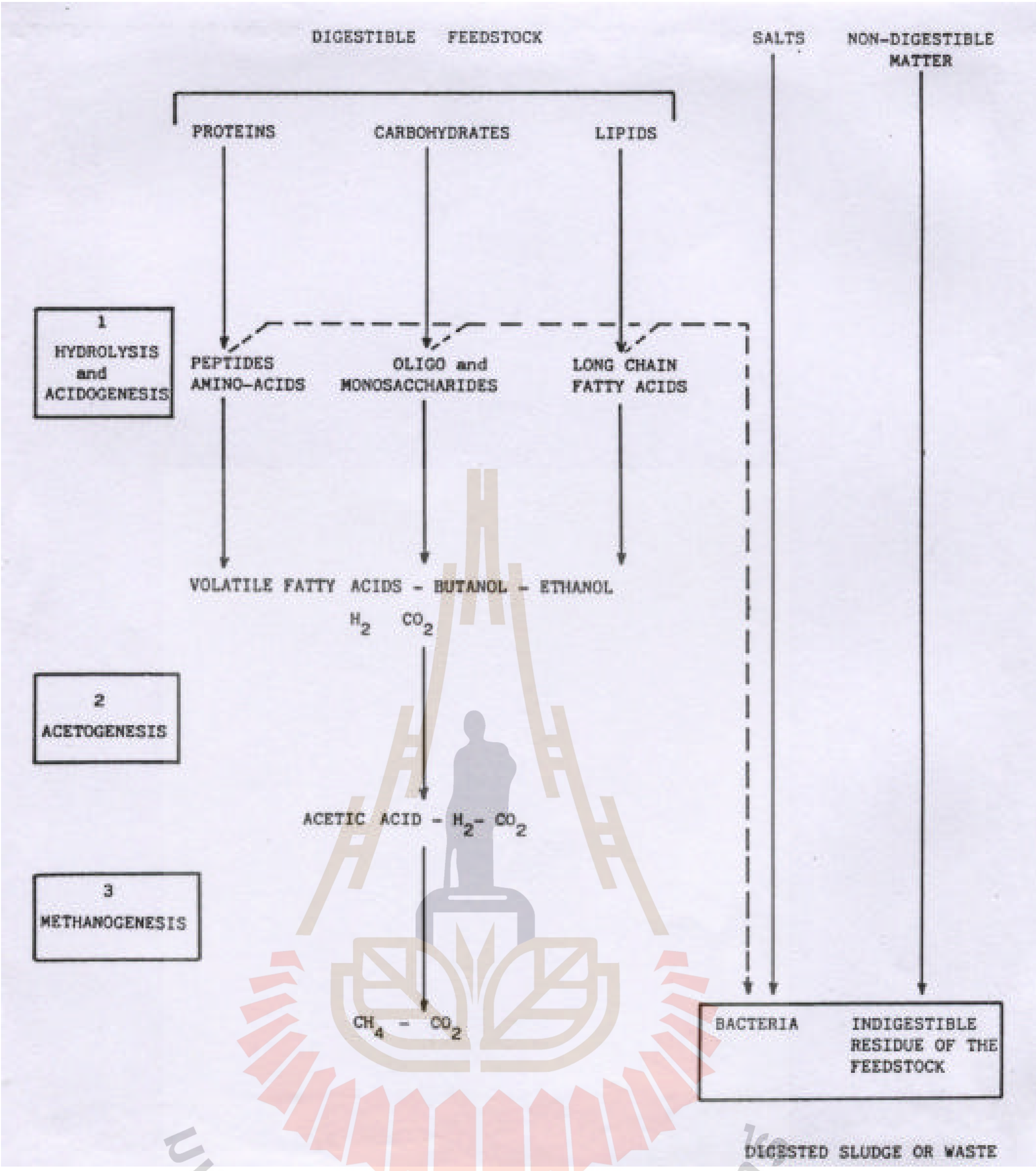


Figure 2-3. General scheme of anaerobic digestion.
(Source: Bruce et al,1986)

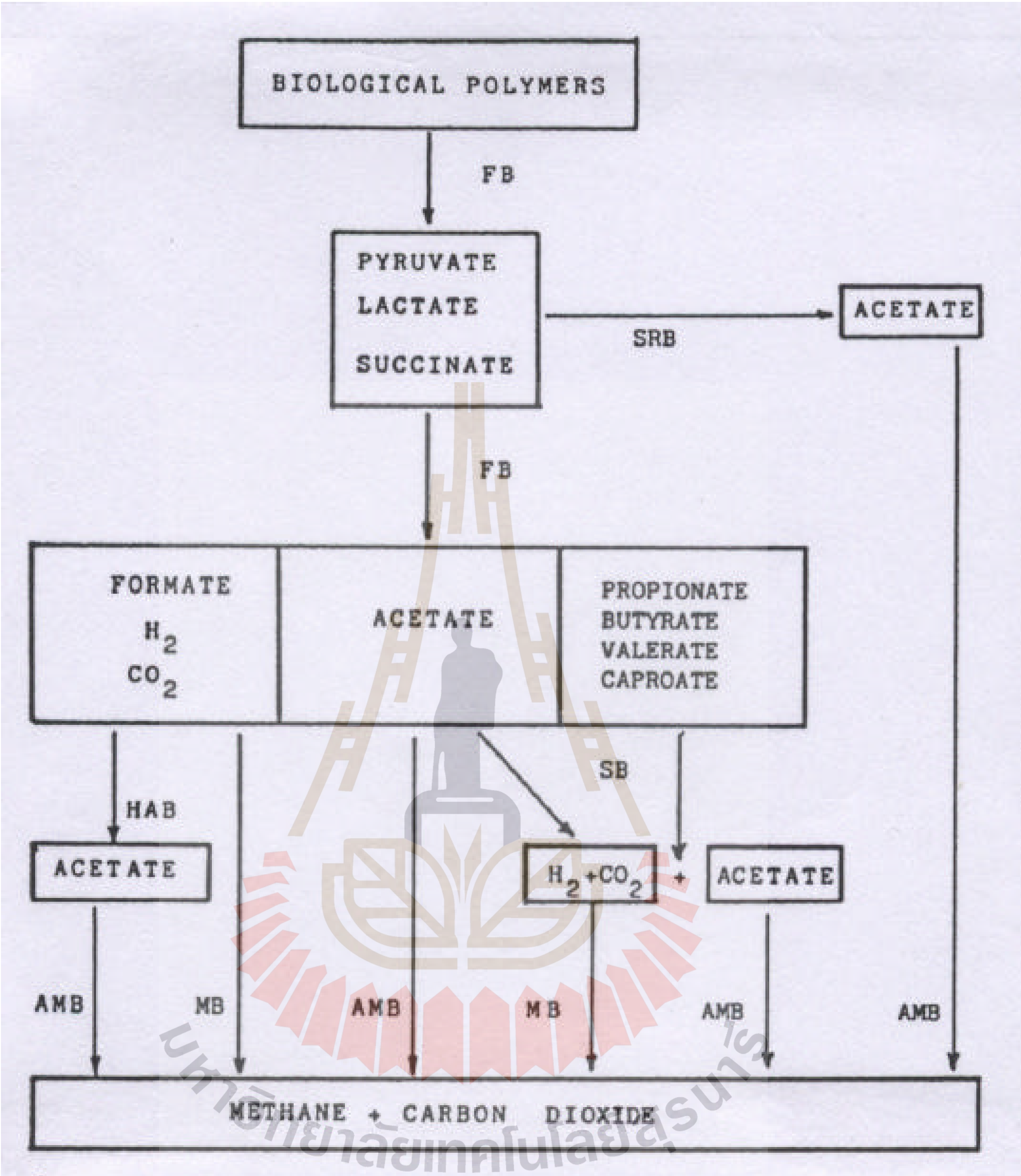


Figure 2-4. Scheme of main pathways in anaerobic digestion (Bruce et al, 1986).

FB : fermentative bacteria
SB : syntrophic bacteria
SRB : sulfate reducing bacteria
AMB : acetophilic methanogenic bacteria
HAB : homoacetogenic bacteria
MB : methanogenic bacteria

The greatest components of non-hazardous community waste are high molecular weight polymers, e.g. cellulose. For the bacteria to ferment these feedstocks, they must be hydrolyzed to subunits that can be absorbed into the bacterial cells. Extracellular enzymes excreted by the hydrolytic bacteria accomplish hydrolysis. An extremely close association of the bacteria with the cellulose to efficiently accomplish hydrolysis and retain the hydrolysis products for absorption is required. Once absorbed, subunits are fermented to simpler compounds, e.g. fatty acids and alcohols, and excreted. A second group, transitional bacteria, absorbs these compounds and converts them to hydrogen, carbon dioxide and acetic acid, their excretion products. Finally, methanogenic bacteria, utilizing these products, generate methane and carbon dioxide as end products of their metabolism.

2.3.4 Conditions for anaerobic composting

Appropriate cultures of microorganisms can easily be obtained from an operating anaerobic digester at a wastewater treatment plant for seeding a new digester. All of the required organisms are there but concentrations of individual functional groups will require adaptation to the new community waste feedstock and operating conditions in the digester. For example, sewage sludge is low in total solids and cellulose but high in nitrogen, a low in nitrogen, with relatively high total solids. Thus, a period of adjustment period is over, the microbial population is quite resilient to minor shocks.

2.3.5 Anaerobic digesters classified

The application of the various digestion systems is discussed below

a) Batch digester systems. A batch reactor is filled completely with organic matter and seed inoculum, sealed, and the process of decomposition is allowed to proceed for a long time until gas production is decreased to a low rate. Then it is unloaded, leaving 10 – 20 percent as seed, then reloaded and the operation continues.

b) Accumulation systems. Unlike the batch-system the accumulation system is continuously fed and characterized by an increasing effective reactor volume in time. The reactor is, like the batch-system, emptied in one go. The accumulation system actually is the simplest system for on-farm application of slurry digestion.

c) Plug flow. The plug flow system is continuously fed and the feed passes through the reactor in a horizontal direction. No mixing is provided. All slurry remains in the reactor for the full detention time. A plug flow system provides a constant gas production at a constant loading rate.

d) Continuous Stirred Tank Reactor (CSTR). A CSTR system is characterized by a continuous feeding rate and a complete mixture of bacteria and substrate. Bacteria and substrates consequently have an equal detention time. At a constant loading rate, a constant gas production rate is provided.

2.3.6 Environmental requirements

a) Particle size. Most materials that comprise the organic fraction of solid waste tend to be irregular in shape. This irregularity can be reduced substantially by shredding the organic materials before they are composted. Particle size influences the bulk density. Howichit (1986) proposed the most desirable particle size for composting is between 2.5 to 7.5 cm. JICA (1982) mentioned the appropriate size as 0.5 to 1.5 inch. The significance of particle size is in the amount of surface area of the waste particles exposed to microbial attack, rate of bacterial attack is in part a function of the ratio of surface area to mass. The higher the ratio, the faster the rate of decomposition (Diaz et al, 1993). Tantipisarnkul et al (1990) studied the composting with water hyacinth. They found the increase in the reaction rate depends on the size of water hyacinth. The finely grinded one can increase the decomposition rate to 60 percent in 7 to 10 days, and in 14 days if size of about 2 to 3 cm.

b) Carbon-Nitrogen ratio. Nitrogen, N is utilized for cell structure. To guarantee normal biogas production it is important to mix the raw materials in accordance with a proper C/N ratio. Bacteria use up carbon, C 25 – 30 times faster than they use nitrogen (Polprasert, 1996). The carbon to nitrogen (C/N) ratio in a substrate is important because high nitrogen levels with low C/N ratio can cause toxicity, and high C/N ratio can inhibit the rate of digestion. Meynell (1976), National Academy of Sciences (1977), UNEP (1981) present the C/N ratios of various feeds and state categorically that a C/N ratio of 30:1 is optimal. Gotaas (1956) reported the initial carbon to nitrogen ratio of 30/1 is optimum for composting. If this value is higher, then the bacteria use there is more carbon.

c) Moisture content. Moisture is important for the growth of bacteria rate on surface of compost pile. Moisture can be adjusted by blending of components or by addition of water. When the moisture content of compost falls, the rate of composting will be slowed. According to JICA (1982), the optimum moisture content between is 50 to 60 percent. Leemaharoungrung (1988) reported that the optimum moisture content between 45 to 57 percent is appropriate to decomposition rate of bacteria.

d) Temperature. The rate of methane production increases as the temperature increases, but there is a distinct break in the rise at about 45 ^{o}C. Below 10 ^{o}C gas production decreases drastically; there fore operation below this level is not recommended due to the limited amount of gas production. Hassan et al. (1975) concluded that 35 ^{o}C was the optimum temperature for mesophilic. Havang et al. (1981) claimed that 55 ^{o}C - 60 ^{o}C were the optimum temperatures for thermophilic. The optimum temperature in decomposition by

Eumycetes and Actinomycetes are between 45 °C to 55 °C which is suitable for long-chain polymer decomposition such as cellulose and lignin (Chang and Hudson, 1967).

e) pH and alkalinity. Generally, the pH in anaerobic digesters is considered to be in the range of 6.6 to 7.6, with the optimum rang being 7 – 7.2 (Polprasert, 1996). Although acid-forming bacteria can tolerate a pH as low as 5.5, the methanogenic bacteria are inhibited at such low pH values. The pH of a digester may drop to below 6.6 if there is an excessive accumulation of volatile fatty acids. Such an accumulation may occur when the organic loading rates are excessively high and/ or when toxic materials are present in the digester, all producing inhibitory effects to the methanogenic bacteria. Fungi can growth in the pH range of 5.5 to 8.0. Bertoldi et al (1996), studied the optimum pH in composting process in the pH range of 5.5 to 8.0. At the beginning, the pH was decreased because of acidogenic bacterial action.

2.4 Composting substrates

Municipal solid waste is all of the wastes arising from human activities that are normally solid and discarded as useless or unwanted. Paper, wood, food, and yard wastes are major components of the municipal solid waste stream and are suitable composting substrates. As a result, composting as a management option for municipal solid waste has been pursued for many decades (Haug, 1993).

2.4.1 Biodegradable organic fraction of solid waste (except food wastes)

Municipal solid waste is all of the wastes arising from human activities that are normally solid and discarded as useless or unwanted. Biodegradable organic fraction of solid waste is the part of municipal solid waste, such as, paper, cardboard, plastic, textiles, rubber, leather, yard waste, wood, and vegetable etc.

2.4.2 Food wastes

As the food waste portion of the solid wastes is suitable for recycling (e.g. through composting), it should ideally be stored and collected separately for this purpose. However, for convenient and practical reasons the food waste is normally collected together with other kinds of waste to be processed and treated at a solid waste treatment plant. If composting is to be employed as a means to stabilize and produce fertilizer from the solid wastes, several methods of solid waste processing have to be utilized to separate out the food waste (Polprasert, 1996).

A variety of wastes from the food processing are suitable substrates for composting. In general, if it is out of the ground, vegetative or animal in nature, and not contaminated, it can be composted. The literature contains examples of a large assortment of food wastes that have been composted, such as:

- orange and citrus culls
- fish wastes including lobster shells, crab scraps (the shells and viscera), scallop viscera, whole fish, and fish scraps
- cranberry and prune waste
- garbage wasted from food preparation

The above list is by no means complete but it does highlight the wide variety of vegetable wastes that can be converted into useful composts.

2.4.3 Septage

Septage produced by a person on daily basis varies in volume, weight, moisture content and chemical composition, depending on his/her dietary habits, metabolism, as well as climatic conditions and other personal factors like health and psychological state. For this reason, any previous attempt to establish the mean values is justified only for specific purpose.

Septage can contain highly potential infective pathogens, of which the most important are Schistosoma and Ascaris eggs. Therefore, efficient disposal of septage involves primarily destroying these disease-causing parasite eggs in their early surviving days. Septage is often low in volatile solids as much as 90 to 98% water. Nevertheless, William et al (1990) reported successful composting of septage which was dewatered and conditioned with wood shavings. Volatile solids content of the septage solids was only 27 to 30 % and the wood shavings supplied additional organics to the process. Nitrogen addition in the form of urea was required to enhance decomposition of the wood shavings and to increase the generation of heat.

2.4.5 Hay

Hay is a green forage crop harvested for livestock feed and stored at low moisture levels so no special storage structures or preservatives are required. High-quality hay can have nutrient levels nearly equivalent to many concentrates. Hay is one of the least expensive sources of protein.

2.5 Past studies

According to Gotaas (1956), there appears to be considerable interest in composting as an economical method for the disposal and reclamation of organic wastes in many parts of the world. During the period that the early composting practices were being refined in India, China, Malaya, and elsewhere, other investigators, notably in Europe, were devoting considerable effort to mechanizing the composting process, particularly for use as a method for the treatment and sanitary disposal of the garbage and refuse from cities. These efforts resulted in various mechanical innovations, usually with the objectives of improving the aesthetics of the process by enclosing the material in some type of structure, of speeding it up, and of making it more economical. There has been little new information on the use of anaerobic digestion of garbage, refuse, and night-soil in piles since the development of the Beccari process. There may be less tendency to lose nitrogen in anaerobic composting because of the lower temperatures, but the problems of odor nuisance, fly-breeding, and poorer destruction of pathogens are important disadvantages of anaerobic composting in piles.

Sakulpram et al, (1979) conducted anaerobic digestion of solid wastes in batch loading experiments with the seeding of organisms. The different kinds of animal manure, water-hyacinth, and grass were used as feeding materials to produce biogas. Six bricks digester boxes were constructed, each with the size 0.42 x 0.42 x 0.50m. Each box was fitted with gas holders of size 0.40 x 0.40 x 0.15m. The composting was completed within 21 days at temperatures 26.5-28.5 °C.

According to Rabbani et al (1983), there is little information on the bacterial species active in anaerobic composting, although several investigations concerning the bacteria involved in anaerobic digestion of sewage sludge have been made. Probably, more species of bacteria are involved in the aerobic process than in the anaerobic one. Many of the same organisms are, no doubt, as active in anaerobic composting as in sludge digestion. However, since the environment of anaerobic compost stacks differ greatly from that of sludge digestion tanks, especially in terms of moisture and nutritional materials, the biological population would also be expected to differ.

Derikx et al, (1990) carried out a study on the biomass and biological activity during the production of compost used as a substrate in mushroom cultivation. In their experiments, the maximum temperature was found to be 80°C. Although it was aerobic static pile composting process, they reported that, considerable concentrations of methane were present in the air evolving from the composting material, indicating the presence of anaerobic microenvironments. It was calculated that at least 3.5% of the loss of dry matter was achieved by anaerobic breakdown. In all composting processes, the aerobic and/or anaerobic breakdown of solid organic matter by microorganisms was the crucial step.

Six et al, (1992) conducted a study on dry anaerobic conversion of municipal solid waste by means of the Dranco process. The Dranco process had been developed for the conversion of organic waste, specifically the organic fraction of municipal solid waste, to energy and a humus-like final product, called Humotex. In their experiments, the operating temperature in the digester was 55°C and the total solids concentration was 32%. The final product was dewatered and further stabilized in a 10 day aerobic post-treatment. Humotex had a C/N ratio of less than 15, which indicated that it is stable. In a comparative study, faecal coliforms could not be detected in Humotex, whereas the original fraction contained $3x10^3$ CFU/g DW and a conventional aerobic compost produced in windrows from the same original substrate stll counted $2x10^2$ CFU/g DW.

Gorecki et al, (1993) studied anaerobic treatment of the centrifuged solid fraction of piggery wastewater in an inclined plug flow reactor. In there paper, they reported that many data are available on piggery manure composting. However, the results showed that, in spite of the good characteristics of the final product as a soil conditioner, the process presented high investment and management costs and relevant environmental impact problems.

Han et al, (1997) conducted laboratory studies on the temperature-phased anaerobic digestion of domestic primary sludge. In their experiments, two-stage treatment methods combining short retention time thermophilic step and longer retention time mesophilic step were known to provide both pathogen control and effective organic matter treatment. Similarly, anaerobic thermophilic and anaerobic mesophilic two-stage treatment was able to provide improved treatment of waste sludge in terms of VS reduction and gas production compared to the single stage mesophilic treatment.

