Study on Bin Composting Process: Application of Forced and Passive Aeration

by

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A project submitted to the Department of Civil Engineering of Khulna University of Engineering & Technology (KUET), Khulna in partial fulfillment of the requirements for the degree

of

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APPROVAL

This is certify that the thesis submitted by Md. Shajadur Rahman, Roll No- 0401515, entitled as "Study on Bin Composting Process. Application of Forced and Passive Aeration" to the Department of Civil Engineering, Khulna University of Engineering & Technology (KUET), Khulna, Bangladesh has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, in May, 2008.

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ABSTRACT

Composting is an age-old technique to manage solid waste. Composting with appropriate process of aeration reduces solid waste volume and the end product can be used as organic fertilizer and other beneficial purposes. Some times larger scale composting process is difficult due to big investment and other management problems. However, there is an option that, the individuals can convert their kitchen and garden waste efficiently to compost using different bins. This study work was conducted to investigate the effect of forced and passive aeration on bin composting process. For this six runs of bin composting process is performed. For both forced and passive aeration composting specially designed 50 liters capacity plastic bins were used. Suitable organic waste was collected from student's hall of Khulna University of Engineering & Technology, KUET and saw dust from local sawmills and paper from offices of KUET. The individuals sold waste were mixed with selected proportions. Before and after experiments the physical parameters like moisture content, volatile solids and fixed solid was performed. Temperature was measured regularly in bin composting process for forced and passive aeration. Degree and extent of degradation of waste mixture were identified through different composting process. Simple mass balance analysis was developed for two types of bin composting process. The analysis also helps to characterize the compost. The compost released from every experiments of bin composting was used as feedstock of self-heating test. Some thermo flask was used for self-heating test. Temperature developed in the flask was measured manually using thermometer. The physical parameters were tested before and after all self-heating test runs. The available data from self-heating test are used to find out the biological stability of the compost. The results shows that (i) Similar set of composting using similar initial waste mixture shows almost similar area under temperature curve, that is the area is almost same for forced and passively aerated composting. In first experiment (Exp-1) of this type the areas are 8174 °Ch and 9541 °Ch for passively and forced aerated bin respectively. In another experiment (Exp-4) of this type the areas are 10584 °Ch and 10350 °Ch for passively and forced aerated bin respectively. (ii) Since the range of degradation and area under temperature curve for both process is almost same, therefore the passively aerated bin composting is suggested for batch purpose. It does not need external energy for aeration. In forced aerated bin composting 0.06 kw/h energy is needed for aeration for single aquarium aerator. (iii) Almost no leachate and offensive odor were detected during all bincomposting experiments. This can be taken as effectiveness of the bin composting process. (iv) Most of the mass balance shows the general trend of volatile solid reduction from beginning to end of the composting process. This creates a physical feeling of mass reduction in composting process.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure No.		Page No.

ABBREVIATIONS

SW	: Solid Waste
MC	: Moisture Content
VS	: Volatile Solid
FS	: Fixed Solid
KUET	: Khulna University of Engineering & Technology
BUET	: Bangladesh University of Engineering & Technology
KCC	: Khulna City Corporation
BRAC	: Bangladesh Agricultural Research Center
BBS	: Bangladesh Bureau of Statistic
NGO	: Non – Government Organization
PVC	: Polly Venial Chloride

CHAPTER ONE

INTRODUCTION

1.1 General

Solid wastes are all wastes generated from human activities in daily life that are normally solid in nature and are discarded as useless or unwanted. The increasing rate of solid waste generation from different sources creates environmental hazards. More stringent environmental regulations for new landfill sites and incinerators have introduced many new techniques of waste disposal. This includes costly and cost effective solid waste management polices. It is found from the characteristic analysis of solid waste particularly the domestic waste that it contains mostly organic wastes as kitchen garbage is the dominant part of domestic waste in Bangladesh. The huge quantity of organic waste (above 70% of total waste) can therefore be dumped directly into the landfill or can be degraded. If the waste dumped directly into the land fill may create different problems due to the long term (20-30 years) anaerobic reactions. The anaerobic reaction usually generates methane and other air pollutants. The leacheates of this anaerobic decomposition also pollute under ground water. On the other hand, if the degradable part of organic solid waste converted to compost offers a short-term waste management. The Composting is the controlled aerobic biological decomposition of organic matter into stable, humus like product called compost. It is essentially the same process as natural decomposition except that it is enhanced and accelerated by controlling environmental conditions and mixing organic waste with other ingredients to optimize microbial growth.

The main objectives of composting are to reduce its volume, weight and moisture content, minimize potential odor, decrease pathogens and increase potential nutrients. This process minimizes spread of diseases because of the destruction of some pathogens and parasites at elevated (composting) temperature. The final product of composting (aerobic degradation) is known as compost can be beneficially used as soil conditioner, fertilizer or other purposes. Presently composting is gaining increased popularity for recovering of organic part of solid waste.

In Bangladesh from small scale to family size bin-composting processes has been started in different places (Waste Safe 2005). This type of bin composting process is cost effective and environmental friendly. However very few scientific results are available so far. For this reason this project has been under taken. Presently the research has greater importance in the field of solid waste management to convert the organic part of solid waste into compost using bins with different mode of aeration.

1.2 Objectives of the study

- To know the temperature variation in two types of bin composting process namely forced aerated bin composting and passively aerated bin composting.
- To determine the degree and extent of degradation of compost produced after first stage and second stage composting.
- To develop different mass balances for two types of bin composting process.

1.3 Organization of the study

This report contains introduction, literature review, methodology and experimental result as shown below.