Smet et al, (1999) investigated the emission of volatile compounds during the aerobic and the combined anaerobic/aerobic composting of biowaste. In their experiments, the combined anaerobic/aerobic composting process could be considered as an attractive alternative for aerobic biowaste composting. In order to reduce the size and volume of solid waste to be disposed off, composting of the biodegradable fraction of the household waste, being 50-60% of the total mass, became a widely accepted technique in recent years. A new biowaste composting technology was the combined anaerobic/aerobic composting process. In Belgium, only one biowaste composting plant was working according to this technique up to now. In this plant, an intensive thermophilic (55-50 °C) solid state fermentation (phase I) takes place in a vertical reactor with a biowaste retention time of 3 weeks and a biogas production of ± $100 m^3 ton^{-1}$ biowaste. As a result of the closed fermentor design, all volatiles emitted during phase I were collected in the biogas. On-site, part of this biogas in converted into steam for process heating (7%), while the remaining gas was converted into electricity upon burning in an electricity generator. After digestion (phase I), the residue was dewatered in a press and the press cake is aerated during a 2-week period (phase II). With regard to the emission of volatiles, however, no data were found for this combined anaerobic/aerobic composting process.

Pagilla et al, (2000) carried out a study on aerobic thermophilic and anaerobic mesophilic treatment of swine waste. In their experiments, aerobic thermophilic reactor was operating at 60°C and anaerobic mesophilic digestion at 37°C. Municipal waste sludge processing by aerobic thermophilic treatment at 1-day retention time followed by 14-day retention time anaerobic mesophilic treatment was successful in reducing pathogens and vector attraction potential to levels that allow unrestricted reuse of the processed solids. Furthermore, both volatile solids (VS) reduction and methane gas production were much higher in the two-stage thermophilic-mesophilic system than those in the control single stage anaerobic mesophilic digester, both operating at the same overall retention time. A two-stage digestion process was better than a single stage process because the two-stage separates faster acidogenesis reactions in the first stage from the slower methanogenesis reactions in the second stage. Such kinetic separation of different steps in anaerobic digestion enhances the overall process by enhancing the individual steps.

Alvarez et al, (2000) presented a review on anaerobic digestion of organic solid wastes. In this review, special attention was paied to the advantages of anaerobic digestion in limiting the emission of greenhouse gases. Few fundamental studies look at different aspects of the anaerobic digestion of the solid waste. However, it was also concluded that aerobic digestion effluents were not generally suitable for putting directly onto land. They are too wet, contain a notable amount of volatile fatty acids which are somewhat phytotoxic and, if digestion has not occurred within the thermophilic range of temperatures, are not hygienised. Thus, it is generally accepted that post-treatment after anaerobic digestion is needed to obtan a high-quality, finished product.

CHAPTER III

MATERIAL AND METHODOLOGY

3.1 Experiment site

The experimental site for this study was set up at a location in Suranaree Military Camp in Nakhon Ratchasima, about 15 km from the Suranaree University of Technology (SUT). The location of the site is shown in Figure 3-1.

3.2 Experimental set-up

Eight bricks digesters, each with the size of 1.0 x 0.5 x 0.5 m, (as shown in Figure 3-2), were used in this study. Four digesters were for composting of food waste mixed with hay, and the other four were for composting of organic commingled waste (except food waste) mixed with septage. Gas outlets were provided in the lids of the digesters made with zinc (Figure 3-3). Each digester was provided with 0.02 m wide channel along the periphery, filled with water to provide a seal.

3.3 Solid waste samples preparation

The solid wastes were collected daily from Suranaree Military Camp in Nakhon Ratchasima and were separated manually into two catergories, (i) food-waste and (ii) organic commingled waste.

Food waste and organic commingled waste (except food waste) from Suranaree Military Camp were ground into the sizes 1 to 1.5 inch. Subsequently, they were mixed with hay and septage, respectively, in the proportions as shown in Table 3-1.

Table 3-1. Proportions of raw material of two waste combinations used for composting (wet weight basis).

Waste Combination C/N ratio 30 : 1	Ratio by volume (L : L)	Ratio by weight (kg : kg)
Hay : Food waste	161.22/63.78 = 1/0.40	12.58/59.95 = 1/4.77
Septage : Organic commingled Waste	27.92/197.08 = 1/7.06	27.50/43.36 = 1/1.58

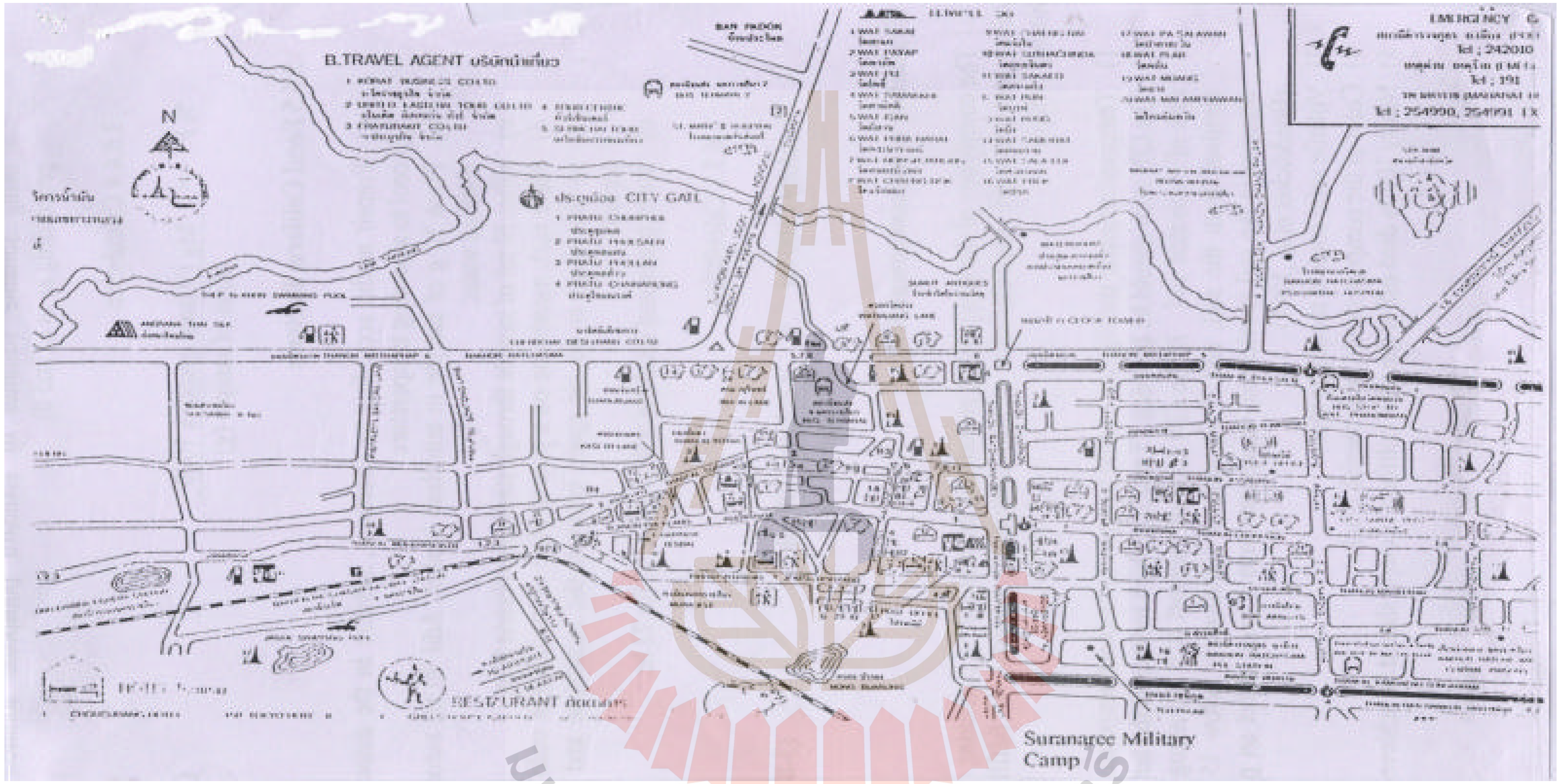


Figure 3-1. a). Nakhon Ratchasima map.

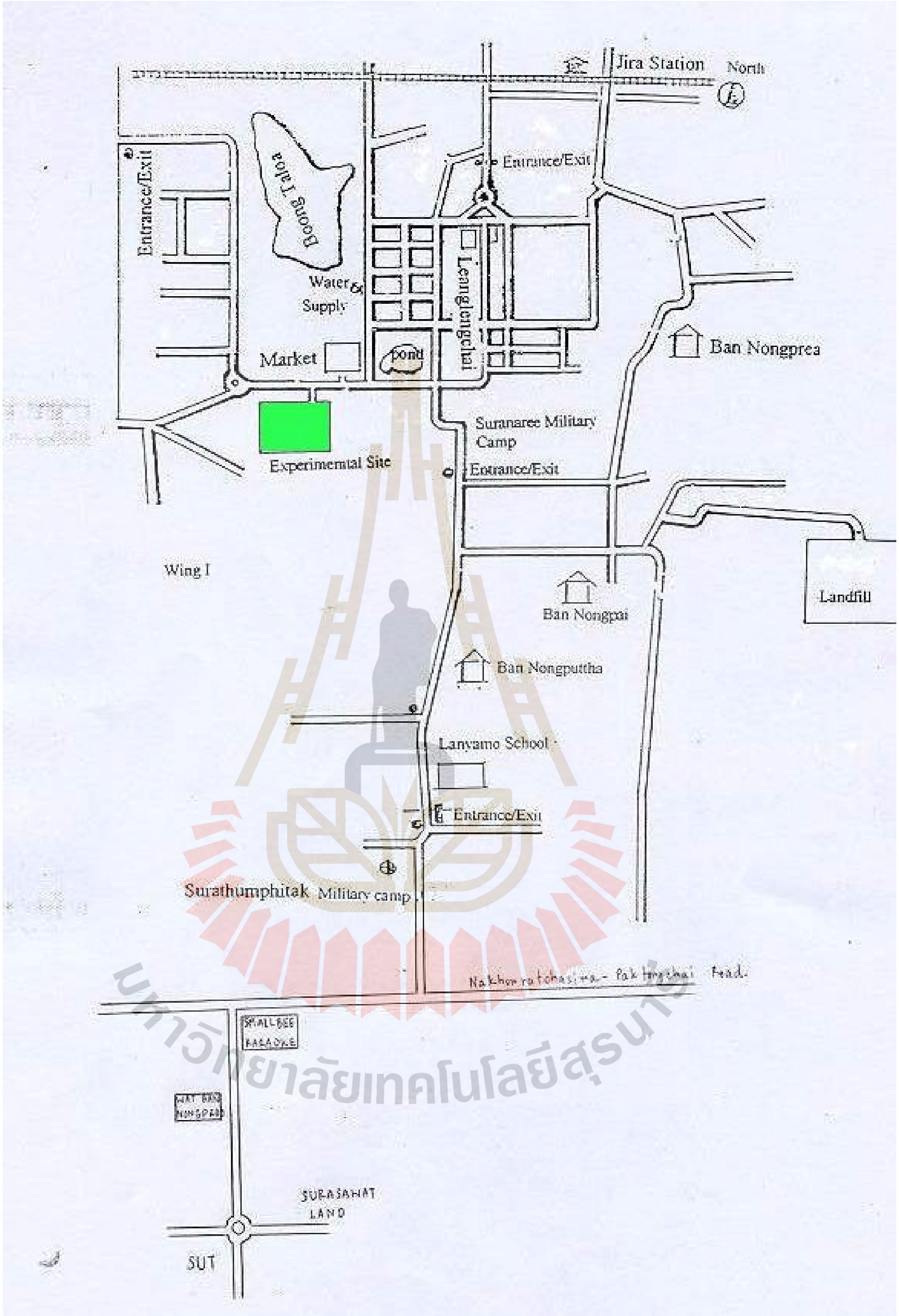


Figure 3-1. b). Suranaree Military Camp map-Experimental site.

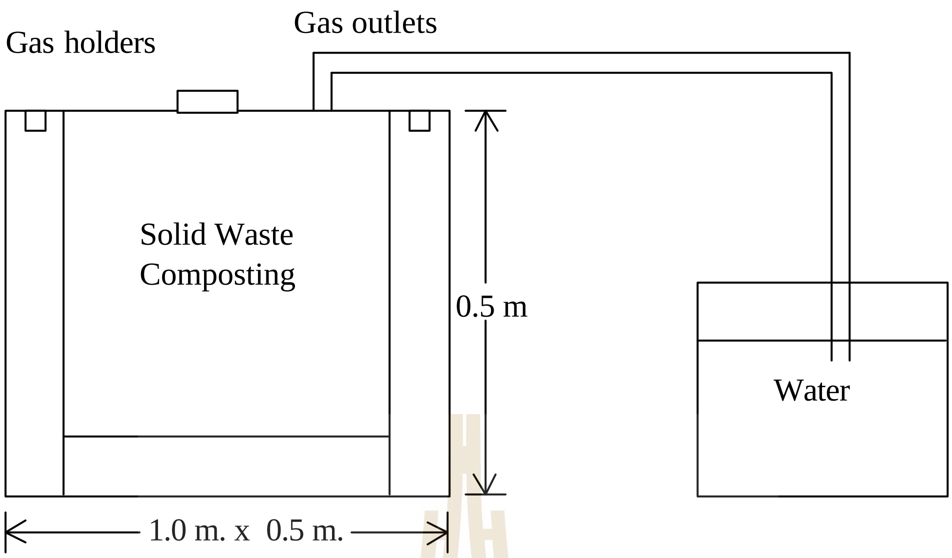
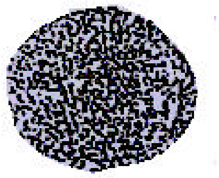


Figure 3-2. Schematic layout of the composting digester.

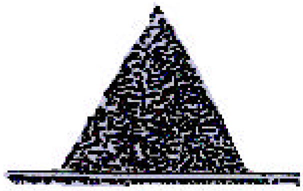
Figure 3-3. The front-view of the experimental setup.

The prepared samples were processed as follows (as shown in Figure 3-4):

1) Pile each sample up to 1.5 m. high
2) Remove the top 30 cm.
3) Mix the remaining of each pile together
4) Separate the mix into four parts and select one part for composting.

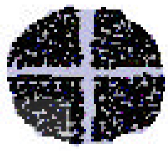


1) Mixing the solid waste.



2) To pile up into cone.

3) To cut the tapering spire part.



4) To divide in four parts.

Figure 3-4. Preparation of solid waste samples.

After preparing the waste materials of two categories (food waste and organic commingled waste) as above, the hay and septage were mixed in the proportions given in the Table 3-1. Subsequently, the two combinations, (food waste mixed with hay, and organic commingled waste mixed with septage) were loaded into 4 digesters each as shown in Figure 3-5. Finally, the lids of the digesters were closed.

Figure 3-5. Top view of the loaded digesters.

3.4 Plan of experimental runs

Four experimental runs, designated by Run I, Run II, Run III, and Run IV, respectively, were carried out during a period of 5 months and 17 days (26 November 2000 – 13 May 2001). As the process had to be anaerobic, once the digesters were loaded they could only be opened at the end of the run. However, it was also desired to follow the gradual change of various physical, chemical, and biological parameters of the composting material during the run. Therefore, the 4 runs were planed as described below.

After determining the initial parameters of the composting waste materials, all the 8 digesters, that were filled with two waste combinations (waste combination 1: food waste mixed with hay, and waste combination 2: organic commingled waste mixed with septage), were used for Run I. Thereafter, 2 digesters (one of each waste combination) were opened in succession at the intervals of 20, 40, 60, and 90 days, respectively. At these times, after determining the parameters of the waste materials that had been composted for various time periods during the Run I, each group of two opened digesters were refilled with the corresponding waste combinations for starting the Run II, Run III, and Run IV, respectively. Thus, the Run II, Run III, and the Run IV were started at different times after the parameters'analyses for the composted materials of the Run I were carried out at the intervals of 20, 40, and 60 days, respectively. However, for these 3 runs, the parameters were only analyzed at the beginning and at the end of the composting periods.

3.5 Sampling and analysis

In order to monitor the anaerobic composting process of the two waste combinations, ten physical, chemical, and biological parameters, as shown in Table 3-2, were determined on the waste samples at various times as described in the plan of experimental runs in section 3.4.

Table 3-2. Physical, chemical, and biological parameters and their analyses methods.

No.	Parameter	Method
1.	Temperature	Thermometer
2.	PH	pH meter
3.	Moisture content	80°C for 36 hr.
4.	Total Solid	103-105°C for 1 hr.
5.	Volatile Solid	550-650°C for 30 min.
6.	Carbon content	Calculation
7.	Total Kjehdahl nitrogen	Macro Kjehldahl Method
8.	C/N ratio	Calculation
9.	Total Phosphorus	Spectrophotometer
10.	Total Coliform bacteria	Membrane-filter Technique

3.6 Analytical methods

Various analytical methods used for the determination of physical, chemical, and biological parameters are described below (Carter, 1993):

3.6.1 Bulk Density

In addition to the above mentioned 10 parameters, the bulk densities of the 4 types of solid waste materials (food waste, organic commingled waste, hay, and septage) were determined as described below.

Bulk mass of material was packed in a given volume. This bulk density includes the pore space within the packing (Mohsenin, 1980). The samples were filled in a volumetric cylinder up to 1000 ml mark and samples weight were measured. Many replications of the tests were carried out to determine the average bulk density of each type of waste.

3.6.2 Moisture content, Solids content, Volatile solids, Ash content, and Carbon content

3.6.2.1 Apparatus

a) Evaporating dish of 100 ml capacity made of high-silica glass.
b) Muffle furnace for operation at 550 ± 50 °C
c) Dessiccator provided with a desiccant containing a color indicator of moisture concentration.
d) Drying oven, for operation at 103 to 105 °C
e) Analytical balance, capable of weighing up to 10 mg.

3.6.2.2 Procedure

a) Total Solids

i) Preparation of evaporating-when volatile solids are to be measured, ignite a clean evaporation dish at 550 ± 50°C for 1 hr in a muffle furnace. For total solids measurement, heat dish at 103 to 105°C for 1 hr in an oven. Cool in dessiccator, weigh, and store in dessiccator until ready for used.

ii) Pulverize the entire sample coarsely on a clean surface by hand, using rubber gloves. Place 25 to 50 g. in a prepared evaporating dish and weight. Place in an oven at 103 to 105°C overnight. Cool to balance temperature in an individual dessiccator containing fresh dessiccant and weigh.

b) Volatile solids: transfer to a cool muffle furnace, heat furnace to 550 ± 50 °C, and ignite for 30 min. If the sample contain large amounts of organic matter, first ignite the sample over a gas burner and under exhaust hood in the presence of adequate air to lessen losses due to reducing conditions and to avoid ordors in the laboratory. Cool in dessiccator to balance temperature and weigh.

3.6.2.3 Calculation

$$\% \text{ Moisture} = \frac{(W - D)}{W} \times 100 \qquad (3\text{-}1)$$

$$\% \text{ Total Solids} = \frac{(A - B)}{(C - D)} \times 100 \qquad (3\text{-}2)$$

$$\% \text{ Volatile Solids} = \frac{(A - E)}{(A - B)} \times 100 \qquad (3\text{-}3)$$

$$\% \text{ Ash} = 100 - \%VS \qquad (3\text{-}4)$$

$$\% \text{ Carbon} = \frac{100 - \% \text{ Ash}}{1.8} \qquad (3\text{-}5)$$

where:

W = initial sample weight, g.
D = sample weight after drying, g.
A = weight of dried residue + dish, g.
B = weight of dish, g.
C = weight of wet sample + dish, g.
E = weight of residue + dish after ignition, g.

3.6.3 Nitrogen content

3.6.3.1 Apparatus

a) Digestion: Digest over a heating device adjusted so that 250 ml water at an initial temperature of 25°C can be heat to a rolling bail in approximately 5 min. A heating device meeting this specification should provide the temperature rang of 365 to 370 °C for effective digestion.
b) Distillation: Arrange a borosilicate glass flask of 500 ml capacity attached to a vertical condenser so that the outlet tip may be submerged to at least 2 cm below the surface of the receiving acid solution. Use an all-borosilicate-glass apparatus or one with condensing units constructed of block tin or aluminium tubes.

3.6.3.2 Reagents

a) Digestion mixture: Dissolve 250 g Na_2SO_4, 2.5 g Se, and 2500 ml conc. H_2SO_4 in 5 L erlenmeyer flask
b) Boric acid plus indicator: place 80g of boric acid (H_3BO_3) into 3800 ml of H_2O and stir. Once wet, the H_3BO_3 dissolves readily. Add 80 ml of mixed indicator prepared as follows: 0.099 g bromcresol green and 0.066 g methyl red dissolved in 100ml

ethanol. Add 0.1 M NaOH cautiously until the solution turns reddish-purple (pH 4.8 – 5.0). Make up to 4 L with deionized H_2O and mix thoroughly.

c) Sodium hydroxide 10 N: prepared in CO_2-free deionized water.
d) H_2SO_4: 0.01 M (standardized).

3.6.3.3 Procedure

a) Place 1 – 3 g of sample in a dry digestion tube.
b) Add 5 ml of digestion mixture and swirl to wet all the soil.
c) Place the digestion tubes into the digestion block.
d) After digestion is complete, add 75 ml of 10 N NaOH in sample.
e) Place a 125 ml Erlenmeyer flask with H_3BO_3 under the condenser so that the tip of the condenser is immersed in the H_3BO_3 and distillation. Collect 25 ml of distillate.
f) Titrate the distillate with 0.025 N H_2SO_4. The color change at the end point is from green to pink.

3.6.3.4 Calculation

1 ml of 0.025 N H_2SO_4 is equivqlent to 0.28 mg of N.

$$\text{Total N (\%)} = \frac{\text{ml (Sample – Blank) x M x 2.8}}{\text{Mass of sample (g)}} \qquad (3\text{-}6)$$

Where: M = concentration of H_2SO_4 (ml).

3.6.4 Phosphorus Content

3.6.4.1 Apparatus

Spectrophotometer, for use at 440 nm.

3.6.4.2 Reagents

a) acid mixture: Dissolve conc. HNO_3:conc H_2SO_4:conc. $HClO_4$ ratio at 5:1:2
b) ammonium molybdate solution 5%: Dissolved 25 g of ammonium molybdate in 500 ml distilled water.
c) ammonium metavanadate solution 0.25%: Dissolved 1.25 g of ammonium metavanadate by heating to boiling in 500 ml distilled water.
d) Standard phosphate solution: Dissolved KH_2PO_4 in 1 L distilled water.

3.6.4.3 Procedure

a) Place sample 0.4 g in erlenmeyer flask. Add 10 ml of acid mixture and digest in digestion apparatus.
b) Make up to 50 ml with distilled water, mix thoroughly, and centrifuge the suspension.
c) Place 5 ml of sample in volumetric flask. Add 1 ml of ammonium molybdate and ammonium metavanadate, 2 ml of distilled water.
d) After 20 min, measure absorbance of sample versus a blank at a wavelength of 440 nm.
e) Preparation of calibration curve: Prepare a calibration curve by using suitable volumes of standard phosphate solution and proceeding as in c) and d).

3.6.4.4 Calculation

$$\% P = \frac{\text{Mg P (from graph) x 1000}}{\text{Mass of sample (g)}} \quad (3\text{-}7)$$

3.6.5 Fecal Coliform Bacteria

a) Prepair media according to directions, sterilize in the autoclave, cool to a pouring temperature
b) Place 10 g of sample in autoclave beaker. Add 90 ml autoclave distilled water.
c) Filter 10 ml of sample through sterile membrane filter.
d) Place each membrane on a poured plate of modified m endo agar so that there is no air space between the membrane and agar surface.
e) Invert plates and incubate at 41.5 ± 0.5 °C for 72 hr.

3.6.5.1 Calculation

$$\text{\# colony / 100 ml} = \frac{\text{\# colony / 100 ml}}{\text{Volume of water}} \quad (3\text{-}8)$$

3.7 Evaluation of process completion

The completion of the composting period was determined by examining some physical, chemical, and biological characteristics of the composted material to fulfill the following criteria:

1) Temperature inside the digester should be equal to ambient temperature.
2) The C/N ratio should be between 15 and 20, which represents the nutrient mix of cultivated soil. If the C/N ratio of compost is < 20, nitrogen is removed from the soil, and if the ratio is significantly below 15, the

nitrogen in the soil is released, which can have a toxic effect on plants (Boeddicker et al,1994).

3) Volatile solid content should be low.
4) Color of the compost should be brownish black.
5) Nearly 100 % died-off of the total coliform bacteria should be achieved.

Haug (1993) proposed some of the approaches to measure the degree of compost stabilization as follows:

1) Temperature decline at the end of batch composting;
2) Decrease in organic content of the compost as measured by the volatile solid (VS) content, percentage of carbon or ash content, and C/N ratio;
3) Lack of attraction of insects or development of insect larvae in the final product; and
4) Absence of obnoxious odor.

Further guidelines regarding the characteristics of an "Ideal Compost" as mentioned by Pos (1991) are:

1) The color should be dark brown to black, with little or no identifiable particles of the original raw materials.
2) The organic content should be at least 40-50 % on an oven dried basis (ODB)
3) The total nitrogen content should range between 1.0 – 3.5 %.
4) The compost may exhibit a slightly soil odor.

CHAPTER IV

RESULTS AND DISSCUSSION

The results of the eight simultaneous experiments in four runs conducted in eight digesters are presented in this chapter. Two different types of composting material were used in this study. Out of the eight digesters, four were filled with food waste mixed with hay (designated as waste combination 1), and the other four with organic commingled waste (except food waste) mixed with septage (designated as waste combination 2).

4.1 Solid waste composition in Suranaree Military Camp

Investigation of the solid waste generation rate and the various waste components was carried out on 3 separate days before starting each run between November 2000 to February 2001. Daily generation rate was obtained by the average load and the total number of collection trucks transporting and unloading the waste at the dumping site inside the Suranaree Military Camp, as shown in Table 4-1.

Table 4-1. The daily generation rate of solid waste inside the Suranaree Military Camp.

Run No.	Day	No. of trucks	Average load (kg)	Daily generation rate (kg)
1	1	9	377.07	3393.62
	2	10	382.73	3827.34
	3	11	453.88	4992.71
2	1	11	400.10	4401.13
	2	10	416.37	4163.72
	3	10	411.48	4114.84
3	1	10	380.69	3806.93
	2	9	410.55	3694.95
	3	9	427.83	3850.45
4	1	10	414.33	4143.3
	2	11	425.83	4684.1
	3	11	431.55	4747.1
Average				4151.68

Table 4-2. Solid waste composition in Suranaree Military Camp.

Characteristic	Quantity (Kg/day)												Average	(%)
	1	2	3	4	5	6	7	8	9	10	11	12		
Organic waste														
1. Food waste	240.87	590.36	706.73	330.56	451.23	861.02	623.28	578.90	654.82	421.38	512.21	695.53	555.57	13.38
2. Paper	23.95	38.74	46.18	28.31	20.22	34.29	38.98	45.12	28.54	38.29	15.40	29.65	32.31	0.78
3. Cardboard	20.51	0.00	11.89	21.36	15.32	3.98	18.23	17.84	9.58	14.00	58.00	18.75	17.46	0.42
4. Plastic	45.77	160.93	457.92	254.78	289.32	152.34	156.63	98.45	158.31	157.23	258.54	151.04	195.11	4.70
5. Textiles	56.33	20.54	261.08	87.45	125.46	247.23	146.90	54.17	59.20	145.23	105.30	98.71	117.30	2.83
6. Rubber	0.00	15.31	19.97	2.54	14.32	20.21	3.40	10.25	4.83	19.85	5.23	17.29	11.10	0.27
7. Leather	7.82	2.56	8.00	2.63	8.93	4.05	15.37	7.86	11.75	14.25	8.42	10.42	8.51	0.20
8. Yard waste	360.47	593.02	495.63	451.25	410.20	510.20	573.24	405.27	398.72	409.78	395.23	578.54	465.13	11.20
9. Wood	336.81	749.81	866.70	869.54	758.45	348.21	648.75	874.54	487.24	588.56	910.20	756.24	682.92	16.45
Total organic waste	1092.53	2171.27	2874.10	2048.42	2093.45	2181.53	2224.78	2092.40	1812.99	1808.57	2268.53	2356.17	2085.40	50.23
Inorganic waste														
1. Glass	264.33	364.18	297.85	354.87	125.87	257.39	347.25	198.54	258.24	312.54	403.50	283.71	289.02	6.96
2. Tin can	37.40	7.36	13.17	25.87	12.54	28.45	31.24	27.54	19.87	27.54	34.18	19.54	23.73	0.57
3. Aluminium	2.69	6.40	16.36	1.24	6.84	20.54	0.00	21.54	5.68	9.87	15.87	10.58	9.80	0.24
4. Other Metal	121.44	156.66	159.73	125.48	201.57	198.54	98.54	172.48	181.54	109.54	210.78	184.23	160.04	3.85
5. Dust, ashes, etc	1875.23	1121.47	1631.50	1845.25	1723.45	1428.39	1105.12	1182.45	1572.13	1875.24	1751.24	1892.87	1583.70	38.15
Total inorganic waste	2301.09	1656.07	2118.61	2352.71	2070.27	1933.31	1582.15	1602.55	2037.46	2334.73	2415.57	2390.93	2066.29	49.77
Total	3393.62	3827.34	4992.71	4401.13	4163.72	4114.84	3806.93	3694.95	3850.45	4143.30	4684.10	4747.10	4151.68	100.00

As shown in Table 4-1, the average daily generation rate at Suranaree Military Camp was 4,152 kg. On each observation day at the dumping site, waste components'analysis was performed by separating the various fractions and weighting them for individual truck loads, during 8 a.m. to 4 p.m. Table 4-2 shows the results of the observations made for determination of solid waste composition at the study area.

4.2 Physical, chemical, and biological characteristics

The initial physical and chemical characteristics of the four fractions of raw material composted are summarized in Table 4-3.

Table 4-3. The physical and chemical characteristics of raw material to be composted.

Raw Material	% TS	% TVS	% Moisture	% C	% N
Food waste	15.87	93.32	84.13	51.84	2.07
Hay	45.00	76.74	55.00	42.63	0.84
Organic commingled waste	54.87	93.97	45.13	51.87	1.51
Septage	18.06	65.71	81.94	36.51	2.30

The two waste combinations (food waste mixed with hay, and organic commingled waste mixed with septage) were prepared by mixing them in proportion as shown in Table 3-1. Subsequently, four experimental runs were conducted as described in section 3.4.

The results of eight experiments in four sequential runs, with the duration of 90 days in the first run and 100 days in other runs, are summarized in Table 4-4 and Table 4-5. During the first run, the C/N ratio of both combinations of composted materials reached at less than 20 in 90 days. The gradual changes in the 10 physical, chemical, and biological parameters during the four runs are shown in Table 4-6 and Table 4-7 for the two waste combinations, respectively.

4.2.1 Moisture content

As a prerequisite for successful composting, the moisture content of the waste was maintained in the range of 40-50 %. The variations in the moisture content during the first run are shown in Figure 4-1. For waste combination 1, the moisture content was 67.53 % at the beginning and decreased to 62.44 %, 50.34 %, 45.13 %, and 43.24 % after the intervals of 20, 40, 60, and 90 days, respectively. For waste combination 2, the moisture content was 72.03 % at the beginning and decreased to 66.94 %, 54.85 %, 49.82 %, and 45.64 % after the intervals of 20, 40, 60, and 90 days, respectively. As shown in Figure 4-1, the moisture content dropped about 20 % during the first 40 days and then decreased slightly. The food waste mixed with hay had a total loss in moisture content slightly less (24.3 %) than the organic commingled waste (except food waste) mixed with septage (26.4 %).

Table 4-4. Initial and final characteristics of the waste combination 1 (food waste mixed with hay during the four runs).

No.	Parameter	Run 1		Run 2		Run 3		Run 4	
		0 day 26/11/00	90 days 24/02/01	0 days 20/12/00	100 days 30/03/01	0 days 06/01/01	100 days 16/04/01	0 days 02/02/01	100 days 13/05/01
1	Temperature	27	30	27	31.5	28	32	28	29
2	pH	5.88	7.23	5.78	7.71	6.78	7.95	6.14	7.91
3	Moisture content (%)	67.53	43.24	61.49	46.16	54.04	48.69	59.81	47.21
4	Total Solid (% TS)	32.47	56.76	38.51	53.84	45.96	51.31	40.19	52.79
5	Volatile Solid (% TVS)	73.31	57.64	73.75	41.00	78.66	45.06	70.40	40.95
6	% C	40.73	32.02	40.97	22.78	43.70	25.03	39.11	22.75
7	TKN (% N)	1.34	1.73	1.37	1.63	1.48	1.69	1.25	1.45
8	C / N ratio	30.39	18.51	29.91	13.97	29.53	14.81	31.29	15.69
9	Total Phosphorus (% P)	0.13	0.22	0.14	0.20	0.15	0.20	0.13	0.21
10	Total Coliform bacteria (# cell / ml H_2O)	$1.37x10^6$	$3.31x10^2$	$1.31x10^6$	$2.34x10^3$	$2.11x10^6$	$4.07x10^3$	$1.52x10^6$	$1.87x10^3$

Table 4-5. Initial and final characteristics of the waste combination 2 (organic commingled waste mixed with septage during the four runs).

No.	Parameter	Run 1		Run 2		Run 3		Run 4	
		0 day 26/11/00	90 days 24/02/01	0 days 20/12/00	100 days 30/03/01	0 days 06/01/01	100 days 16/04/01	0 days 02/02/01	100 days 13/05/01
1	Temperature	27	30	27	31	27	31	27	28
2	pH	7.50	7.68	7.44	7.43	7.84	7.62	7.8	7.75
3	Moisture content (%)	72.03	45.64	67.56	56.44	61.7	46.02	65.48	48.53
4	Total Solid (% TS)	27.97	54.36	32.44	43.56	38.30	53.98	34.52	51.47
5	Volatile Solid (% TVS)	60.48	41.62	59.56	52.88	64.11	53.89	57.05	45.73
6	% C	33.60	23.12	33.09	29.38	35.62	29.94	31.69	25.41
7	TKN (% N)	1.08	1.62	1.15	1.73	1.19	1.7	1.09	1.53
8	C / N ratio	31.11	14.27	28.77	16.98	29.93	17.61	29.08	16.60
9	Total Phosphorus (% P)	0.08	0.20	0.12	0.22	0.10	0.23	0.07	0.20
10	Total Coliform bacteria (# cell / ml H_2O)	$1.63x10^8$	$2.67x10^2$	$1.85x10^8$	$3.36x10^2$	$1.25x10^8$	$2.87x10^2$	$1.50x10^8$	$2.42x10^2$

Table 4-6. The gradual changes in the 10 parameters of the food waste mixed with hay during the first run.

No.	Parameter	Run 1				
		0 day 26/11/00	20 day	40 day	60 day	90 days 24/02/01
1	Temperature	27	28	30	29	30
2	pH	5.88	4.47	4.32	5.94	7.23
3	Moisture content (%)	67.53	62.44	50.34	45.13	43.24
4	Total Solid (% TS)	32.47	37.56	49.66	54.87	56.76
5	Volatile Solid (% TVS)	73.31	69.80	64.76	60.03	57.64
6	% C	40.73	38.78	35.98	33.35	32.02
7	TKN (% N)	1.34	1.33	1.32	1.49	1.73
8	C / N ratio	30.39	29.16	27.26	22.38	18.51
9	Total Phosphorus (% P)	0.13	0.19	0.21	0.21	0.22
10	Total Coliform bacteria # cell / ml. H_2O)	1.37×10^6	2.67×10^5	2.45×10^5	2.06×10^3	3.31×10^2

Table 4-7. The gradual changes in the 10 parameters of the organic commingled waste mixed with septage during the first run.

No.	Parameter	Run 1				
		0 day 26/11/00	20 day	40 day	60 day	90 days 24/02/01
1	Temperature	27	30	29	30	30
2	pH	7.50	5.81	5.75	6.79	7.68
3	Moisture content (%)	72.03	66.94	54.85	49.82	45.64
4	Total Solid (% TS)	27.97	33.06	45.15	50.18	54.36
5	Volatile Solid (% TVS)	60.48	55.40	46.17	43.67	41.62
6	% C	33.60	30.78	25.65	24.26	23.12
7	TKN (% N)	1.08	1.18	1.04	1.41	1.62
8	C / N ratio	31.11	26.08	24.66	17.21	14.27
9	Total Phosphorus (% P)	0.08	0.15	0.19	0.19	0.20
10	Total Coliform bacteria # cell / ml. H_2O)	1.63×10^8	1.46×10^7	6.90×10^6	7.14×10^4	2.67×10^2

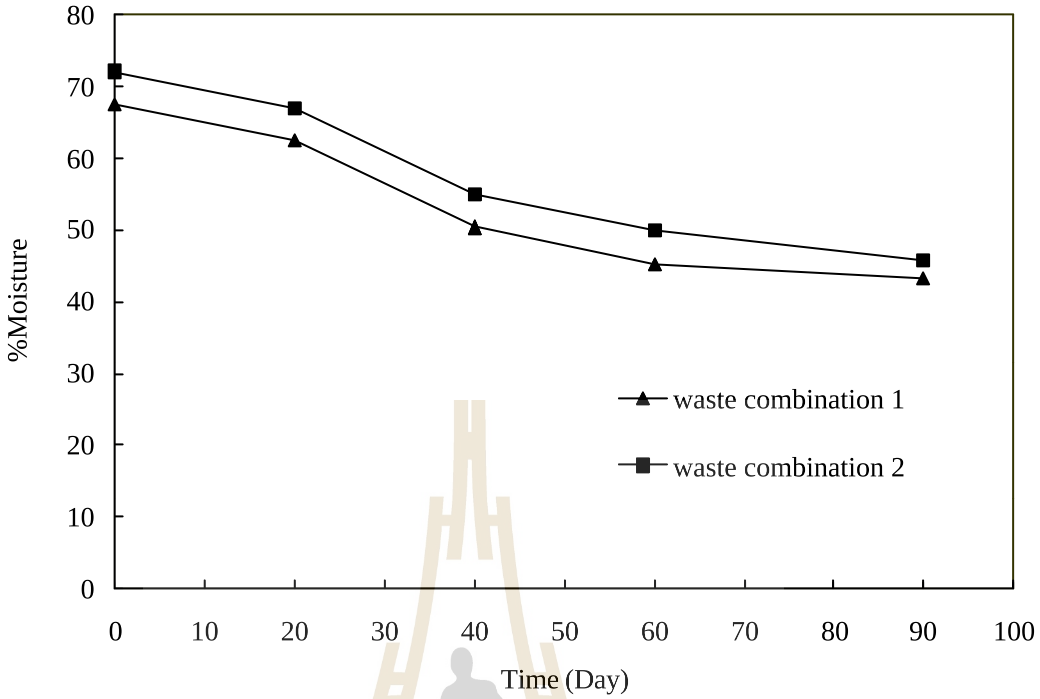


Figure 4-1. Time variation curves of moisture content during Run I.

The initial and final moisture contents of the composting materials during the 4 experimental runs are shown in Figures 4-2 and 4-3 for the waste combination 1 (food waste mixed with hay) and the waste combination 2 (organic commingled waste mixed with septage), respectively. The initial moisture contents of waste combination1 varied between 54-67.5%, while it ranged between 61.7-72% for the waste combination 2. The final moisture contents were in the range of 43.20-48.70% and 45.60-56.45% for the two waste combinations.

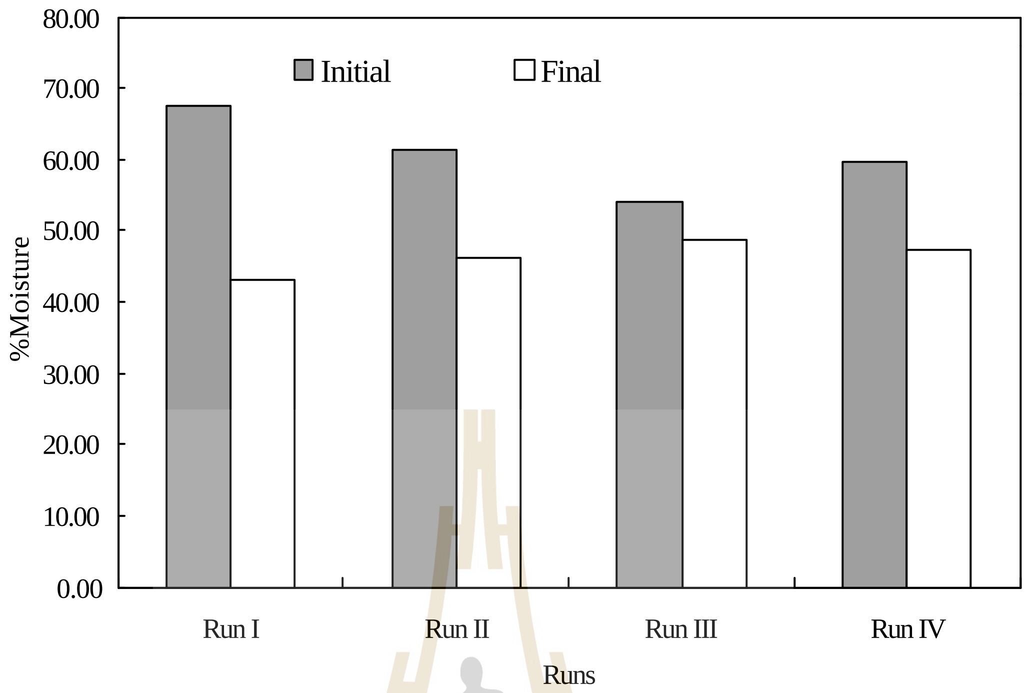


Figure 4-2. The initial and final moisture contents of the waste combination 1 during the 4 experiment runs.