Chapter 1 (One): Includes general introduction, objectives of this study. In chapter 2 (Two) literature review covering details of composting. Various control parameters, microbiology of composting. In chapter 3 (Three), a brief description of methods and methodology including construction of bin are presented. Chapter 4 (Four) includes the experimental results including analysis of various physical parameters and simple mass balance of bin composting and analysis of biological stability of compost by means of self-heating test. In chapter 5 (Five) a general discussion on the findings of the study, conclusions and a number of recommendation for future study are provided.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical Overview

It is believed that composting began shortly after humans started to cultivate food. The type of compost was most likely animal manure. Compost was known to the Romans, the Greeks, and the Tribes of Israel. The act of composting was discussed in the ten th or twelve th century by Ibn al Awam, in his "Book of Agriculture" or "Kitab al Falahah". In North America the native tribes and the European settlers both used compost. Jean Baptiste Boussingault of France laid the foundations of agricultural chemistry in 1834, by disproving the humus theory by demonstrating that plants obtain nourishment from certain chemicals in solution and not the humus itself (VSANRCC-1992).

Post World War II, agriculture became more mechanized and synthetic fertilizers began to reduce the use of manure and compost to help soil fertility. In 1940, Sir Albert Howard published "An Agricultural Testament" which started the movement of organic farming and gardening (VSANRCC-1992). Today organic methods of farming and gardening are more popular than ever as farmers are moving away from harmful fertilizers and pesticides. With this growing movement, ironically, there comes a return to past methods involving the use of natural compost or manure to re-nourish soils. Over the past two to three decades, farmers have not exclusively been the ones to see the benefits of large scale composting. Cities, towns, and municipalities are starting to become aware of the value of large scale composting because of the disappearing space in landfills and the difficulty and cost associated in establishing new ones.

2.2 Composting Substrates

The organic matters that are biodegradable are known as composting substrates.

Organic matters
• Food wastes • Vegetable wastes • Waste paper • Saw dust • Wood saw

Each person is likely to produce 0.45 kg of solid waste per day with an organic content of 50 to 70 percent and moisture content between 60 to 70 percent (Waste safe 2005 and Ahmed & Rahman -2000).

2.3 Microorganisms

The major objectives in most biological conversion processes are the conversion of the organic matter in the waste to a stable product. In accomplishing this type of treatment, chemo heterotrophic organisms are primary importance because of their requirement of organic compounds for both carbon and energy source. To continue to reproduce and function properly, an organism must have a source of energy. Two most common source of carbon for cell tissue are organic carbon and carbon dioxide. Organisums that use organic carbon for formation of cell tissue called heterotrophs. Organisms that derive carbon from carbon dioxide are called autotrophs as shown in Table2.1.

Table 2.1 General classifications of microorganisms by source of energy and carbon

Classification	Energy source	Carbon source
Autotrophic		
• Photoautotrophic	Light	CO_2
• Chemoautotrophic	Inorganic oxidation-reduction reaction	CO_2
Heterotrophic		
• Photoheterotrophic	Light	Organic carbon
• Chemoheterotrophic	Organic oxidation-reduction reaction	Organic carbon

(Tchobanoglous, 1993)

2.3.1 Types of Microorganisms

Organisms that are dependent on aerobic respiration to meet heir energetic needs can exists only where there is a supply of molecular oxygen. These organisms are called obligate aerobic. There is another groups of microorganisms, which has the ability to grow in either the presence or absence of molecular oxygen. These organisms are called facultative anaerobes. Microorganisms are commonly classified, on the basis of cell structure and function of eukaryotes, eubacteria and archaebacteria as shown in Table 2.2 (Tchobanoglous, 1993 and Metcalf and Eddy, 1993). The prokaryotic groups (eubacteria and archaebacteria) are of primary importance in biological conversion of the organic fraction of solid waste are generally refer to simply be bacteria. The eukaryotes are important in biological conversion of organic waste include fungi, yeasts and actinomycetes.

Table 2.2 Classification of Microorganisms

Group	Cell Structure	Characterization	Representative Members
Eucaryotes	Eucaryotic	Multicellular with extensive differentiation of cells and tissue Unicellular or myceliar; little or no tissue differentiation	Plants (Seed plants, ferns mosses) Animals (vertebrates invertebrates) Protists (algae, fungi protozoa)
Eubacteria	Procaryotic	Cell chemistry Similar to eukaryotes	Most Bacteria
Archaebacteria	Procaryotic	Distinctive cell chemistry	Methanogens, halophiles, thermacidophilics

(Tchobanoglous, 1993 and Metcalf and Eddy, 1993)

2.3.2 The biology of composting

Bacteria and "germs" have a negative reputation for causing disease. In case of microorganisms this reputation is positive. It is essentially a natural process of decomposing in which dead organic matters are beneficially converted to plant nutrients. The earth would be cluttered with the bodies of dead plants and animals were it not for natural organisms that convert nature's waste into humus. Composting is a method of harnessing these organisms to rapidly accelerate the rate of organic waste decomposition. Composting can be understood as a type of bacteria farming. The standard methods are followed to determine various bacteria in the compost sample. All analysis is performed by spread plate method according to standard procedure (Parks, et al, 1988). Like other forms of livestock, microorganisms need food, air, and water. Food is the organic waste. Mixing and aerating provide air. With the proper balance of food, air, and water coupled with sufficient volume to hold heat, microorganisms will thrive and generate heat to initiate and sustain the composting reaction.