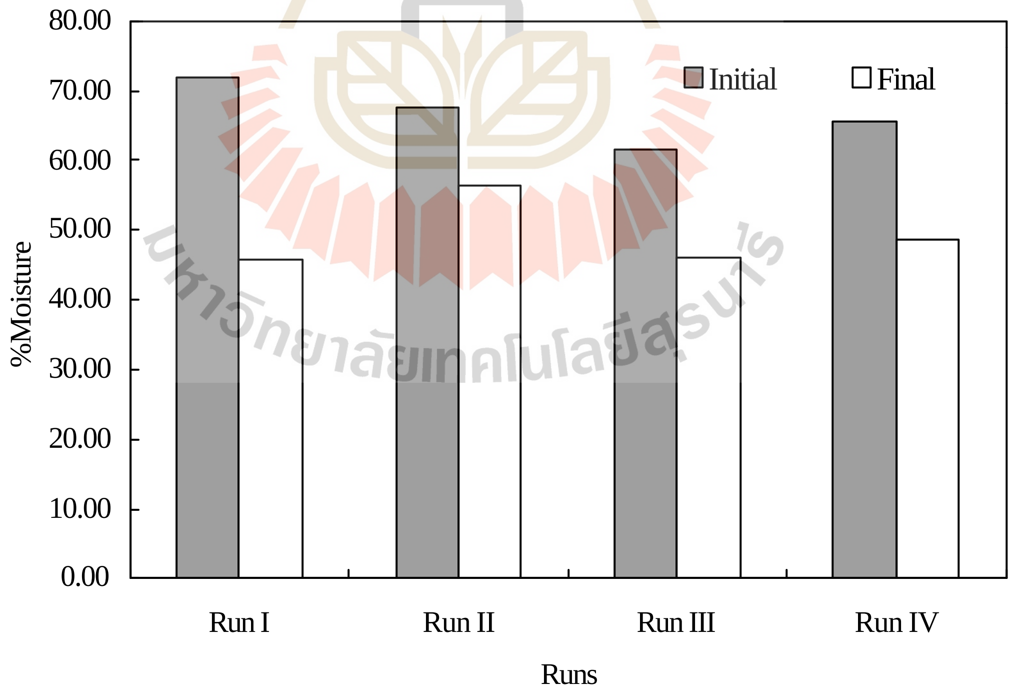


Figure 4-3. The initial and final moisture contents of the waste combination 2 during the 4 experimental runs.

Based on the Figures 4-2 and 4-3, and the statistical analysis (ANOVA method) it could be observed that there was no significant difference in the initial moisture contents (p = 0.140), as well as, in the final moisture contents (p = 0.345) of the two waste combinations during the four composting runs as shown in Tables B1-1 and B1-2 (Appendix B).

4.2.2 Temperature

The daily variations in the temperature during all the runs are shown in Figures 4-4 - 4-7, respectively. Temperature was measured at the center of the digesters at 2 PM daily throughout the entire composting period of the 4 runs.

The starting temperatures of both combinations of composted materials for all the 4 runs were found in the mesophilic phase as shown in Tables 4-4 and 4-5, respectively. Normally the digester temperature should start in mesophilic phase and then reach the thermophilic phase (Polprasert, 1996). At thermophilic phase, temperature increase the rate of biodegradation of compost materials in digesters and reduce the number of potentally pathogenic organism in composted materials.

The temperature rise in the food waste mixed with hay (waste combination 1) was lower than the organic commingled waste mixed with septage (waste combination 2). The maximum temperatures were achieved within 2 days of starting the runs and ranged between 52-56 °C and 55-60 °C in waste combinations 1 and 2, respectively. After reaching the thermophilic stage, the temperature in the digesters decreased sharply within 1-2 days in each composting run as shown in Figures 4-4 - 4-7. High temperatures are essential for the destruction of pathogenic organisms. Decomposition also proceeds much more rapidly in the thermophilic temperature range.

The reason for high temperature development during the initial stage of composting were the increase in both microbial activities and rates of exothermic decomposition which were responsible for liberating heat from the metabolism of the complex organic matters.

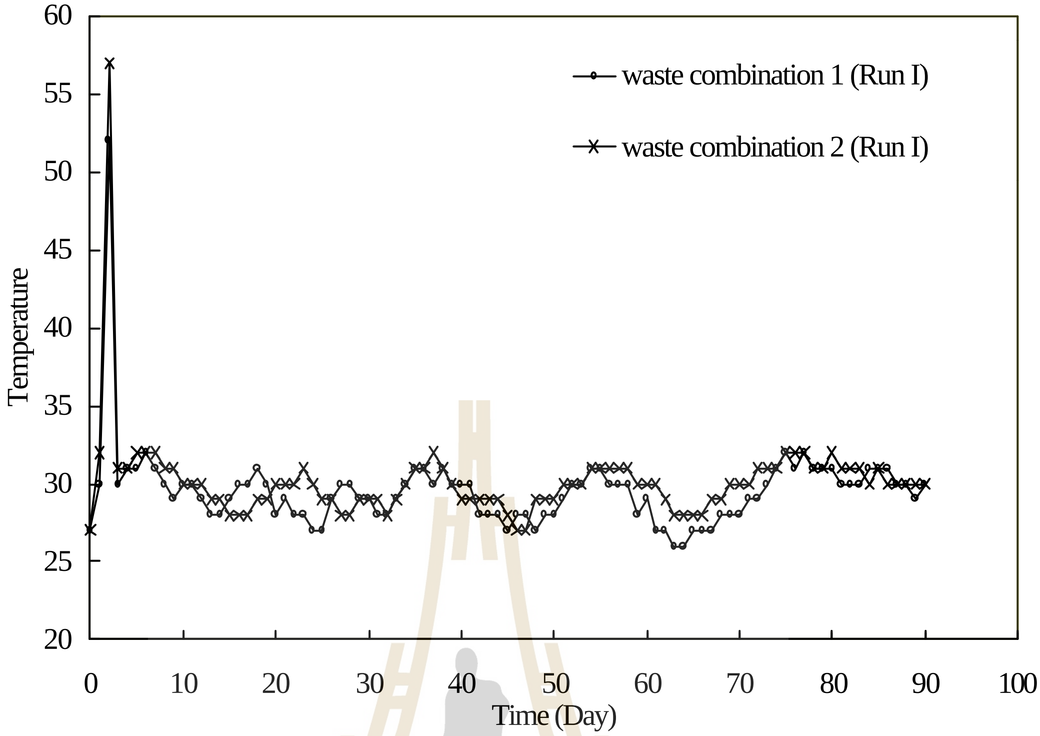


Figure 4-4. Time variation curve of temperature during Run I.

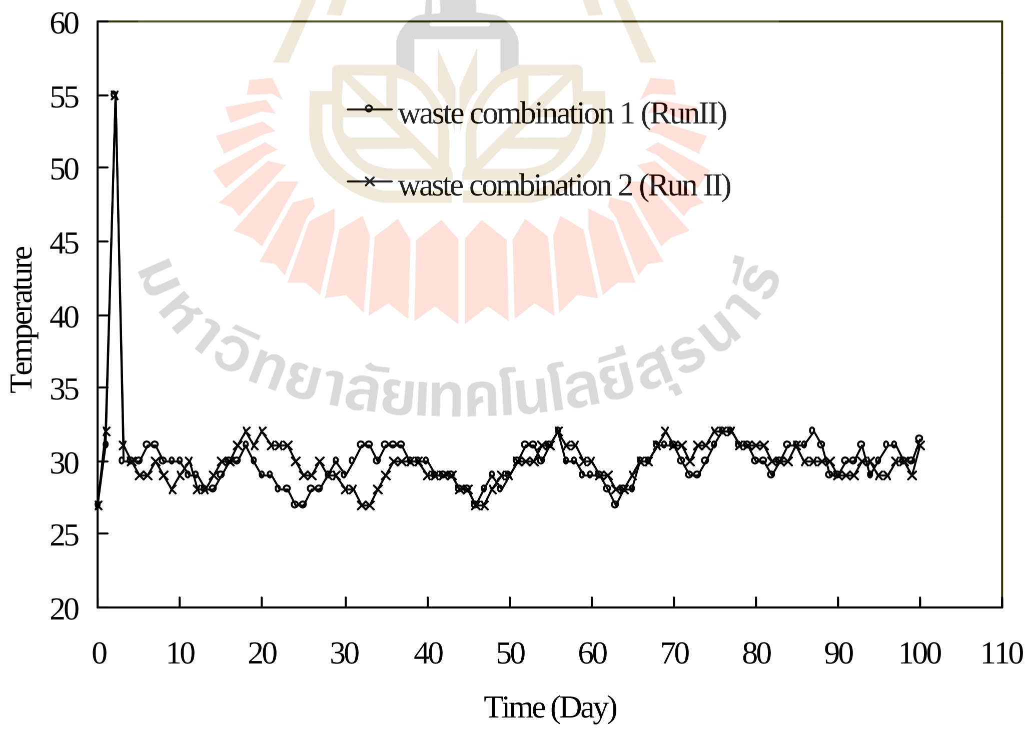


Figure 4-5. Time variation curve of temperature during Run II.

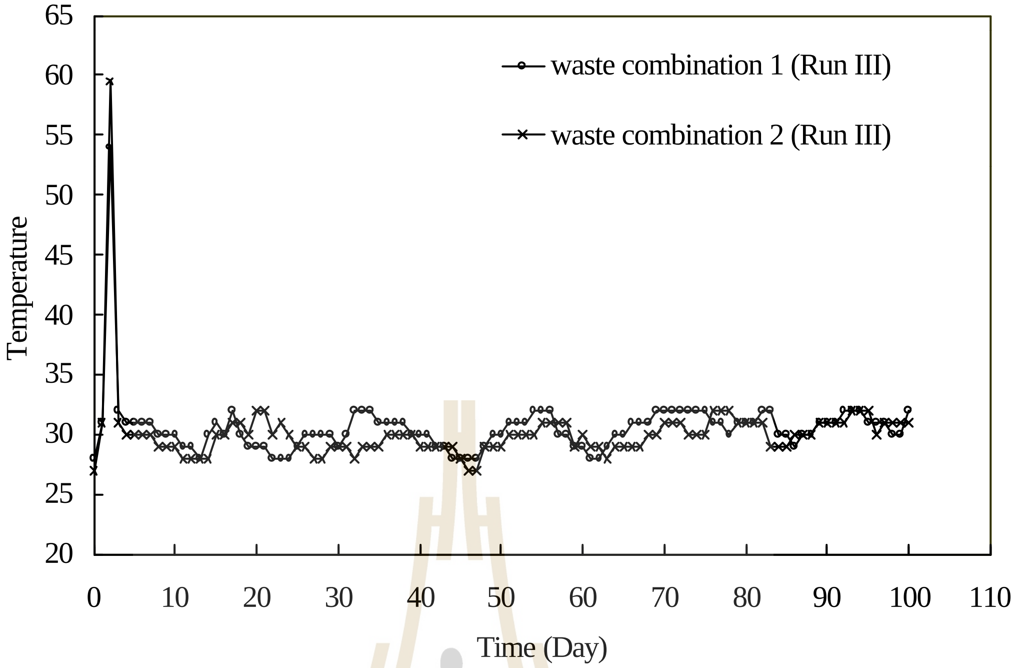


Figure 4-6. Time variation curve of temperature during Run III.

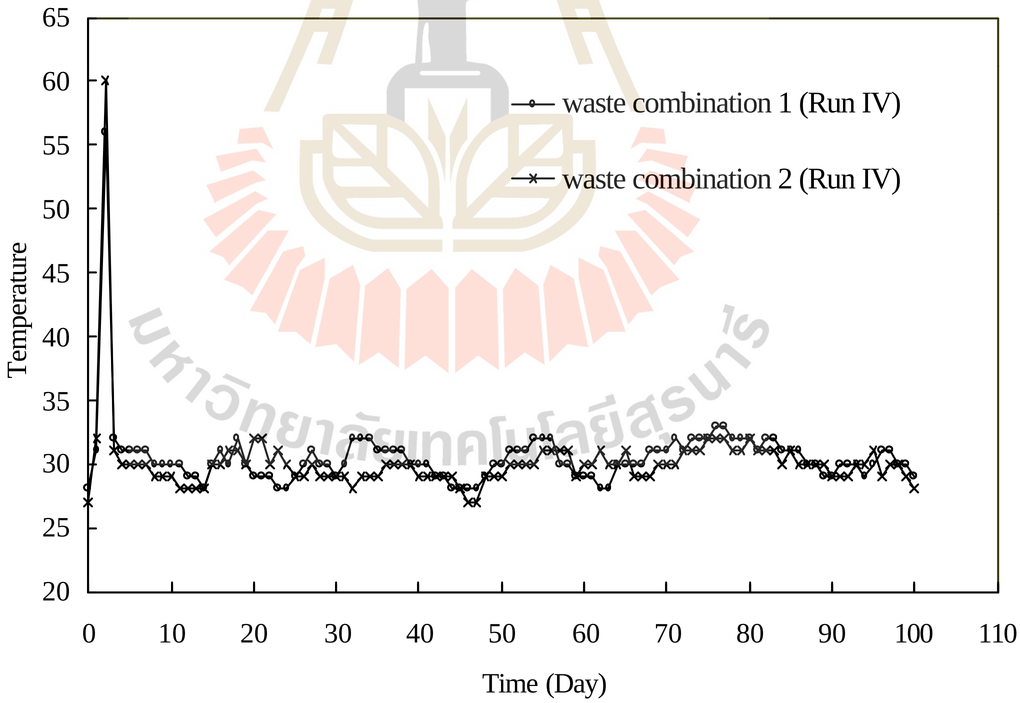


Figure 4-7. Time variation curve of temperature during Run IV.

The hourly variation in the temperature was monitored during the first 72 hours of the third run as shown in Figure 4-8. The initial temperature of the both waste combinations was 27 °C. Subsequently, it rapidly increased to 54 °C within the first 28 hours of composting for waste combination 1, and to 59.5 °C within the 27 hours of composting for waste combination 2. From this point onwards, the temperature started decreasing. After 3 days, the temperature had reached to the ambient air temperature level (32 °C). The final temperatures after 100 days of composting were 31 °C for both waste combinations.

From the statistical analysis (ANOVA method) as shown in Tables B1-1 and B1-2 (Appendix B), it could be observed that there was no significant difference in the initial temperature (p = 0.134), as well as, in the final temperature (p = 0.550) of the two waste combinations during the four composting runs.

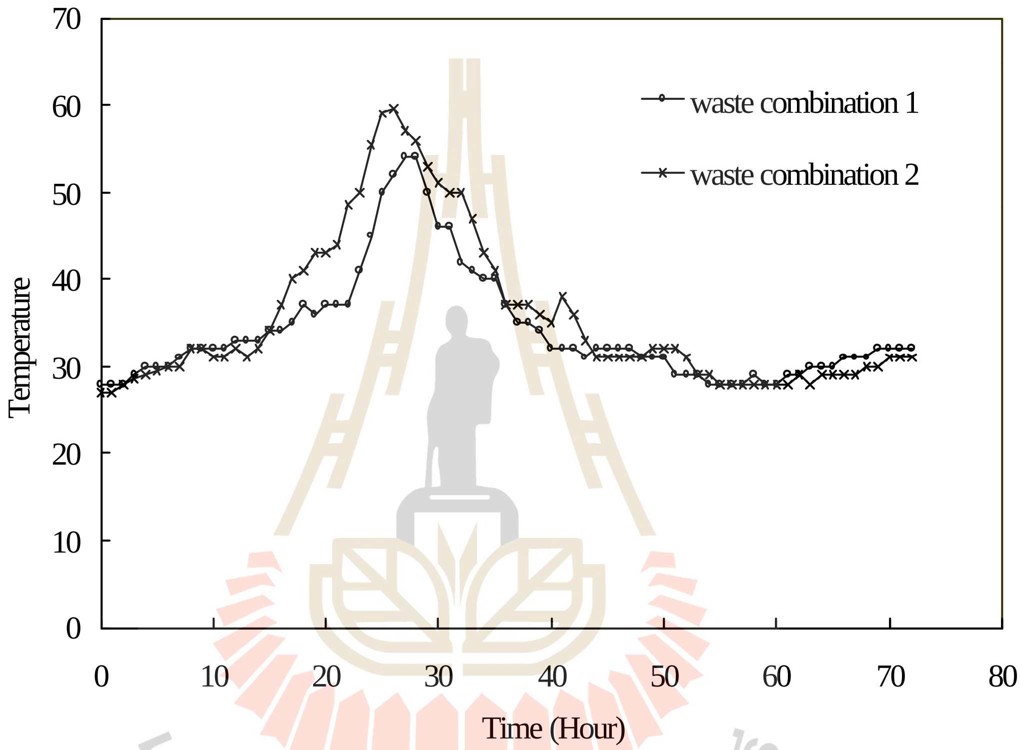


Figure 4-8. Hourly time variation curves of temperature during the first 72 hours of Run III.

4.2.3 pH

The pH values observed in the composting masses during the first run are shown in Figure 4-9. For waste combination 1, the pH was 5.88 at the beginning, and first decreased to 4.47 and 4.32 after the intervals of 20 and 40 days, respectively, and then increased to 5.94 and 7.23 after the intervals of 60 and 90 days, respectively. For waste combination 2, the pH was 7.50 at the beginning and first decreased to 5.81 and 5.75 after the intervals of 20 and 40 days, respectively, and then increased to 6.79 and 7.68 after the intervals of 60 and 90 days, respectively.

For the both combinations of composting materials, it was observed that pH first gradually decreased because of acidogenic bacterial action. The composition of some part of organic material are further converted to acetic acid, H_2, and CO_2 by the acidogenic bacteria. During the later part of the composting process, the pH increased until reaching alkaline range. The high pH in each digester towards the end caused a loss of nitrogen through volatilization of ammonia during composting. Ammonia was detected by the presence of pungent smell.

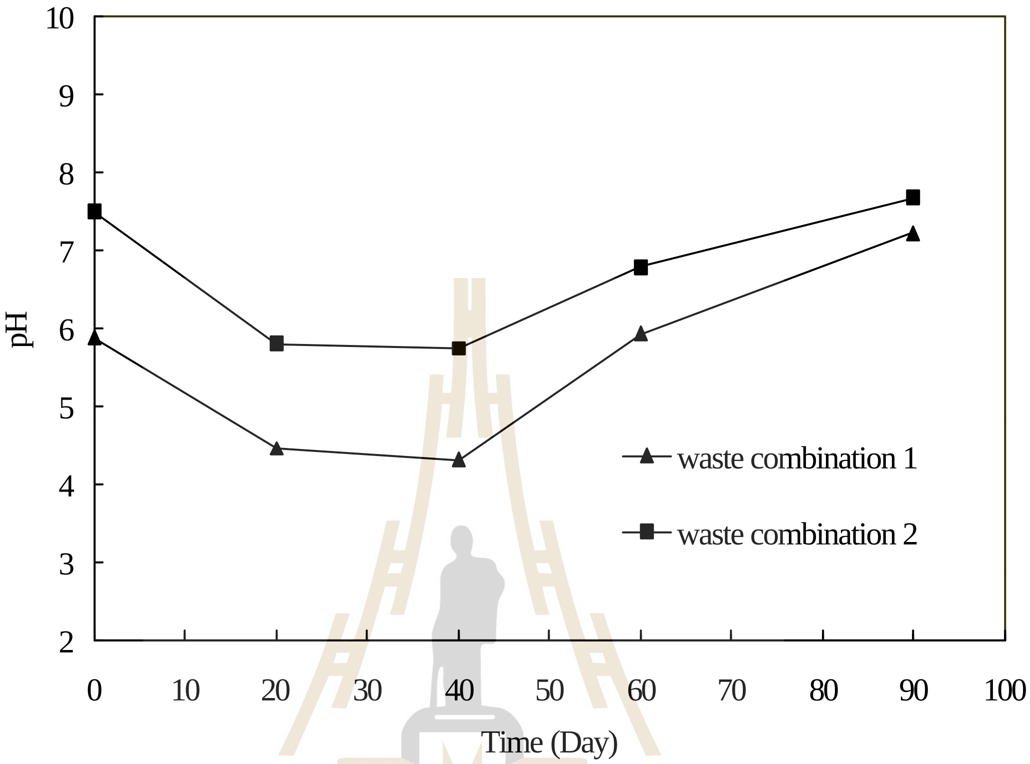


Figure 4-9. Time variation curve of pH during the Run I.

The initial and final pH values of the composting materials during the 4 experimental runs are shown in Figures 4-10 and 4-11 for the waste combination 1 (food waste mixed with hay) and the waste combination 2 (organic commingled waste mixed with septage), respectively. The initial pH varied between 5.7-6.8 for the waste combination 1 and 7.4-7.85 for the waste combination 2. The final pH of both waste combinations were in the range of 7.20-8.0.

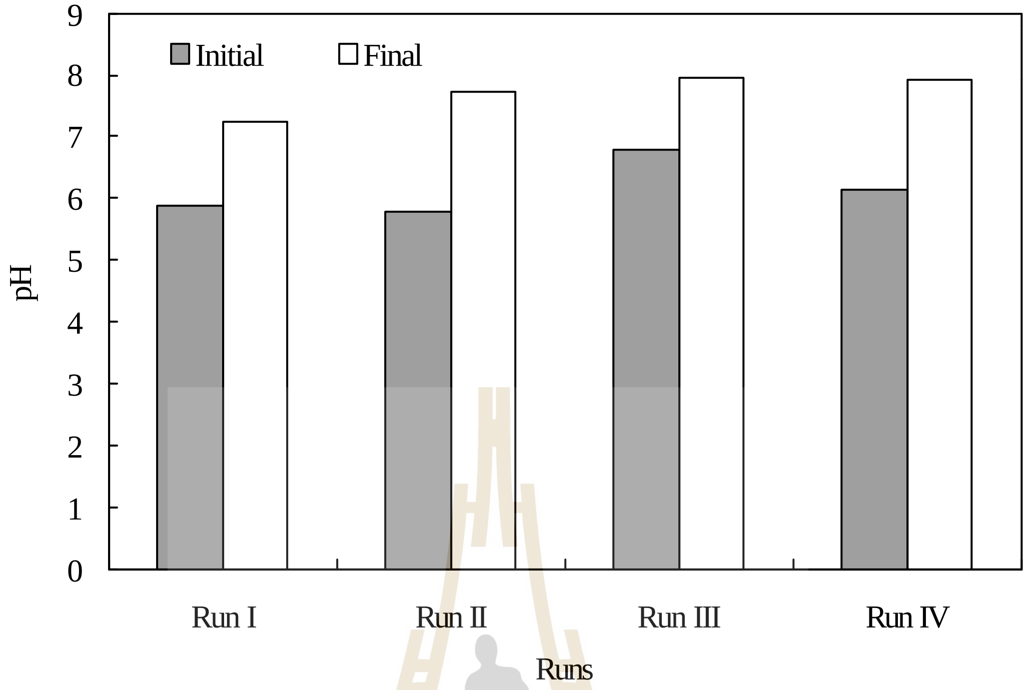


Figure 4-10. The initial and final pH values of the waste combination 1 during the 4 experimental runs.

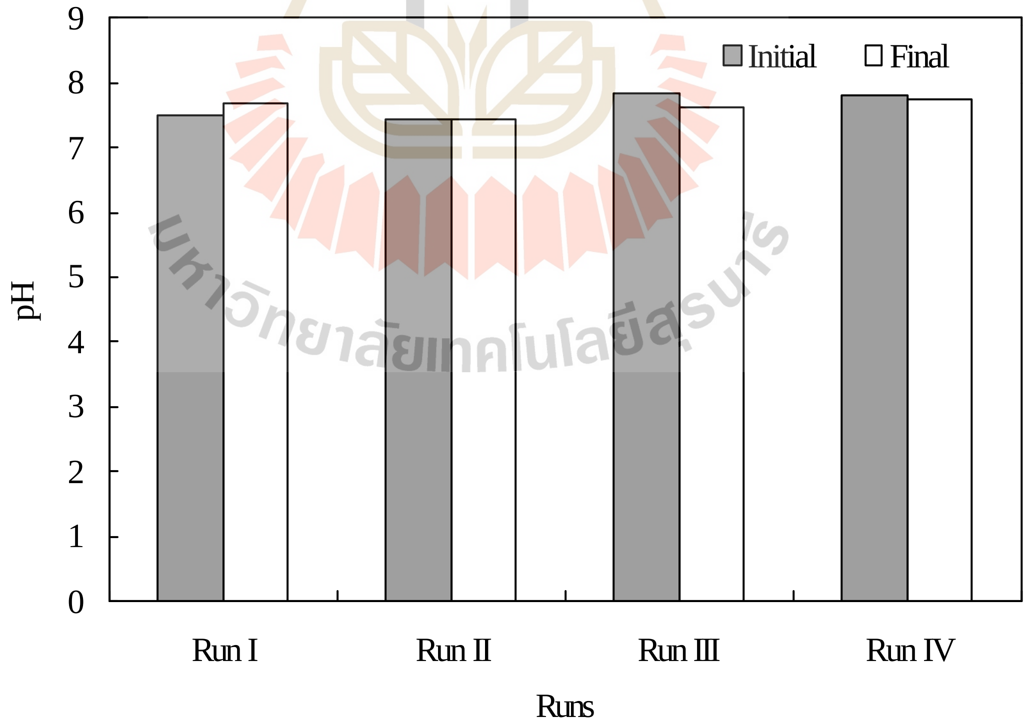


Figure 4-11. The initial and final pH value of the waste combination 2 during the 4 experimental runs.

Based on the Figures 4-10 and 4-11, and the statistical analysis (ANOVA method) it could be observed that there was significant difference in the initial pH value (p = 0.001) of the two waste combinations during the four composting runs as shown in Table B1-1 (Appendix B). However, there was no significant difference in the final pH value (p = 0.670) of the two waste combinations during the four composting runs as shown in B1-2 (Appendix B).

4.2.4 Total coliform bacteria

The reduction in the total coliform bacteria (number/100 ml) during the first run is shown in Figure 4-12. For waste combination 1, the number of total coliform bacteria was 1.37 x 10^6 at the beginning and decreased to 2.67 x 10^5, 2.45 x 10^5, 2.06 x 10^3, and 3.31 x 10^2 after the intervals of 20, 40, 60, and 90 days, respectively. For waste combination 2, the total coliform bacteria was 1.63 x 10^8 at the beginning and decreased to 1.46 x 10^7, 6.90 x 10^6, 7.14 x 10^4, and 2.67 x 10^2 after the intervals of 20, 40, 60, and 90 days, respectively. Both combinations of composted materials had a reduction of 99.99 % in total coliform bacteria in 90 days.

Since most studies in the literature have indicated a complete inactivation of the *Ascaris lumbricoids* eggs at the temperature of 50 °C with an exposure time of two hours (Gotaas, 1956), no attempt was made to examine their survival in the composted material because the maximum temperatures were in the range of 52-60°C for about two days during the all four runs.

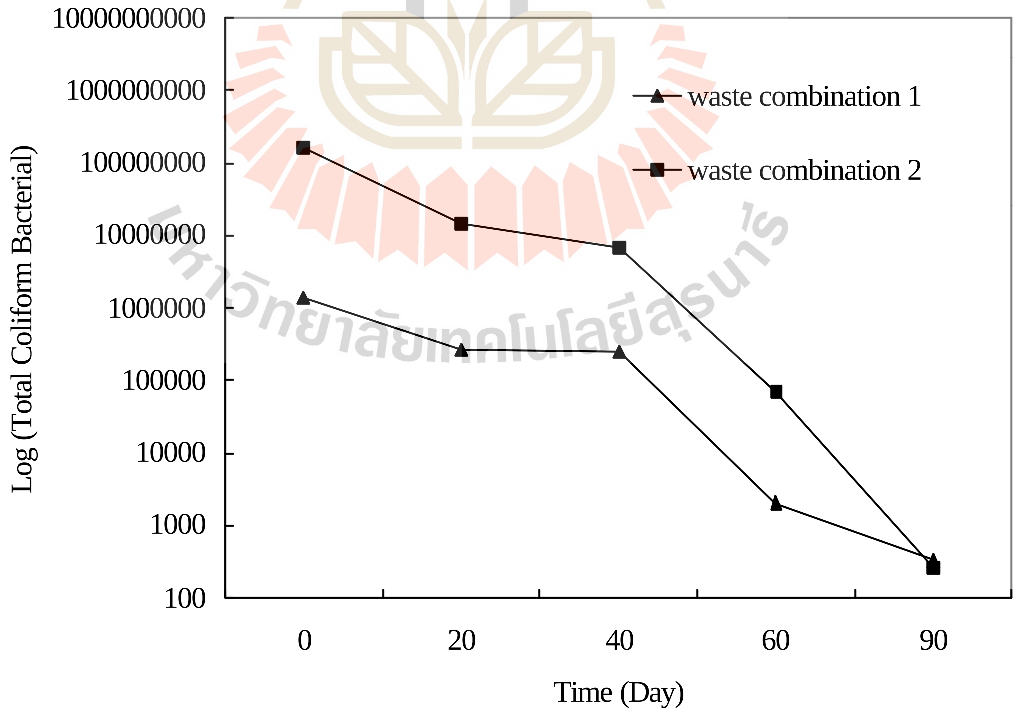


Figure 4-12. Time variation curves of total coliform bacteria during the Run I.

All in all, a 99.80-99.99% kill of total coliform bacteria was achieved for food waste mixed with hay and organic waste mixed with septage, respectively during the four runs are shown in Figure 4-13.

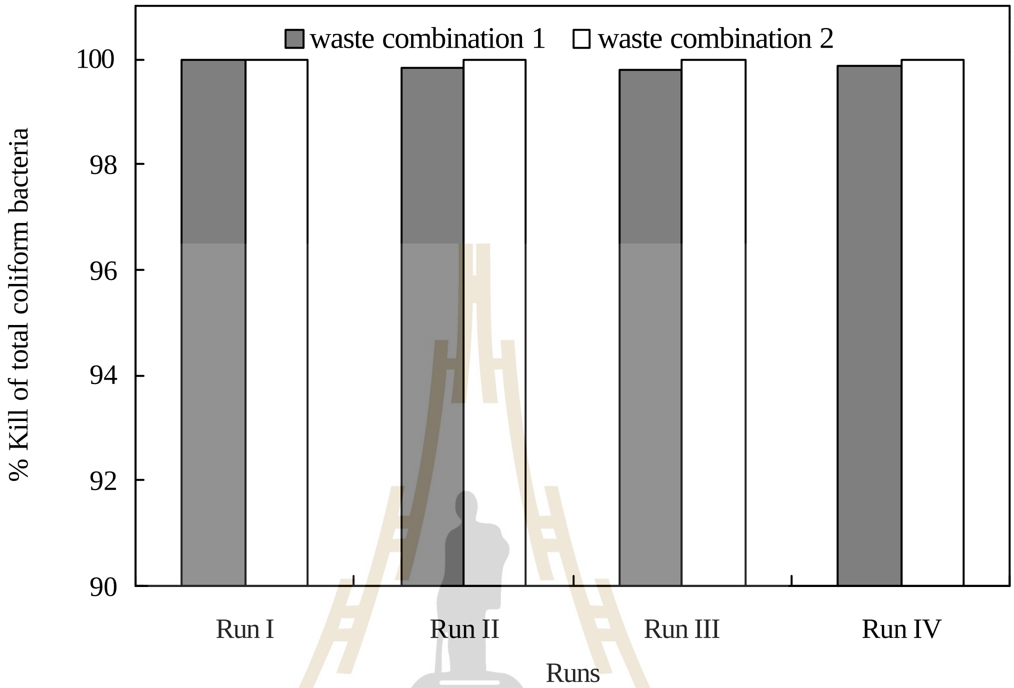


Figure 4-13. The percent kill of total coliform bactria of the two waste combination during the 4 experimental runs.

From the statistical analysis (ANOVA method) as shown in Tables B1-1 and B1-2 (Appendix B), it could be observed that there was significant difference in the initial total coliform bacteria (p = 0.00002) of the two waste combinations during the four composting runs. However, there was no significant difference in the final total coliform bacteria (p = 0.051) of the two waste combinations during the four composting runs.

4.3 Nutrient content

The bacteria responsible for waste conversion and stabilization in the anaerobic process require nitrogen, phosphorus and other materials in trace quantities for optimum growth. Therefore, are important environmental condition is the presence of the required nutrients in adequate quantities. Municipal wastewater sludge usually contains all the required nutrients in adequate quantities but other substrates, industrial and solid wastes in particular, might not. If the nutrients are not present in the required quantities, they must be either added or supplemented (Stafford et al, 1979).

The two most important nutrients are carbon and nitrogen. Few other inorganic chemical reactions have been studied. The C to N ratios during composting affect the process and the product. The important parameter is the carbon available to microorganisms, not the total carbon in the material. During microbial growth, approximately 25 to 30 parts of C are need for every unit of N (Epstein, 1997).

4.3.1 Carbon content

The variations in the carbon content during the first run are shown in Figure 4-14. For waste combination 1, the carbon content was 40.73 % at the beginning and decreased to 38.78 %, 35.98 %, 33.35 %, and 32.02 % after the intervals of 20, 40, 60, and 90 days, respectively. For waste combination 2, the carbon content was 33.60 % at the beginning and decreased to 30.78 %, 25.65 %, 24.26 %, and 23.12 % after the intervals of 20, 40, 60, and 90 days, respectively.

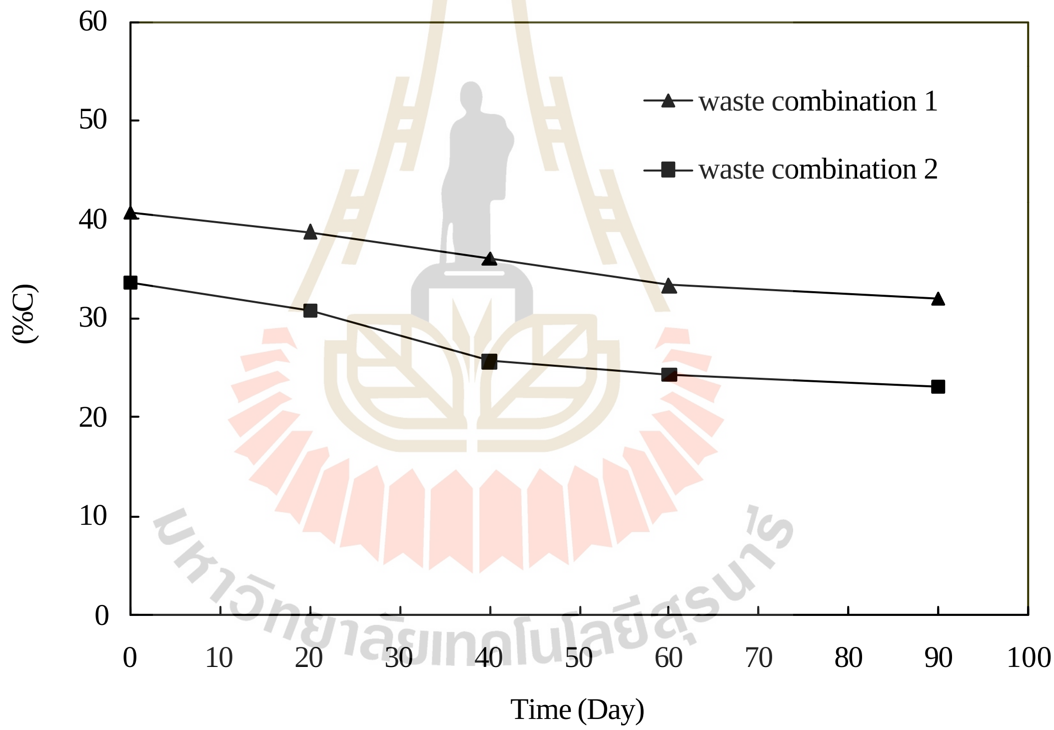


Figure 4-14. Time variation curves of carbon content during the Run I.

The initial and final carbon contents of the composting materials during the 4 experimental runs are shown in Figures 4-15 and 4-16 for the waste combination 1 (food waste mixed with hay) and the waste combination 2 (organic commingled waste mixed with septage), respectively. The initial carbon contents varied between 39-44% for the waste combination 1 and 32-36% and for the waste combination 2. The final carbon contents of the both waste combinations ranged between 22-32%.

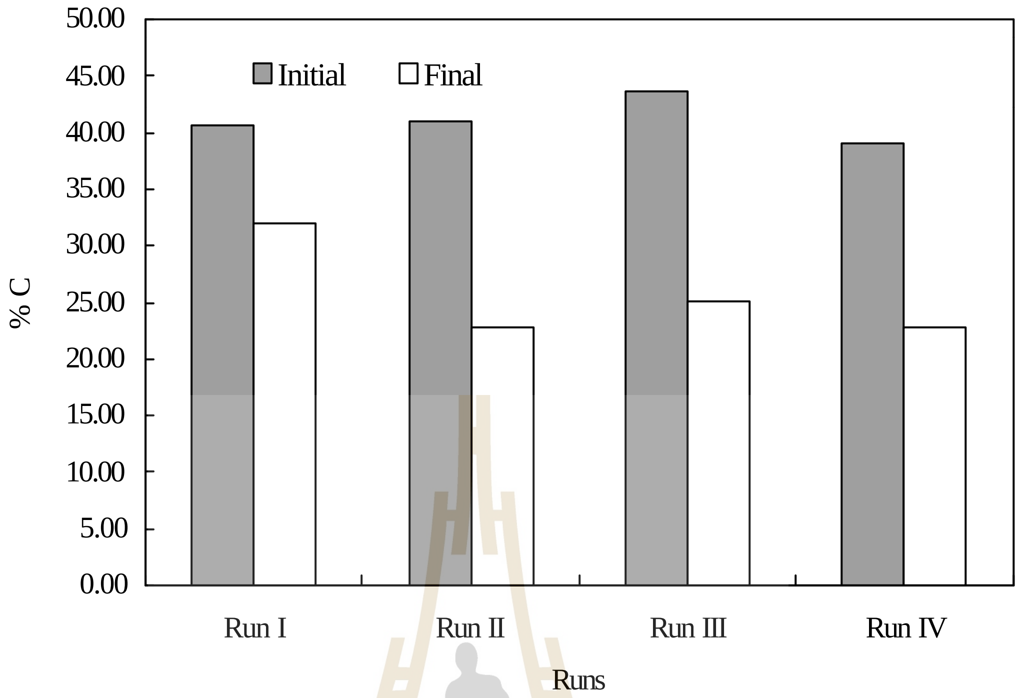


Figure 4-15. The initial and final carbon contents of the waste combination 1 during the 4 experimental runs.