2.4 Composting process

Composting is the process of bacterial conversion of organic solid and semi- solid organic waste to stable solid transported without any environmental adverse effect and can be used as organic manure for improvement of soil quality and fertility. Composting is an ancient resource recovery process practiced, widely in both developing and industrialized part of the world.

2.4.1 Types of composting

Natural Composting: If yard waste is left to accumulate in a pile for extended periods of time, it is no longer begins to enter into the territory of composting. The simplest compost piles are increasingly larger mounds of organic waste that are left to sit and rot over time. The householder often cares little for using the dark and crumbly material that appears after several years of composting.

Passive composting: In passive composting mix raw material needs to be turned periodically to rebuild the porosity. Aeration is accomplished through the passive movement of air through the waste. This requires that the volume of waste should be small enough to allow passive air movement. If it is too large, anaerobic zones form. Special attention should be given to the mixing of raw material. The mix must be capable of maintaining the necessary porosity and structure for adequate aeration throughout the entire composting period. The passive composting method requires minimal labor and equipment. The method is often used to compost leaves.

Active Composting: It is a process of maximizing the natural decomposition of organic matter to produce stable humus in as short a time as possible in a minimal amount of space without generating odors or other nuisances. It is characterized by various degrees of mixing and aeration within a controlled mass of organic material and moisture. When properly managed, an active compost pile generates temperatures over 60°C and reduces the volume of the original waste down three to ten times in as little as thirty days. Active composting involves either a bin enclosure or a properly formed pile without a bin.

2.4.2 Basic composting process

Composting is basically a biological process and is dependent on several important actors. Basic composting process is shown in the following Figure 2.1.

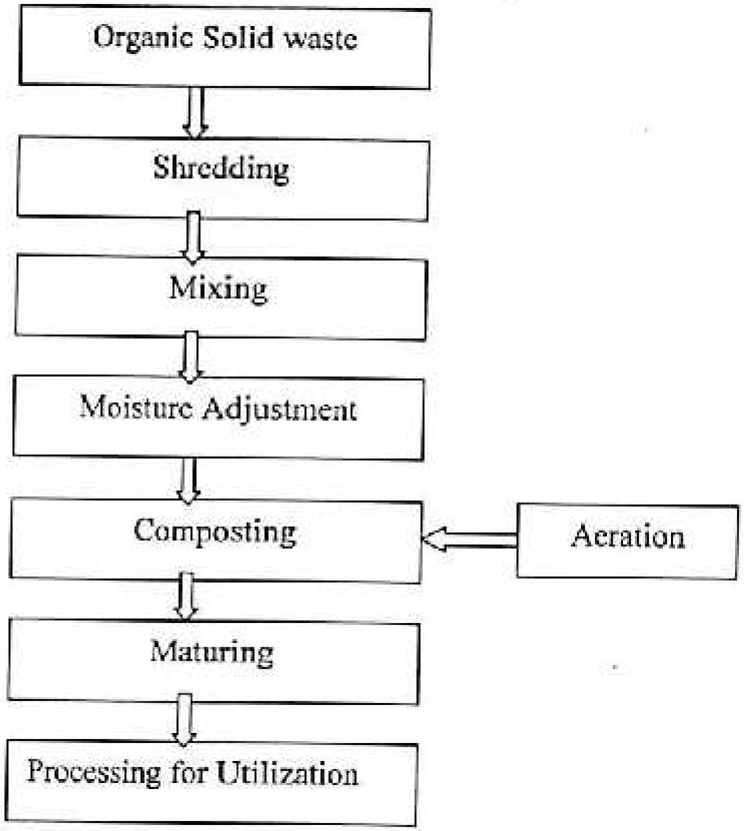

Figure **2.1** Flow diagrams for basic composting process (Ahmed and Rahman, 2000)

2.5 Classification of composting system

Several composting methods are applicable to farm operation. The method chosen is dependent on the quality, capital investment, labor investment, time investment, and land and raw material availability. The four broad methods of composting developed for use in large-scale composting are passive piles, windrows, aerated static piles, and in-vessel systems.

2.5.1 Passive composting piles

The passive composting pile method involves forming the mixing of waste and formation of pile as shown in Figure 2.2. The pile may be turned periodically primarily to rebuild the porosity. Aeration is accomplished through the passive movement of air through the pile. This requires that the pile be small enough to allow for this passive air movement. If it is too large, anaerobic zones form. Special attention should be given to the mixing of raw material. The mix must be capable of maintaining the necessary porosity and structure for adequate aeration throughout the entire composting period. The passive composting method requires minimal labor and equipment. The method is often used for composting leaves. Because aeration is passive, this method is slow and the potential for development of anaerobic conditions is greater. This, of course, increases the potential for odor problems.

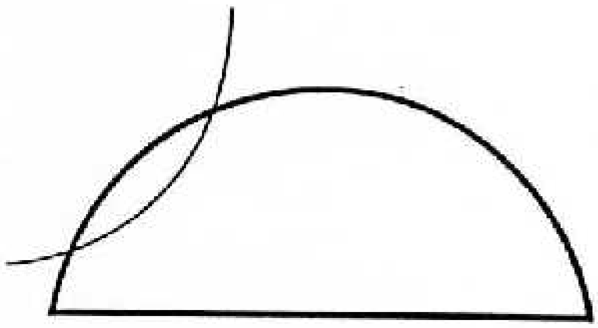

Figure 2.2 Passive compost pile (National Engineering Handbook, Part 637 Environmental Engineering, Chapter 2, Composting, page 2-37)

2.5.2 Windrow

The configuration of windrows is shown in Figure 2.3. These piles are turned regularly. Raw material is either mixed before pile formation or mixed as a part of pile formation. Windrow's shapes and sizes vary and depend on the climate, equipment and on the material used. Typically, windrows are 6 to 10 feet high, 15 to 20 feet wide, and are up to several hundred feet long. A wet climate requires a windrow shape that allows moisture runoff. A concave top may be required in drier climates to collect water and maintain pile moisture. Smaller windrows experience greater heat loss, while larger piles have the risk of formation of anaerobic zones and odors. Dense material, such as manure, should be piled at a lower height than fluffy material, such as leaves. Bucket loaders and backhoes can produce higher windrows than turning machines.

Windrows are aerated by passive aeration as in the passive composting method. The porosity necessary for adequate passive aeration is maintained by regularly turning the windrows. Turning windrows also serves to aerate the pile, mix the material; releases heat, water vapor, and gases; and composts material more evenly. Because significant amounts of heat are released upon turning the windrow, turning prevents excessive temperature accumulation within the windrow. Turnings are more frequent during the initial stages of composting when the most intense microbial activity takes place and temperature evolution is the greatest. The schedule of turnings during composting varies from operation to operation depending on temperature levels in the pile, consistency of the manure, labor and equipment availability, season, and how soon the compost is needed.

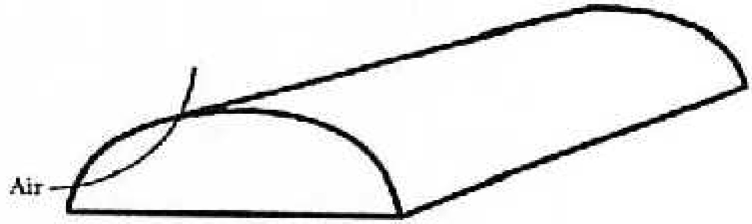

Figure 2.3 Windrow composting (National Engineering Handbook, Part 637 Environmental Engineering, Chapter 2, Composting, page 2-37)

The turning frequency can range from several times weekly to monthly. The number and frequency of turnings needed to achieve the desired quality compost is best determined through experience of simulation of appropriate model. The duration required finishing the first stage composting process using the windrow method ranges from 3 to 9 weeks. The duration is dependent on the type of material being composted and the frequency of the turnings. The more frequent the turnings, the shorter the duration will be. For a two-month composting period, five to seven turnings are typical. Curing generally lasts at least one month.

Commonly available farm equipment can be used for the initial mixing and pile formation and for turning. Most windrow operations use bucket loaders for mixing, pile formation, and turning. Manure spreaders are used to construct windrows. Backhoes, grapple loaders, potato diggers, and snow blowers are also used. Dump trucks, dump wagons, and bucket loaders can be used for pile formation and material transport. Specialized windrow turners are available. The windrow method is the most widely used by farmers because of its adaptability and flexibility to farm operations and its ability to produce quality compost.

2.5.3 Passively aerated windrows

Passively aerated windrows are not turned as shown in Figure 2.4. Aeration is accomplished solely through the passive movement of air through perforated pipes embedded in the base layer of the pile. Another feature that distinguishes this method from turned windrows is the use of a base layer and a top layer in windrow construction. The base layer is typically composed of peat moss, straw, or finished compost. The main characteristic desired of this layer is that it be porous so that the air that is coming through the pipes is evenly distributed. It also helps to insulate the pile and absorb moisture. The top layer is composed of peat moss or finished compost and serves several functions. The first function is to retain odors through the affinity of peat moss and finished compost for the molecules that cause odors. The top layer also deters flies and retains moisture and ammonia.

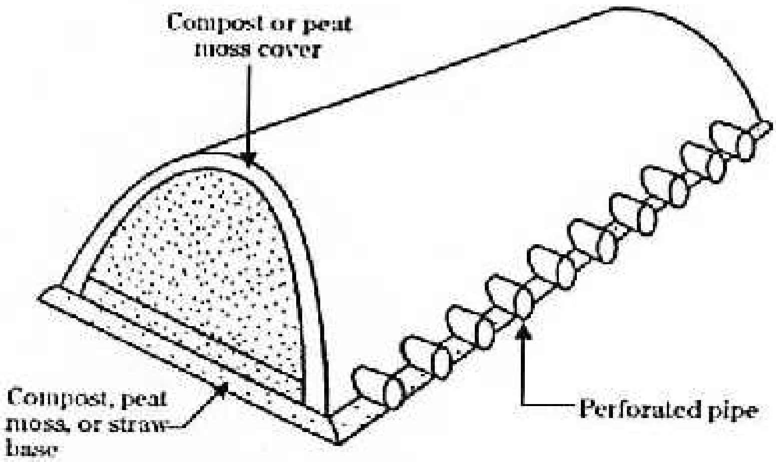

Figure 2.4 Passive aerated windrow (National Engineering Handbook, Part 637 Environmental Engineering, Chapter 2, Composting, page 2-37)

Initial construction of this type of windrow requires more labor than other windrow methods. Once the windrow is formed, however, the labor requirement is primarily that necessary to monitor the temperature and porosity of the pile.

As in the passive composting system, the key element is to formulate a mix with good porosity and structure to allow for adequate aeration. Peat moss has been the primary amendment with this method because of its good porosity and structural qualities. Passive aeration also requires that the piles not be as high as those are for the windrow method. The typical height is 3 to 4 feet with a width of about 10 feet. The bottom and top layers should each be about 6 inches thick.

2.5.4 Aerated static pile

In aerated windrow method the air is forced into the static pile as shown in Figure 2.5. The main difference between a passively aerated windrow and an aerated static pile is that the aerated static pile uses blowers that either suction air from the pile or blow air into the pile using positive pressure.