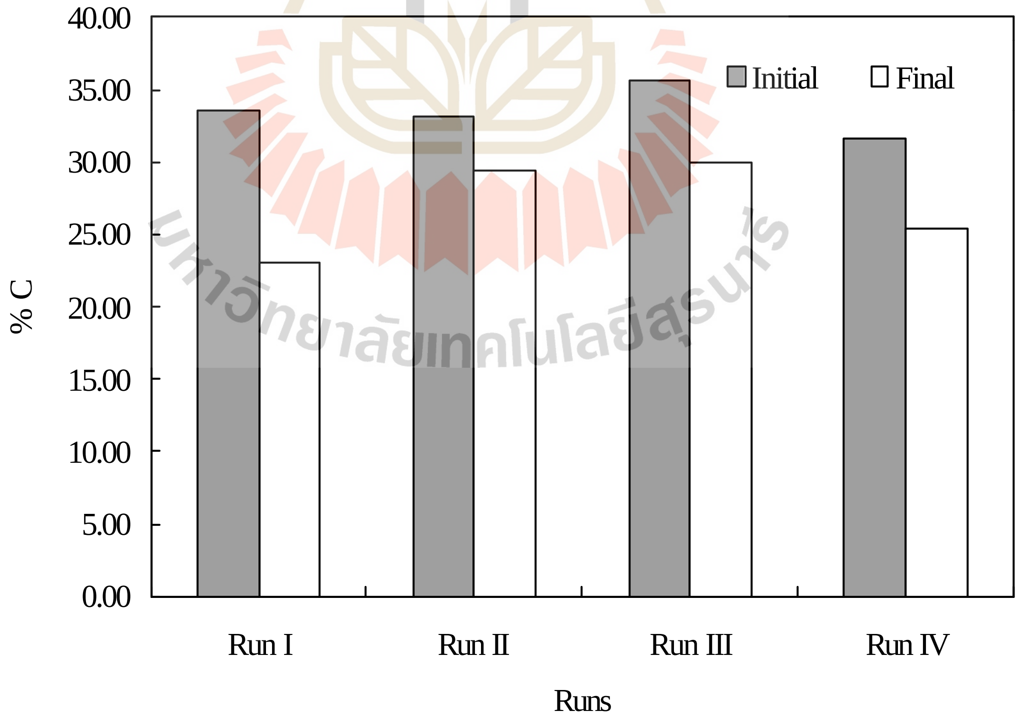


Figure 4-16. The initial and final carbon contents of the waste combination 2 during the 4 experimental runs.

For the organic commingled waste (except food waste) mixed with septage, the rate of decomposition of organic carbon was 31.6% (10% higher) than the food waste mixed with hay (21.4%). This can be seen through the comparison of the rate of decrease in both combinations of composted materials. The rate of decomposition ultimately depends upon the capability of microorganisms to break-down the materials by making appropriate use of oxygen added into system. The capability of microorganisms also depends upon their genetics make-up where the environment permits their expression of the genetic make-up (Rabbani et al, 1983).

According to the microbial reaction process, the declination of carbon content occurred as time elapsed. This was due to utilization of organic matter by the organisms involved, a portion of organic matter utilized through metabolism of new cell, while the other portion converted to CO_2 to meet the organisms physiological energy needs (Gray, 1971).

Carbon is provided to the microbial community from decomposing plants and wastes from animals and humans. The carbon is utilized for cellular growth. Some of the microbial biomass returns carbon to the cycle. During microbial activity, respiratory CO_2 is evolved and emitted to the atmosphere. The readily available carbon is utilized initially. As the composting process continues, however, the rate of CO_2 evolution decreases as a result of decreased metabolic activity and the decrease of available carbon (Epstein, 1997).

Based on the Figures 4-15 and 4-16, and the statistical analysis (ANOVA method) it could be observed that there was significant difference in the initial carbon contents (p = 0.001) of the two waste combinations during the four composting runs as shown in Table B1-1 (Appendix B). However, there was no significant difference in the final carbon contents (p = 0.647) of the two waste combinations during the four composting runs as shown in B1-2 (Appendix B).

4.3.2 Nitrogen content

The variations in the nitrogen content as TKN during the first run are shown in Figure 4-17. For waste combination1, the nitrogen content was 1.34% at the beginning and first decreased to 1.33% and 1.32% after the intervals of 20 and 40 days, respectively, and then increased to 1.49% and 1.73% after the intervals of 60 and 90 days, respectively. For waste combination 2, the nitrogen content was 1.08% at the beginning and first increased to 1.18% after 20 days, then decreased to 1.04% after 40 days, and again increased to 1.41%, and 1.62% after the intervals of 60 and 90 days, respectively.

During the composting, certain increase in nitrogen content has been found in all digesters because of loss of carbon by the metabolic reactions of anaerobic microorganisms. A part of nitrogen content may escape in the form of NH_3 (gas) or other volatile nitrogen gas to atmosphere.

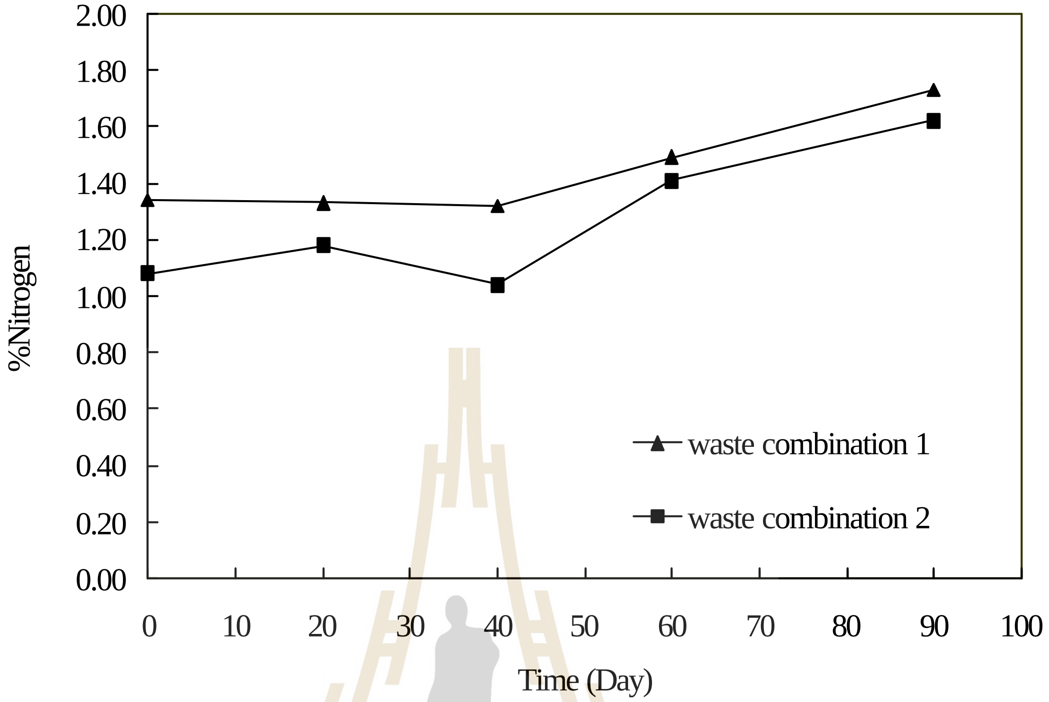


Figure 4-17. Time variation curves of nitrogen content during the Run I.

The initial and final nitrogen contents of the composting materials during the 4 experimental runs are shown in Figures 4-18 and 4-19 for the waste combination 1 (food waste mixed with hay) and the waste combination 2 (organic commingled waste mixed with septage), respectively. The initial and final nitrogen contents of the two waste combinations ranged between 1-1.5% and 1.4-1.75%, respectively.

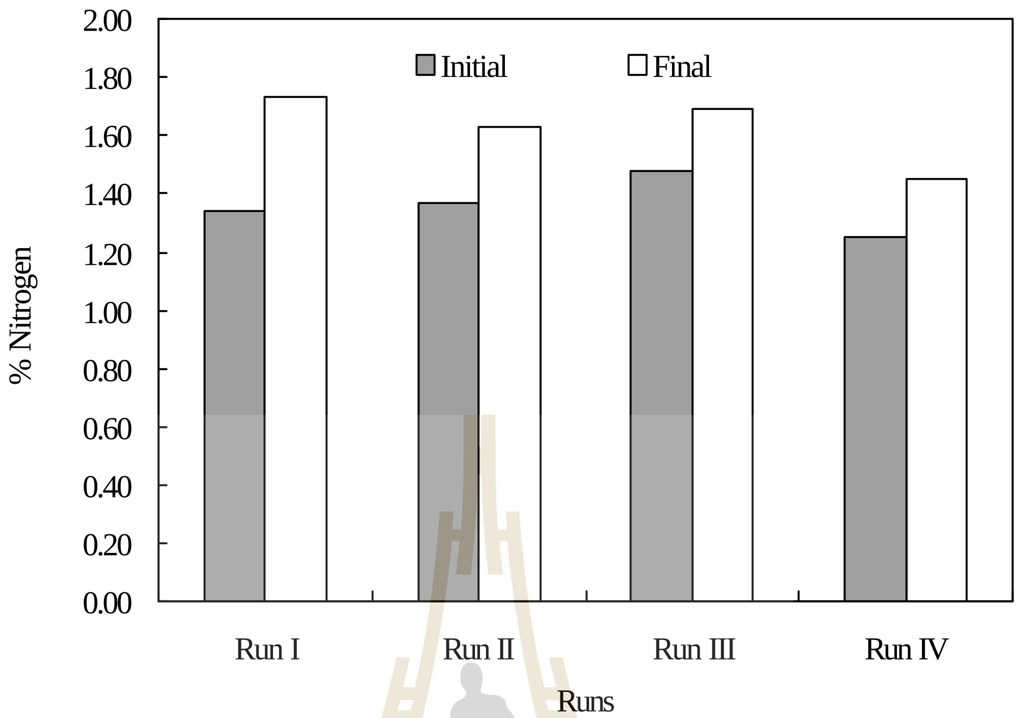


Figure 4-18. The initial and final nitrogen contents of the waste combination 1 during the 4 experimental runs.

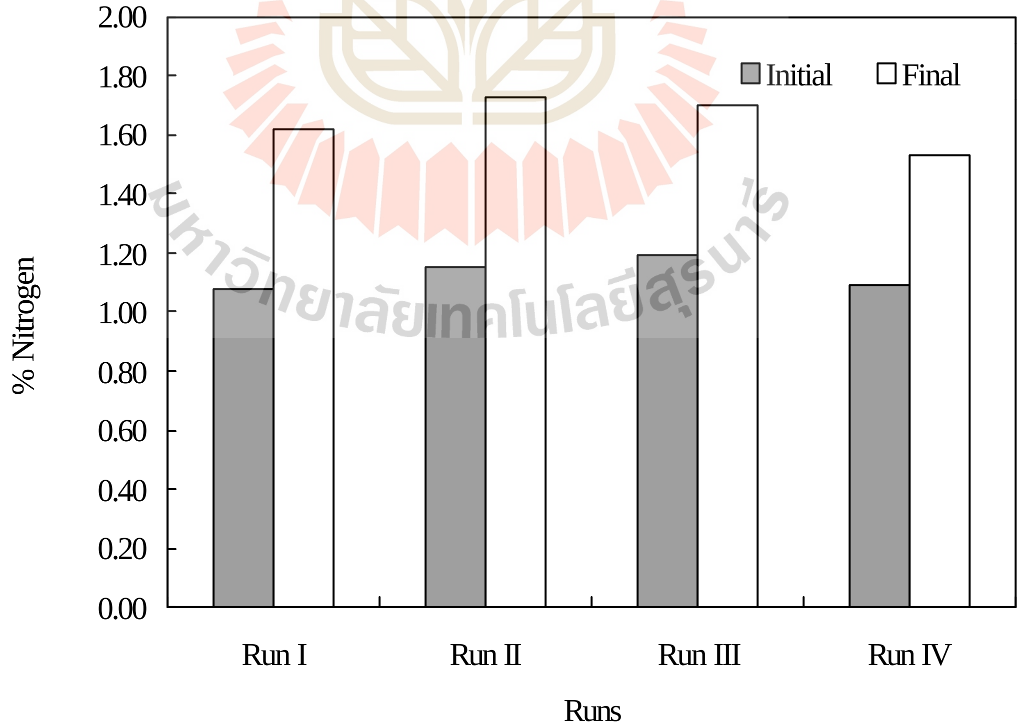


Figure 4-19. The initial and final nitrogen contents of the waste combination 2 during the 4 experimental runs.

While comparing the amount of nitrogen present in the both combinations of composted materials, it was noticed that waste combination 2 may have lost more nitrogen in form of NH_3 (gas) during the composting. Microorganisms utilize carbon and nitrogen at a ratio of 30/1. Low C/N ratio in feedstocks result in nitrogen volatilization in the form of ammonia

Based on the Figures 4-18 and 4-19, and the statistical analysis (ANOVA method) it could be observed that there was significant difference in the initial nitrogen contents (p = 0.005) of the two waste combinations during the four composting runs as shown in Table B1-1 (Appendix B). However, there was no significant difference in the final nitrogen contents (p = 0.802) of the two waste combinations during the four composting runs as shown in B1-2 (Appendix B).

4.3.3 Carbon to nitrogen ratio

The C/N ratio has been considered an important indicator of the degree of decomposition and the suitability of the compost product for utilization. It is very important in the nutrient balance of all organisms. Carbon is a source of energy for the microorganisms and nitrogen is necessary for the synthesis of protoplasm. More carbon than nitrogen is required, but when there is a too great excess of either, biological activity diminishes and the completion of the process is delayed. Two-thirds of the carbon consumed by micro-organisms is given off gas CO_2, and the rest is combined with nitrogen in the cell. When there is insufficient carbon to convert to the nitrogen into protoplasm, micro-organisms make full use of the small amount of carbon available and eliminate the excess nitrogen as ammonia. Large amounts of ammonia can be formed, and if the compost is applied during this phase of active composting, it may prove toxic to plants (Lardinois and Van De Klundert, 1993).

The variations in the C/N ratio during the first run are shown in Figure 4-20. For waste combination 1, the C/N ratio was 30.35 at the beginning and decreased to 29.19, 27.16, 22.37, and 18.54 after the intervals of 20, 40, 60, and 90 days, respectively. For waste combination 2, the C/N ratio was 31.05 at the beginning and decreased to 26.17, 24.65, 17.24, and 14.24 after the intervals of 20, 40, 60, and 90 days, respectively. The change in C/N values were due to change in proportions of carbon and nitrogen in the compost.

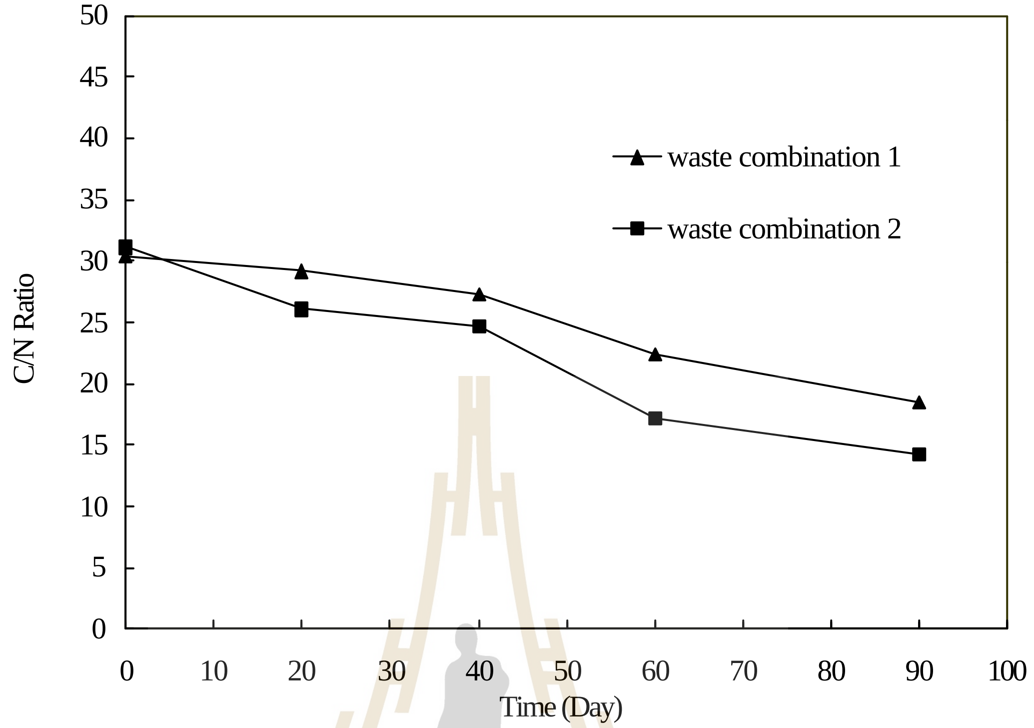


Figure 4-20. Time variation curves of carbon to nitrogen ratio during the Run I.

The initial and final carbon to nitrogen ratio of the composting materials during the 4 experimental runs are shown in Figures 4-21 and 4-22 for the waste combination 1 (food waste mixed with hay) and the waste combination 2 (organic commingled waste mixed with septage), respectively. The initial and final carbon to nitrogen ratio in the two waste combinations ranged between 28-31:1 and 14-19:1, respectively.

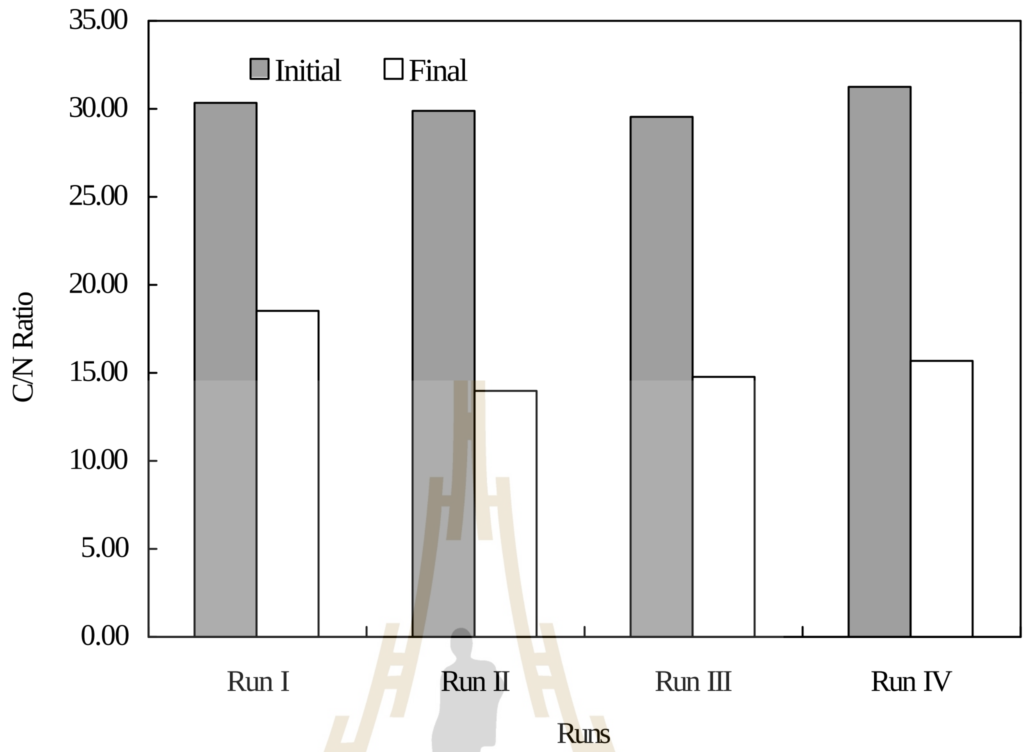


Figure 4-21. The initial and final carbon to nitrogen ratio of the waste combination 1 during the 4 experimental runs.

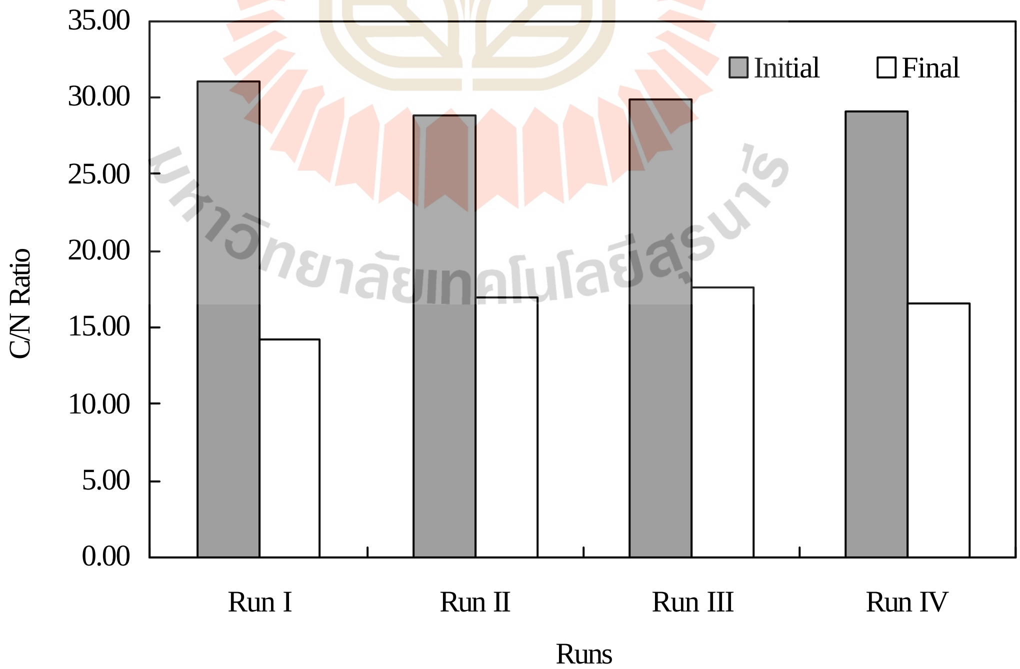


Figure 4-22. The initial and final carbon to nitrogen ratio of the waste combination 2 during the 4 experimental runs.