The suction method of aeration allows better odor control than positive pressure aeration, particularly if the air is directed through an odor filter. An odor filter is essentially a pile of finished compost that has an affinity for odor causing molecules. Some other odor treatment system can also be used to treat the air coming out of the pile. The disadvantage of using suction is that not as much air can be pulled through the pile as can be pushed through using positive pressure.

The blowers used for aeration serve not only to provide oxygen, but also to provide cooling. Blowers can be run continuously or at intervals. When operated at intervals, the blowers are activated either at set time intervals or based on compost temperature. Temperature- set blowers are turned off when the compost cools below a particular temperature. Blower aeration with temperature control allows for greater process control than windrow turning.

A forced aeration static pile has a base layer and top layer much like the passively aerated windrow. The purpose of the base layer for the aerated static pile is to distribute air evenly either as it enters or leaves the aeration pipes. This requires porous material, such as wood chips or straw. The top layer is generally composed of finished compost or sawdust to absorb odors, prevent fly, and retain moisture, ammonia, and heat.
As with all static piles, the initial mix and pile formation must have proper porosity and structure for adequate air distribution and even composting. A decay-resistant bulking agent is required to provide the necessary porosity. Wood chips are a good example of a bulking agent. They undergo minimal degradation during the composting process and can be screened from the finished compost and reused.

The use of forced aeration also requires additional calculations. The size of the blower as well as the number, length, diameter, and types of pipes to use for adequate aeration must be determined. Pipes and blowers interfere with pile formation and cleanup operations. Aerated static piles are not commonly used for farm-scale composting operations.

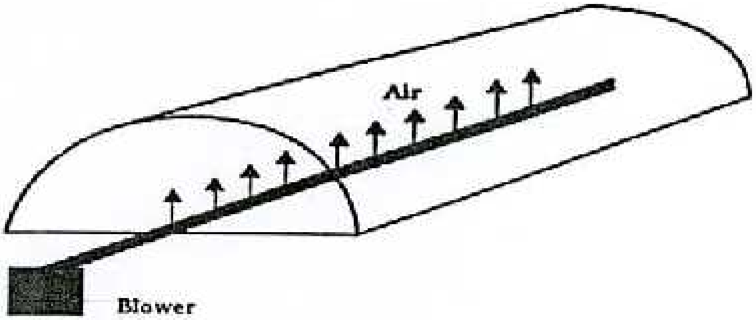

Figure 2.5 Aerated static piles (National Engineering Handbook, Part 637 Environmental Engineering, Chapter 2, Composting, page 2-38)

2.5.5 In-vessel system

2.5.5.1 Bin Composting

Bin composting is the most popular and advance version of home composting system that over comes problems experienced in other composting systems. There are different types of bins available for home composting and generally it varies from 200- 300L in size. These are from different materials such as cement/concrete, plastic, metal, etc as shown in Figure 2.6. The bins allow higher stacking of composting materials and better use of floor space than freestanding piles. Bins can also eliminate weather problems and reduce problems of odors, and provide better temperature control. At present, most bins are designed to suit the urban landscape as well. As mentioned before, composting bins are popular in urban areas with emerging solid waste disposal problems and therefore, it is important to give proper guidance to the community in using composting bins. It is identified that some technical and management problems have been the main constraints in popularizing the composting bin among citizens.

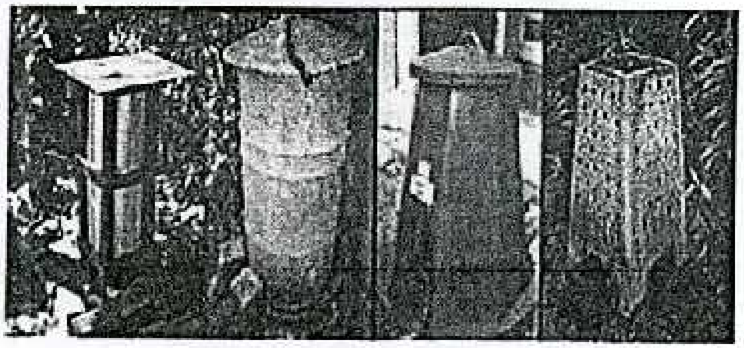

Figure 2.6 Different composting bins available in Sri Lanka

2.5.5.2 Rectangular agitated bed

The rectangular agitated bed method is shown in Figure 2.7, uses long, narrow beds in which to compost and an automated turner for periodic turning. The turner is supported on rails that are mounted on either side of the bed for its whole length. As the turner moves along the bed, the compost is turned and moved a set distance until it is ejected at the end of the bed. In some systems blowers are also used to force air into the beds. The length of the bed and the turning frequency determines the duration of the composting process. An extended curing period is generally required.

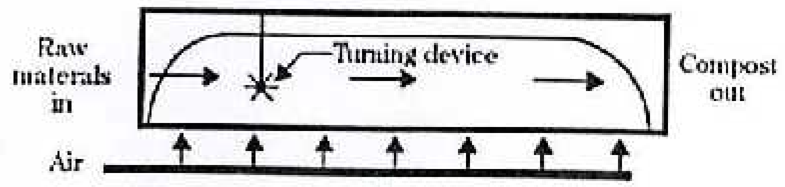

Figure 2.7 Rectangular agitated bed composting (National Engineering Handbook, Part 637 Environmental Engineering, Chapter 2, Composting, page 2-39)

2.5.5.3 Silo

The silo method shown in Figure 2.8 is a rapid composting method that requires a prolonged curing stage. Compost material is loaded into the silo at the top and removed from the bottom using an auger. Aeration is provided through the base of the silo so that air is forced upward through the compost material. Outlet air can be collected from the top and directed to an odor treatment system, such as a bio filter.

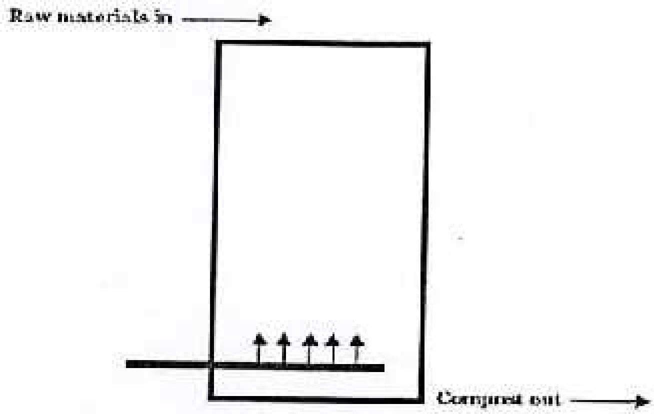

Figure 2.7 In-vessel silo composting (National Engineering Handbook, Part 637 Environmental Engineering, Chapter 2, Composting, page 2-39)

2.5.5.4 Rotating tube

The rotating tube shown in Figure 2.9 is a method that can be used where small amounts of waste require composting. The compost mix is loaded in the upper part of the tube. The mix will rest on the first baffle plate. When the tube has filled from the first baffle plate to the top of the tube, it is rotated to aerate the compost mix and empty the tube above the first baffle plate. This allows additional compost mix to be loaded in the tube. Ideally, the tube is operated so the composting process is complete by the time the material exits the tube. Tube size will be limited to what can be rotated when it is filled to capacity.

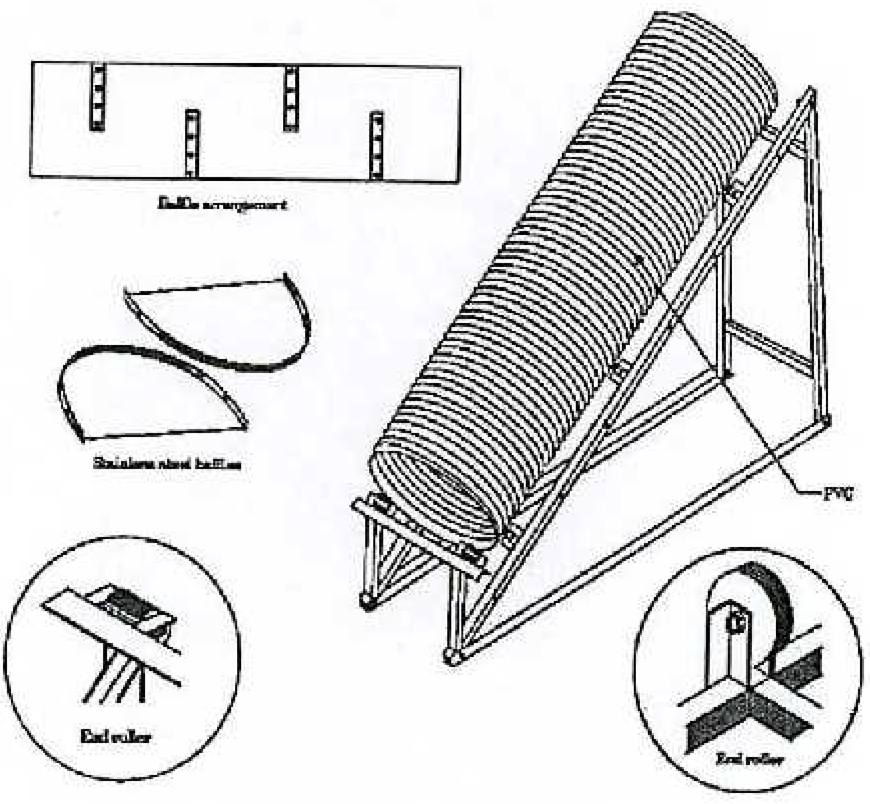

Figure 2.9 Rotating tube composting (National Engineering Handbook, Part 637 Environmental Engineering, Chapter 2, Composting, page 2-40)

2.6 Factors affecting the composting process

2.6.1 Particle size, porosity, structure and texture

The ideal particle size is around 2 to 3 inches. In some cases, such as in the composting of kitchen waste, the raw material may be too dense to permit adequate airflow or may be too moist. A common solution to this problem is to add a bulking agent (straw, dry leaves) to allow for proper airflow. Mixing materials of different sizes and textures also helps aeration the compost pile.

2.6.2 Oxygen/aeration

If there is insufficient oxygen, a different set of anaerobic microorganism dominates the degradation process and produce odorous intermediate products such as methane, organic acids and hydrogen sulphide. A constant supply of oxygen will give the aerobic microorganisms an advantage over the anaerobic microorganisms. Approximately a 5% minimum concentration of oxygen is required within the pore spaces in the media. Aeration is the process of providing oxygen into the composting material. This will also provide a platform to remove water vapour, gases and excess heat trapped within the material. Aeration is common practice with high rate large scale composting facilities.

2.6.3 Moisture content

Moisture supports the metabolic processes of the microorganisms. Water is the medium for chemical reactions. Biological activity ceases below 30% (Bari & Koning 2001) moisture content and in theory activity is optimal when materials are saturated. Generally moisture content of between 40% and 65% should be maintained. The moisture content below ideal levels is the best approach (Becker and Köter, 1995). To determine the moisture content the sample is placed in the oven at 105 ^{0}C for 24 hrs. It is expressed as percentage.