Based on the Figures 4-21 and 4-22, and the statistical analysis (ANOVA method) it could be observed that there was no significant difference in the initial carbon to nitrogen ratio (p = 0.422), as well as, in the final carbon to nitrogen ratio (p = 0.631) of the two waste combinations during the four composting runs as shown in Tables B1-1 and B1-2 (Appendix B).

4.3.4 Phosphorus content

The variations in the phosphorus content during the first run are shown in Figure 4-23. For waste combination 1, the phosphorus content was 0.13 % at the beginning and increased to 0.19 %, 0.21 %, 0.21 %, and 0.22 % after the intervals of 20, 40, 60, and 90 days, respectively. For waste combination 2, the phosphorus content was 0.08 % at the beginning and increased to 0.15 %, 0.19 %, 0.19 %, and 0.20 % after the intervals of 20, 40, 60, and 90 days, respectively. The phosphorus contents for each waste combination was inversely related to their respective final C/N ratio. The waste combination with a high C/N ratio had a low phosphorus content and vice versa.

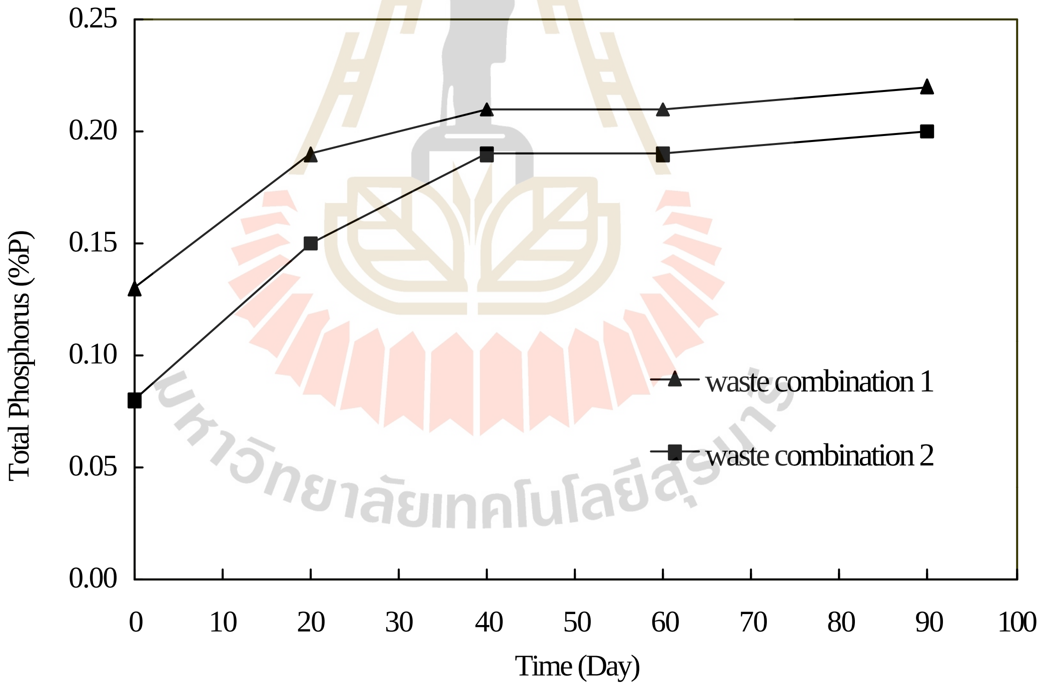


Figure 4-23. Time variation curves of phosphorus content during the Run I.

The initial and final phosphorus contents of the composting materials during the 4 experimental runs are shown in Figures 4-24 and 4-25 for the waste combination 1 (food waste mixed with hay) and the waste combination 2 (organic commingled waste mixed with septage), respectively. The initial and final phosphorus contents for the two waste combinations were in the range of 0.05-0.15% and 0.2-0.25%, respectively.

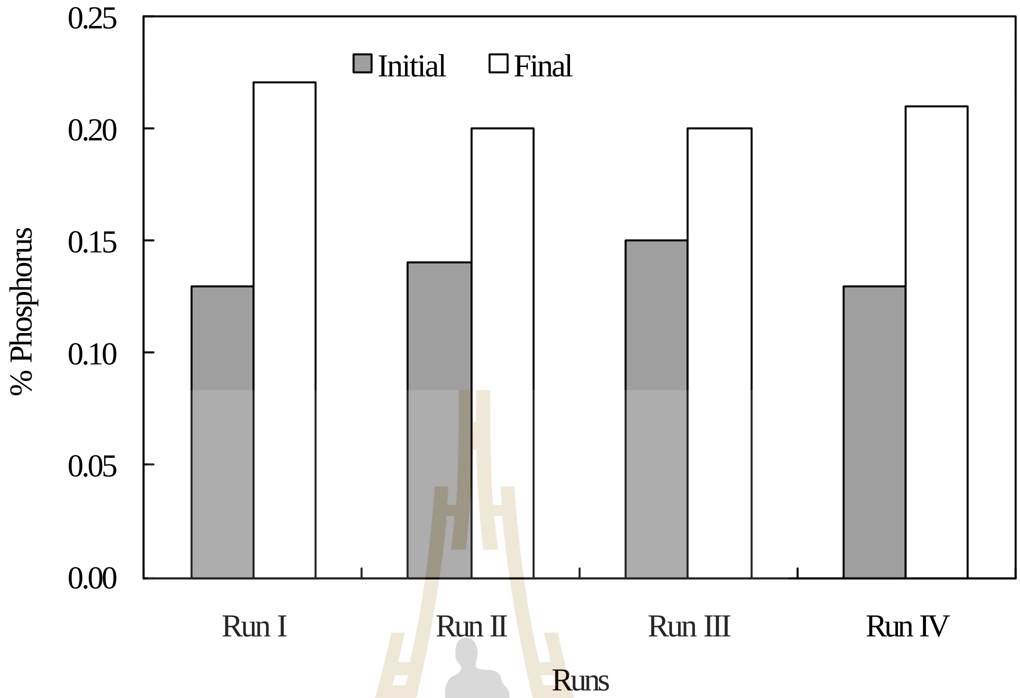


Figure 4-24. The initial and final phosphorus contents of the waste combination 1 during the 4 experimental runs.

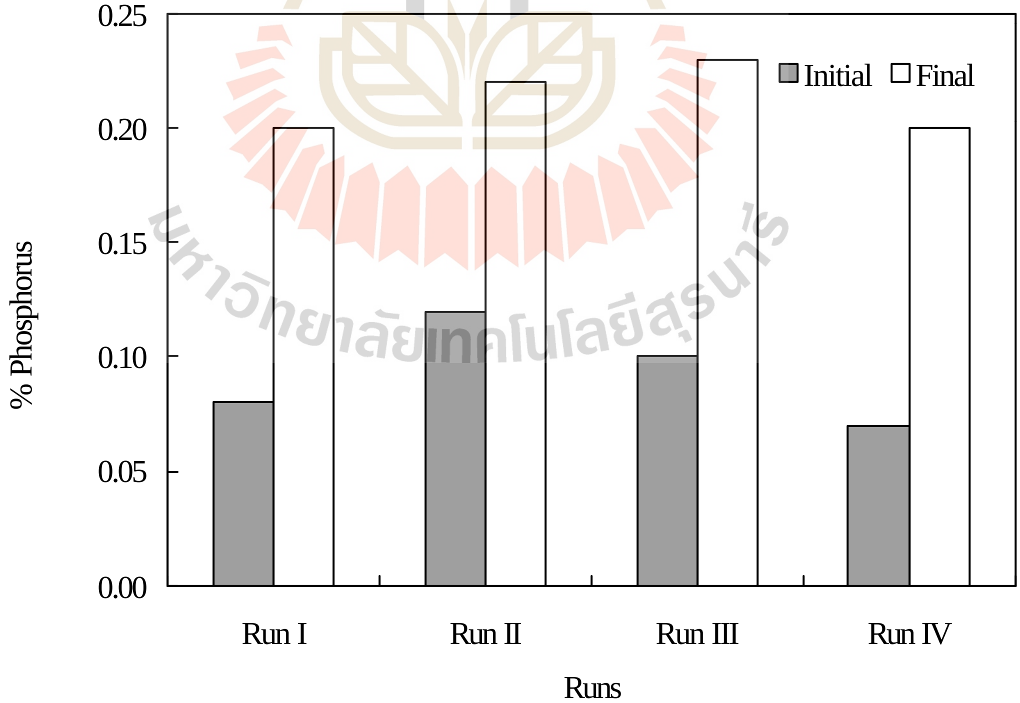


Figure 4-25. The initial and final phosphorus contents of the waste combination 2 during the 4 experimental runs.

The increase in phosphorus content was found in both combinations of composted materials. Such an increase in phosphorus contents is mainly due to loss of carbon or organic matter's mineralization in each compost digester. However such a loss has been found to be less than 1% (Petersen et al, 1998). Georgacakis et al.(1996) have also found increase in phosphorus in the final compost product as found by Arja et al. (1997), Petersen et al. (1998), and Traore et al. (1999) as well, supporting the results found in this study.

Based on the Figures 4-24 and 4-25, and the statistical analysis (ANOVA method) it could be observed that there was significant difference in the initial phosphorus contents (p = 0.01) of the two waste combinations during the four composting runs as shown in Table B1-1 (Appendix B). However, there was no significant difference in the final phosphorus contents (p = 0.595) of the two waste combinations during the four composting runs as shown in B1-2 (Appendix B).

4.4 Finished compost products

Various physical, chemical and biological characteristics of the finished compost products form both waste combinations during the 4 runs are presented in Table 4-8.

The completion of the composting period was determined by examining some physical, chemical, and biological characteristics of the composted material to fulfill the following criteria:

1) Final temperatures inside the digesters of the both waste combinations ranged between 28-32 °C.
2) The final C/N ratios of the compost products of the two waste combinations ranged between 14-19:1.
3) The final volatile solid contents of the compost products of the two waste combinations ranged between 41-58%.
4) Color of the compost was brownish black.
5) According to Haug (1993), a temperature of 53 °C or above for sufficient time effectively eliminates pathogenic bacteria, enteric viruses, and *Ascaris eggs*. Fecal coliform could be found in high concentrations if maximum composting temperatures were < 50 °C. Based on the results of the present study, it can be seen that the composted product from the organic commingled waste mixed with septage (waste combination 2) was safer from the total coliform bacteria point of view because the maximum temperatures were 55-60 °C, and final number of total coliform bacteria (number/100 ml) was only 242-336. In case of food waste mixed with hay (waste combination 1), although maximum temperatures were high enough (52-56 °C) for about 2 days, the final number of total coliform bacteria (number/100 ml) was high (331-2340).

Table 4-8. The various physical, chemical, and biological characteristics of the finished compost products from both waste combinations during the 4 runs.

No.	Composition	Waste Combination 1 (food waste mixed with hay)				Waste Combination 2 (organic commingled waste mixed with septage)			
		Run I	Run II	Run III	Run IV	Run I	Run II	Run III	Run IV
1	Temperature (^{o}C)	30	31.5	32	29	30	31	31	28
2	pH	7.23	7.71	7.95	7.91	7.68	7.43	7.62	7.75
3	Moisture content (%)	43.24	46.16	48.69	47.21	45.64	56.44	46.02	48.53
4	Total solid (%TS)	56.76	53.84	51.31	52.79	54.36	43.56	53.98	51.47
5	Volatile solid (%TVS)	57.64	41.00	45.06	40.95	41.62	52.88	53.89	45.73
6	Carbon content (%C)	32.02	22.78	25.03	22.75	23.12	29.38	29.94	25.41
7	TKN (%N)	1.73	1.63	1.69	1.45	1.62	1.73	1.7	1.53
8	C/N ratio	18.51	13.97	14.81	15.69	14.27	16.98	17.61	16.60
9	Phosphorus (%P)	0.22	0.20	0.20	0.21	0.20	0.22	0.23	0.20
10	Total coliform bacteria (# cell/ml H_2O)	3.31×10^{2}	2.34×10^{3}	4.07×10^{3}	1.87×10^{3}	2.67×10^{2}	3.36×10^{2}	2.87×10^{2}	2.42×10^{2}

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Base on the results of this study, following conclusions can be made:

The initial moisture contents of food waste mixed with hay (waste combination 1) varied between 54-67.5%, while it varied between 61.7-72% for organic commingled waste mixed with septage (waste combination 2). The final moisture contents were in the range of 43.20-48.70% and 45.60-56.45% for the two waste combinations.

The initial temperature of the both waste combinations ranged between 27-28 ° C. Maximum temperature during the anaerobic composting process in the four runs ranged between 52-56 °C and 55-60 °C, for food waste mixed with hay and organic commingled waste mixed with septage, respectively, and was achieved within 2 days from the start up time. The final temperatures after 100 days of composting were 28-32 °C for both waste combinations. The initial pH varied between 5.7-6.8 for the food waste mixed with hay and 7.4-7.85 for organic commingled waste mixed with septage. The final pH of both waste combinations were in the range of 7.20-8.0.

The initial carbon contents varied between 39-44% for food waste mixed with hay and 32-36% and for organic commingled waste mixed with septage. The final carbon contents of the both waste combinations ranged between 22-32%. The initial and final nitrogen contents of the two waste combinations ranged between 1-1.5% and 1.4-1.75%, respectively. The initial and final carbon to nitrogen ratio in the two waste combinations ranged between 28-31:1 and 14-19:1, respectively. The initial and final phosphorus contents for the two waste combinations were in the range of 0.05-0.15% and 0.2-0.25%, respectively.

A 99.80-99.98% and 99.99% reduction in the total coliform bacteria was achieved for food waste mixed with hay and organic commingled waste mixed with septage, respectively.

The completion of the composting period was determined by examining some characteristics of the composted material that fulfilled several criteria, e.g., temperature inside the digester to be equal to ambient temperature, and the composted material to have: brownish black color, C/N ratio between 15 – 20/1, low volatile solid content, and a 99.99% die-off of the total coliform bacteria.

Based on the standards for the conventional fertilizers in Thailand, the finished compost should contain nitrogen not less than 1%, phosphorus not less than 1%, and potassium not less than 0.5% (Charungroung et al, 1998). The finished composts obtained from food waste mixed with hay and organic commingled waste mixed with septage contained 1.63% N, 0.21% P, 0.39% K, and 1.63% N, 0.21% P, 0.34% K, respectively. The nitrogen contents found in the finished compost products in the two waste combinations have clearly met the corresponding standard through phosphorus and potassium contents somehow did not meet the corresponding standards. Hence, these compost products can be partly used as soil conditioner and/or plant nutrient source.

Anaerobic composting for recycling the biodegradable organic fraction of solid wastes is one good option for waste disposal. Although, anaerobic digestion of organic waste is also catching attention due to the high-energy recovery, anaerobic composting may score higher due to the several factors. One of them is that the effluents from anaerobic digestion are not generally suitable for putting directly onto land. Post-treatment after anaerobic digestion is needed to obtain high quality, finished product. Thus, compared to anaerobic composting, anaerobic digestion is a complex process that requires larger investment. On the other hand, end product of anaerobic composing of organic waste is directly applicable onto land.

5.2 Recommendations

The following work is recommended for future research:

1. Anaerobic composting with different waste combinations in various types of digesters should be investigated.

2. Effect of C/N ratio on the composting duration based on the final product characteristics should be evaluated.

3. Investigations on the biogas production during the anaerobic composting process could also be beneficial.

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APPENDIX A

Calculation method

A1-1. Determination of the waste quantities for making the C: N ratio of 30: 1

(a) Food waste mixed with hay:

Food Waste		Hay	
C/N	= 25.04	C/N	= 50.75
Total Solid	= 15.87 %	Total Solid	= 45.00 %
Total Volatile Solid	= 93.32 %	Total Volatile Solid	= 76.74 %
Nitrogen	= 2.07 %	Nitrogen	= 0.84 %
Carbon	= 51.84 %	Carbon	= 42.63 %
Bulk Density	= 940 kg./m^3	Bulk Density	= 78 kg./m^3

Percentage C = (100- Percentage ash)/1.8 (Gotass, 1956)
Percentage ash = 100- Total Volatile Solid

Let x be kg. dry weight of hay needed to be mixed with 1 kg. dry weight of food waste.

For 1 kg. dry weight of food waste

Carbon content = 1(0.518) kg. : Nitrogen content = 1(0.518)(1/25.04) kg.

For x kg. dry weight of hay

Nitrogen content = x(0.84/100) kg.:Carbon content = x(0.84/100)(50.75/1) kg.

By doing material balance, we get

$$(C_f+C_h)/(N_f+N_h) = (C/N)_m \qquad (1)$$

C_f = Carbon content of food waste
C_h = Carbon content of hay
N_f = Nitrogen content of food waste
N_h = Nitrogen content of hay
$(C/N)_m$ = C/N ratio of mixture of food waste and hay = 30:1

Or, $$\frac{1(0.518)+x(0.84/100)(50.75/1)}{1(0.518)(1/25.04)+x(0.84/100)} = \frac{30}{1}$$

Or, x = 0.59 kg.
Volume of hay required = 0.59 kg. /(0.45x 0.078 kg/L.)
= 16.81 L.
Volume of food waste = 1 kg. / (0.16x0.94 kg/L.)
= 6.65 L.

Thus, 6.65 L. of food waste needs 16.81 L. of hay to make the C/N ratio of 30:1.

(b) Organic commingled waste mixed with septage:

Organic commingled Waste		**Septage**	
C/N	**= 34.35**	**C/N**	**= 15.87**
Total Solid	= 54.87 %	Total Solid	= 18.06 %
Total Volatile Solid	= 93.37 %	Total Volatile Solid	= 65.71 %
Nitrogen	= 1.51 %	Nitrogen	= 2.30 %
Carbon	= 51.87 %	Carbon	= 36.51 %
Bulk Density	= 220 kg./m^3	Bulk Density	= 985 kg./m^3

Percentage C = (100- Percentage ash)/1.8 (Gotass, 1956)
Percentage ash = 100- Total Volatile Solid

Let x be kg. dry weight of septage needed to be mixed with 1 kg. dry weight of organic commingled waste.

For 1 kg. dry weight of organic commingled waste

Carbon content = 1(0.519) kg. : Nitrogen content = 1(0.519)(1/34.35) kg.

For x kg. dry weight of septage

Nitrogen content = x(2.30/100) kg.:Carbon content = x(2.30/100)(15.87/1) kg.

By using eq.(1), for this case too, we get

$$\frac{1(0.519)+x(2.30/100)(15.87/1)}{1(0.519)(1/34.35)+x(2.30/100)} = \frac{30}{1}$$

Or, x = 0.21 kg.

Volume of septage required = 0.21 kg. /(0.18x 0.99 kg/L.)
= 1.17 L.

Volume of organic commingled waste = 1 kg. / (0.55x0.22 kg/L.)
= 8.26 L.

Thus, 8.26 L. of organic commingled waste requires 1.17 L. of septage for make in ratio of .30:1

A1-2. Calculation of thermal inactivation coefficient.

Kinetics are often modeled assuming first order decay (Haug, 1993) as follows:

$$dn / dt = -k_d n \quad \text{(A1-2.1)}$$

Where n = viable cell population

k_d = thermal inactivation coefficient

If k_d is constant, integration of equation (A1-2.1) from an initial cell population, n_o to a later population, n_t, at time, t, yields

$$n_t = n_o e^{(-kdt)} \quad \text{(A1-2.2)}$$

Taking the log of both sides and rearranging, one can get

$$k_d = [\ln(n_o / n_t)]/t \quad \text{(A1-2.3)}$$

$$t = [\ln(n_o / n_t)]/k_d$$

Thus, plot of $\ln(n_o / n_t)$ vs t allow determination of thermal inactivation coefficient k_d.