The moisture content is determined by using the following formula (Jackson, 1973).

$$M.C\ \% = 100 \times (\text{Weight of water in the sample} / \text{Total weight of the sample})$$

At moisture content of below 40%, microorganism activity will continue but at a slower rate and above 65% water will displace much of the air in the pore spaces of the composting material. This will limit the movement of air and lead to anaerobic conditions. The water holding or water absorbing capacity of the compost material is also pertinent because the ideal moisture at which a material will compost is related to the water holding capacity of the material. Optimal biological activity occurs at 60 to 80 percent of the water holding capacity (Brinton 1993).

2.6.4 Temperature

Composting takes place within two temperature ranges known as mesophilic (10° – 40°C) and thermophilic (over 44°C). It is generally accepted that maintaining temperatures between 45 °C and 65 °C allows for effective composting. The thermophilic temperatures are favored in the composting materials, because they destroy more pathogens, weed seeds and fly larvae. In some composting processes. Temperatures can continue to rise above 78 °C due to insulation effects and on-going microbial activity. At these temperatures many microorganisms die or become dormant and the process effectively stops until the microorganisms can recover. A convenient and meaningful compost parameter to monitor is temperature. Temperature is an indicator of microbial activity. By recording temperatures daily, a normal pattern of temperature development can be established. Deviation from the normal pattern of temperature increase indicates a slowing of or unexpected change in microbial activity. The temperature should begin to rise steadily as the microbial population begins to develop. If it does not begin to rise within the first several days, adjustments must be made in the compost mix. (Comp. 1)

2.6.5 Nutrients and the Carbon Nitrogen (C: N) ratio

The microbes involved in composting use carbon for energy and nitrogen for protein synthesis. The proportion of these two elements required by the microbe's averages about 30 parts carbon to 1 part nitrogen. Accordingly, the ideal ratio of Carbon to Nitrogen (C: N) is 30 to 1 (measured on a dry weight basis). This ratio governs the speed at which the microbes decompose organic waste. The Carbon-Nitrogen ratio is very near to ideal value of plant life (BRAC, 1997). Most organic materials do not have this ratio and, to accelerate the composting process, it may be necessary to balance the numbers by mixing different substrates. Kitchen waste is rich in nitrogen while garden waste is in poor. The compost produced from kitchen garbage in different seasons in Bangladesh has very good Nutrient values and also very good microbial quality and can effectively be used as soil conditioner (Moqsud M.A. and Rahman, M.H, 2004).

2.6.6 pH

Organic matter with a wide range of pH values from 3 to 11 (Tchobanoglous, 1993) can be composted, but the more desirable pH range for composting is between 5.5 and 8.5. The pH varies with time during the composting process and is a good indicator of the extent of decomposition within the compost mass. The optimum pH range for most bacteria is between 6 to 7.5. During the initial period (first 2 to 3) days pH drops 5 or less and then begins to rise to about 8.5 for the remainder of the aerobic process. If the digestion is allowed to become anaerobic, the pH will drop about to about 4.5. To minimize the loss of nitrogen in the from of ammonia gas, pH should not above 8.5 pH of the compost is determined by adding 10 gm of compost sample (from the plant) in a 100 ml distilled water and mix thoroughly for several minutes (Jackson, 1973). Then the digital pH meter (Model 3051,JENWAY) is used to determine the pH value of the compost directly.

2.7 Product stability and quality of the compost

The following features are visible when the compositing is completed in a proper manner. Good quality control programme is required if it is intended to market or commercialize the product, targeting the large-scale agricultural systems (especially for organic farming).

- Dark brown to black in colour.
- Practically insoluble in water.
- Has a C/N Ratio ranging from 10 to 20
- Has a beneficial effect both on the soil and the growing crops.
- Free from weed seeds and pathogens.

Precaution is necessary when using compost produced from mixed garbage. This compost may be contaminated with:

- Heavy metals of Arsenic, Lead, Cadmium and Mercury are extremely harmful to both humans and domestic animals.
- Pathogens, Tuberculosis etc.

Compost stability as well as quality and maturity could be measured by self-heating test. The stability indexes of compost are shown in Table 2.3.

Table: 2.3 Classification of compost according to degree of biological stability

Degree of Biological Stability (Stability Index SI)	V Stable	IV	III	II	I	I Unstable
T_{max} in °C	20-30	30-40	40-50	50-60	60-70	>70
I_{max} in °C/h	<0.3	0.3-0.45	0.45-0.8	0.8-1.4	1.4-2.0	>2.0
Area A_{72} in °C.h	<1700	1700-2000	2000-2500	2500-3000	3000-3500	>3500
RA in mg O_2/g VS-h	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2.0	

RA =respirometric activity; [a]Based on Iannotti et al.[1994] as cited by Epstein [1997]

Quality of compost depends on some physical and biological parameters like colour, Moisture content, Odour, C:N ratio and Pathogen etc as shown in Table 2.4

Table: 2.4 Important Quality standards for compost

PROPERTIES	REQUIREMENTS
Physical parameters:	
Colour	Brown / grey to dark black
Keeping properties	Not less than 12 months under room temperature
Moisture content	Not more than 25% by dry weight
Odour	Not unpleasant odours
Particle size	Residue should be <2% through 4 mm sieve
Sand content	<10%
Nutrient requirement :	**Minimum requirement**
Nitrogen	1.0%
Phosphorous	0.5%
Potassium	1.0%
C:N ratio	10-25
Heavy metals	**max ppm (maximum parts per million)**
Cadmium	10
Chromium	1000
Copper	400
Lead	250
Mercury	02
Nickel	100
Zinc	1000
Biological parameters:	**Requirement**
Faecal coli forms	Should be free
Salmonella	Should be free
Viable weed seeds	< 16 per square metre