Table A1-2. Value for plot of $\ln(n_o / n_t)$ and t.

Time	Waste combination 1		Waste combination 2	
	Total coliform bacteria (number/100ml)	Log $(N_0/N)_1$	Total coliform bacteria (number/100ml)	Log $(N_0/N)_1$
0	1.37×10^6	0	1.63×10^8	0
20	2.67×10^5	0.71	1.46×10^7	1.05
40	2.45×10^5	0.75	6.90×10^6	1.37
60	2.06×10^3	2.82	7.14×10^4	1.36
90	3.31×10^2	3.62	2.67×10^2	5.79

From the plots of $\ln(n_o / n_t)$ vs t as shown in Figures A1-2.1 and A1-2.1, one can obtain

$k_{d\,(\text{waste combination 1})} = 0.935$ 1/day
$k_{d\,(\text{waste combination 2})} = 1.189$ 1/day

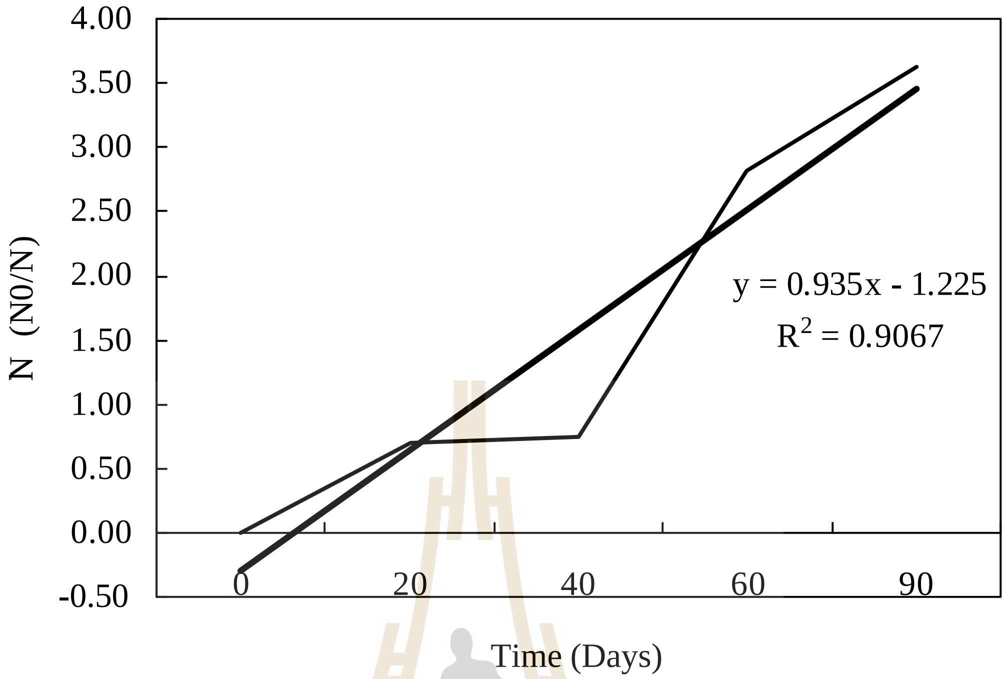

Figure A1-2.1 Plot of ln(n_o/ n_t) vs t for waste combination 1.

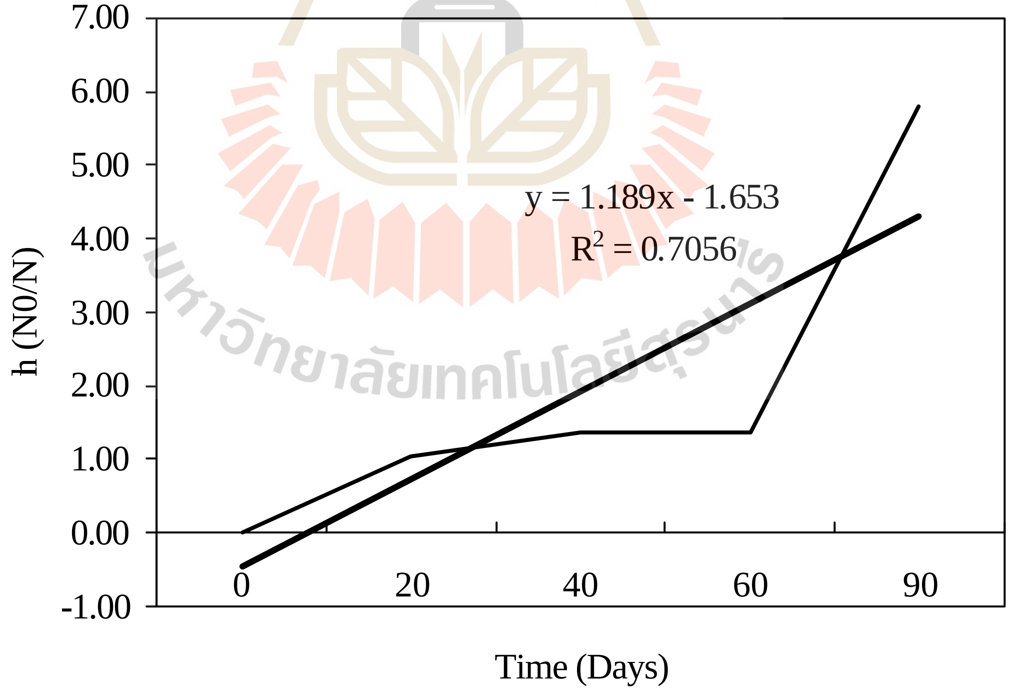

Figure A1-2.2 Plot of ln(n_o/ n_t) vs t for waste combination 2.

A1-3. Calculation of total nitrogen increase.

Analysis of total nitrogen has been done by using total kjedahl method (titrimetric). This method is based on the titration of basic ammonia with standard sulfuric acid using methyl red and bromocresol green indicator mixed with boric acid indicator solution to pale lavender end point. Detail has been given in the book by Patnaik (1997).

Calculation of nitrogen concentration in a sample of compost can be done by using the following formula.

$$\text{mg N/L} = \frac{(V_s - V_b)\,14000X}{\text{mL sample}} \qquad \text{(A1-3.1)}$$

Where V_s = mL of H_2SO_4 required for the titration of sample distillate

V_b = mL of H_2SO_4 required in the blank titration

X = Normality of H_2SO_4

$$\text{Normality } (X) = \frac{\text{molarity of } H_2SO_4 \times \text{weight of } H_2SO_4 \text{ in one mole}}{\text{mL sample}} \qquad \text{(A1-3.2)}$$

Where molarity (M) = 0.02 mole/L for the first titrant standardization (H_2SO_4), and for the second titrant standardization 0.025 mole/L

From equation (A1-2.2), one can get

$$X = \frac{(0.02 \text{ mole / L}) \times (98 \text{ g / mole})}{(98 \text{ g / mole}) / (6 \text{ eq / mole})} \qquad \text{(A1-3.3)}$$

= 0.12 eq/L for concentration of H_2SO_4 = 0.02 mole/L

$$X = \frac{(0.025 \text{ mole / L}) \times (98 \text{ g / mole})}{(98 \text{ g / mole}) / (6 \text{ eq / mole})} \qquad \text{(A1-3.4)}$$

= 0.15 eq/L for concentration of H_2SO_4 = 0.025 mole/L

Substituting the values of X in equation (A1-2.1), one can get

$$\text{mg N/L} = \frac{(V_s - 1)\,1680}{\text{mL sample}}, \text{ for concentration of } H_2SO_4 = 0.02 \text{ mole/L} \qquad \text{(A1-3.5)}$$

$$\text{mg N/L} = \frac{(V_s - 2.9)\,2100}{\text{mL sample}}, \text{ for concentration of } H_2SO_4 = 0.025 \text{ mole/L} \qquad \text{(A1-3.6)}$$

Where V_b = 1 mL , for concentration of H_2SO_4 = 0.02 mole/L

V_b = 2.5 mL , for concentration of H_2SO_4 = 0.025 mole/L

mL sample = 75 mL.

From equations (A1-2.5) and (A1-2.6), using different values of V_s obtained from the titration of sample distillate of each compost pile, the TKN values were evaluated as shown in Table A1-2.1.

Table A1-2.1. TKN evaluation.

Pile no.	V_s (mL)	V_b (mL)	mL sample (mL)	X (mole/L)	N (mg/mL)	Total TKN increase (mg/mL)
Waste Combination 1						
Run 1	120.6	1	75	0.12	2679	
	155.41	1	75	0.12	3459	780
Run 2	123.28	1	75	0.12	2739	
	146.48	1	75	0.12	3259	520
Run 3	133.1	1	75	0.12	2959	
	123.17	2.5	75	0.15	3379	420
Run 4	91.75	2.5	75	0.15	2499	
	106	2.5	75	0.15	2898	399
Waste Combination 2						
Run 1	97.4	1	75	0.12	2159	
	145.6	1	75	0.12	3239	1080
Run 2	103.6	1	75	0.12	2298	
	155.4	1	75	0.12	3459	1161
Run 3	107.2	1	75	0.12	2379	
	123.88	2.5	75	0.15	3399	2020
Run 4	80.3	2.5	75	0.15	2179	
	111.75	2.5	75	0.15	3059	880

APPENDIX B

Temperature change during the four composting runs

Table B1-1. The daily variations in the temperature during Run I.

Time (day)	Run I waste combination 1	Run I waste combination 2
0	27	27
1	30	32
2	52	57
3	30	31
4	31	31
5	31	32
6	32	32
7	31	32
8	30	31
9	29	31
10	30	30
11	30	30
12	29	30
13	28	29
14	28	29
15	29	28
16	30	28
17	30	28
18	31	29
19	30	29
20	28	30
21	29	30
22	28	30
23	28	31
24	27	30
25	27	29
26	29	29
27	30	28
28	30	28
29	29	29
30	29	29
31	28	29
32	28	28
33	29	29
34	30	30
35	31	31
36	31	31
37	30	32
38	31	31
39	30	30
40	30	29
41	30	29
42	28	29
43	28	29
44	28	29
45	27	28
46	28	27
47	28	27
48	27	29
49	28	29
50	28	29
51	29	30
52	30	30
53	30	30
54	31	31
55	31	31
56	30	31
57	30	31
58	30	31
59	28	30
60	29	30
61	27	30
62	27	29
63	26	28
64	26	28
65	27	28
66	27	28
67	27	29
68	28	29
69	28	30
70	28	30
71	29	30
72	29	31
73	30	31
74	31	31
75	32	32
76	31	32
77	32	32
78	31	31
79	31	31
80	31	32
81	30	31
82	30	31
83	30	31
84	31	30
85	31	31
86	31	30
87	30	30
88	30	30
89	29	30
90	30	30

Table B1-2. The daily variations in the temperature during Run II.

Time	Run II		Time	Run II	
(day)	waste combination 1	waste combination 2	(day)	waste combination 1	waste combination 2
0	27	27	51	30	30
1	31	32	52	31	30
2	55	55	53	31	30
3	30	31	54	30	31
4	30	30	55	31	31
5	30	29	56	32	32
6	31	29	57	30	31
7	31	30	58	30	31
8	30	29	59	29	30
9	30	28	60	29	30
10	30	29	61	29	29
11	29	30	62	28	29
12	29	28	63	27	28
13	28	28	64	28	28
14	28	29	65	28	29
15	29	30	66	30	30
16	30	30	67	30	30
17	30	31	68	31	31
18	31	32	69	31	32
19	30	31	70	31	31
20	29	32	71	30	31
21	29	31	72	29	30
22	28	31	73	29	31
23	28	31	74	30	31
24	27	30	75	31	32
25	27	29	76	32	32
26	28	29	77	32	32
27	28	30	78	31	31
28	29	29	79	31	31
29	30	29	80	30	31
30	29	28	81	30	31
31	30	28	82	29	30
32	31	27	83	30	30
33	31	27	84	31	30
34	30	28	85	31	31
35	31	29	86	31	30
36	31	30	87	32	30
37	31	30	88	31	30
38	30	30	89	29	30
39	30	30	90	29	29
40	30	29	91	30	29
41	29	29	92	30	29
42	29	29	93	31	30
43	29	29	94	29	30
44	28	28	95	30	29
45	28	28	96	31	29
46	27	27	97	31	30
47	28	27	98	30	30
48	29	28	99	30	29
49	28	29	100	31.5	31
50	29	29			

Table B1-3. The daily variations in the temperature during Run III.

Time (day)	Run III		Time (day)	Run III	
	waste combination 1	waste combination 2		waste combination 1	waste combination 2
0	28	27	51	31	30
1	31	31	52	31	30
2	54	59.5	53	31	30
3	32	31	54	32	30
4	31	30	55	32	31
5	31	30	56	32	31
6	31	30	57	30	31
7	31	30	58	30	31
8	30	29	59	29	29
9	30	29	60	29	30
10	30	29	61	28	29
11	29	28	62	28	29
12	29	28	63	29	28
13	28	28	64	30	29
14	30	28	65	30	29
15	31	30	66	31	29
16	30	30	67	31	29
17	32	31	68	31	30
18	30	31	69	32	30
19	29	30	70	32	31
20	29	32	71	32	31
21	29	32	72	32	31
22	28	30	73	32	30
23	28	31	74	32	30
24	28	30	75	32	30
25	29	29	76	31	32
26	30	29	77	31	32
27	30	28	78	30	32
28	30	28	79	31	31
29	30	29	80	31	31
30	29	29	81	31	31
31	30	29	82	32	31
32	32	28	83	32	29
33	32	29	84	30	29
34	32	29	85	30	29
35	31	29	86	29	30
36	31	30	87	30	30
37	31	30	88	30	30
38	31	30	89	31	31
39	30	30	90	31	31
40	30	29	91	31	31
41	30	29	92	32	31
42	29	29	93	32	32
43	29	29	94	32	32
44	28	29	95	31	32
45	28	28	96	31	30
46	28	27	97	31	31
47	28	27	98	30	31
48	29	29	99	30	31
49	30	29	100	32	31
50	30	29			

Table B1-4. The daily variations in the temperature during Run IV.

Time (day)	Run IV		Time (day)	Run IV	
	waste combination 1	waste combination 2		waste combination 1	waste combination 2
0	28	27	51	31	30
1	31	32	52	31	30
2	56	60	53	31	30
3	32	31	54	32	30
4	31	30	55	32	31
5	31	30	56	32	31
6	31	30	57	30	31
7	31	30	58	30	31
8	30	29	59	29	29
9	30	29	60	29	30
10	30	29	61	29	30
11	30	28	62	28	31
12	29	28	63	28	30
13	29	28	64	30	30
14	28	28	65	30	31
15	30	30	66	30	29
16	31	30	67	30	29
17	30	31	68	31	29
18	32	31	69	31	30
19	30	30	70	31	30
20	29	32	71	32	30
21	29	32	72	31	31
22	29	30	73	32	31
23	28	31	74	32	31
24	28	30	75	32	32
25	29	29	76	33	32
26	30	29	77	33	32
27	31	30	78	32	31
28	30	29	79	32	31
29	30	29	80	32	32
30	29	29	81	31	31
31	30	29	82	32	31
32	32	28	83	32	31
33	32	29	84	31	30
34	32	29	85	31	31
35	31	29	86	31	30
36	31	30	87	30	30
37	31	30	88	30	30
38	31	30	89	29	30
39	30	30	90	29	29
40	30	29	91	30	29
41	30	29	92	30	29
42	29	29	93	30	30
43	29	29	94	29	30
44	28	29	95	30	31
45	28	28	96	31	29
46	28	27	97	31	30
47	28	27	98	30	30
48	29	29	99	30	29
49	30	29	100	29	28
50	30	29			

Table B1-5. The hourly variations in the temperature during Run III.

Time	Run III		Time	Run III	
(day)	waste combination 1	waste combination 2	(day)	waste combination 1	waste combination 2
0	28	27	42	32	36
1	28	27	43	31	33
2	28	28	44	32	31
3	29	28.5	45	32	31
4	30	29	46	32	31
5	30	29.5	47	32	31
6	30	30	48	31	31
7	31	30	49	31	32
8	32	32	50	31	32
9	32	32	51	29	32
10	32	31	52	29	31
11	32	31	53	29	29
12	33	32	54	28	29
13	33	31	55	28	28
14	33	32	56	28	28
15	34	34	57	28	28
16	34	37	58	29	28
17	35	40	59	28	28
18	37	41	60	28	28
19	36	43	61	29	28
20	37	43	62	29	29
21	37	44	63	30	28
22	37	48.5	64	30	29
23	41	50	65	30	29
24	44	55.5	66	31	29
25	43	55.5	67	31	29
26	44	55.5	68	31	30
27	45	55	69	32	30
28	45	55	70	32	31
29	44	53	71	32	31
30	42	51	72	32	31
31	42	50			
32	41	50			
33	41	47			
34	40	43			
35	40	41			
36	37	37			
37	35	37			
38	35	37			
39	34	36			
40	32	35			
41	32	38			

APPENDIX C

Analysis of variance (ANOVA) results

Table C1-1. Statistical analysis at the beginning period (by ANOVA method).

Parameter		Sum of Squares	df	Mean Square	F	Sig.
% Moisture Content	Between Groups	71.40125	1	71.40125	2.89355	0.13984
	Within Groups	148.05615	6	24.676025		
	Total	219.4574	7			
Temperature	Between Groups	0.5	1	0.5	3.00000	0.13397
	Within Groups	1	6	0.16666667		
	Total	1.5	7			
pH	Between Groups	4.5	1	4.5	36.89533	0.00090
	Within Groups	0.7318	6	0.12196667		
	Total	5.2318	7			
Total Coliform Bacteria	Between Groups	4.75383E+16	1	4.7538E+16	151.14310	0.00002
	Within Groups	1.88715E+15	6	3.1453E+14		
	Total	4.94255E+16	7			
% Carbon	Between Groups	116.3575125	1	116.357513	37.09695	0.00089
	Within Groups	18.819475	6	3.13657917		
	Total	135.1769875	7			
% Total Kjehdahl Nitrogen	Between Groups	0.1081125	1	0.1081125	18.49394	0.00509
	Within Groups	0.035075	6	0.00584583		
	Total	0.1431875	7			
C/N ratio	Between Groups	0.6216125	1	0.6216125	0.74298	0.42182
	Within Groups	5.019875	6	0.83664583		
	Total	5.6414875	7			
% Total Phosphorus	Between Groups	0.00405	1	0.00405	13.88571	0.00978
	Within Groups	0.00175	6	0.00029167		
	Total	0.0058	7			

Table C1-2. Statistical analysis at the end period (by ANOVA method).

Parameter		Sum of Squares	df	Mean Square	F	Sig.
% Moisture Content	Between Groups	16.0461125	1	16.0461125	1.05144	0.34473
	Within Groups	91.566175	6	15.2610292		
	Total	107.6122875	7			
Temperature	Between Groups	0.78125	1	0.78125	0.40107	0.54990
	Within Groups	11.6875	6	1.94791667		
	Total	12.46875	7			
pH	Between Groups	0.0128	1	0.0128	0.19990	0.67049
	Within Groups	0.3842	6	0.06403333		
	Total	0.397	7			
Total Coliform Bacteria	Between Groups	6991930.125	1	6991930.13	5.89672	0.05128
	Within Groups	7114392.75	6	1185732.13		
	Total	14106322.88	7			
% Carbon	Between Groups	3.4716125	1	3.4716125	0.23275	0.64659
	Within Groups	89.492975	6	14.9154958		
	Total	92.9645875	7			
% Total Kjehdahl Nitrogen	Between Groups	0.0008	1	0.0008	0.06857	0.80219
	Within Groups	0.07	6	0.01166667		
	Total	0.0708	7			
C/N ratio	Between Groups	0.7688	1	0.7688	0.25562	0.63118
	Within Groups	18.0456	6	3.0076		
	Total	18.8144	7			
% Total Phosphorus	Between Groups	5E-05	1	5E-05	0.31579	0.59450
	Within Groups	0.00095	6	0.00015833		
	Total	0.001	7			

BIBLIOGRAPHY

Miss Sudthida Kriengkasem was borned on February 26, 1977, in Bangkok. She graduated high school from Chaiyaphumpakdeechumphol School. She received her Bachelor's Degree in Environmental Engineering from Suranaree University of Technology (SUT), Nakhon Ratchasima in 1998 and started Master's Degree Program since 1999.