(Sri Lanka Standards SLS 1246:2003)

2.8 Theoretical analysis of Self-heating test

The temperature curve obtain in the self-heating test is the heat energy changes in the waste sample over time. The simplified heat energy balance can be foemulated and described as follows (Koning 1997):

$$M.c[dT/dt] = [dT/dt]\,H_1 - U.A(T-T_a) - [dH_2O/dt]\,L_e \;......(1) \quad \text{in J/h}$$

Change of heat energy in the sample	Biological heat generated by degradation of VS in waste	Loss of sensible heat to surroundings	Loss of latent heat due to evaporation

Where

M = mass of wet waste sample, with $M = FS + VS + H_2O$, g

M = fixed solids (inert mineral matter in waste) mass of wet waste sample, with $M = FS + VS + H_2O$, g

VS = Volatile solids (degradable organic matter in waste), g

H_2O = water content in the waste sample, g

c = specific heat capacity of the wet waste sample, with $c = (FS.c_{FS} + VS.\,c_{VS} + H_2O.\,c_{H2O})/\,M$, J/g. °C

T = temperature of wet waste sample in vacume flask, °C

t = time since start of test, h

H_1 = heat energy generated by the degradation of VS, J/g

L_e = latent heat of evaporation, J/g

U = over all coefficient of heat transfer through top, side and bottom of the filled vacume flask, j/h.m^2. °C

A = total surface of top, side and bottom of filled vacuum flask, m^2

The heat energy balance is not sufficient for prediction of temperature and would have to be with a mass and water balance. A simplified approach of analysis of the energy balance is based on the temperature curve along and easily obtainable data. Dividing equation 1 by M.c gives the derivatives of the obtained temperature curve versus time, in °C /h :

$$[dT/dt] = [dVST/dt]\,H_1/M.c - U.A/M.c(T-T_a) - [dH_2O/dt]\,L_e/M.c \;...(2 \quad \text{in °C}$$

rate of temperature change in the sample	rate of temperature change due to biological heat generated	rate of temperature decrease due to loss of sensible heat to surroundings	rate of temperature decrease due to loss of latent heat of evaporation

The term (U.A)/(M.c) is the test specific heat transfer coefficient k_c in h^{-1}. If the temperature at the self-heating teast drops again to T_a, then the total area under the curve dT/dt is equal to zero and it can be shown that the integral over time for equation 2 reduce to :

$$\Delta VS.\ H_1 / M_{ave}.c \quad = \quad k_c.F \quad + \quad [\Delta H_2O + \Delta VS.\ f_{vs}]\ L_e/M_{ave}.c \quad \ldots(3)$$

in ^0C

Total biological heat generation	loss of sensible heat to surroundings	loss of latent heat of evaporation

Where

ΔVS = loss of VS over duration of the test, g

ΔH_2O = loss of H_2O over duration of the test, g

f_{vs} = a factor used to estimate the amount of reaction water produced by the degradation of one unit VS. An average value of 0.5 is used based on the approximate stoichiometric reaction (Koenig and Tao 1996).

M_{ave} = Average mass of sample during test, approximately equal to $(M_{initial} + M_{final})/2$,g

F = area under the temperature curve, $^0C.h$

M_{ave}, ΔVS, ΔH_2O can be determined from the initial and final data of the test and F is found graphically. It should be noted that the total water evaporate is comprised of the measured water loss (ΔH_2O) plus the reaction water ($\Delta VS.\ f_{vs}$) formed by the degradation of f VS. The approximate value of k_c can also be found graphically as the logarithm of $(T-T_a)$ verses time, after biological heat generation rate has become negligible i.e when the temperature is rapidly exponentially decline towards the end of self-heating test. Using available c values (Marshall Holmes 1979), the total biological heat generation can now be directly estimated from equation.

2.8.1 Estimation of total biological heat generation rate

If it is assumed that the rate of heat loss from evaporation is proportional to the rate of sensible biological heat generation, then the rate of total biological heat generation can be determined by multiplying the rate of censurable heat generation by the adjustment factor r_a (ratio of total biological heat generation to loss of sensible heat to surroundings):

$$\mathbf{r_a} = \frac{k_c.F \ + \ [\Delta H_2O + \Delta VS.\ f_{vs}]\ L_e/M_{ave}.c}{k_c.F} \quad \ldots\ldots.(4)$$

It should be pointed out, however, that the adjustment factor r_a is test specific and hence not a constant.

2.8.2 Estimation of respirometric activity (RA)

It can be shown that multiplying the obtained biological heat generation rate, in $^0C/h$, with the specific heat capacity c results in the specific biological heat production rate, in J/h.g wet waste sample. From bioenergetic relationships it has been well established that the biological consumption of 1 g O_2 generates about 14000 J of heat (Haug 1993, Koenig and Tao1996), or conversely that the generation of 14000 J of biological heat consumes 1 g of oxygen. Therefore, dividing the maximum specific biological heat production rate by 14000 J/g O_2 results in the maximum respirometric activity, in g $O_{2/h.g}$ wet waste sample that can easily be converted to units of mg O_2/ g VS-h of the sample. Using this method, the maximum respirometric activity, in mg O_2/ g VS-h, estimated for the compost of all self–heating test.

2.9 Use of compost

Compost is more important as a soil conditioner rather than a nutrient supplier. It improves the soil chemical, physical and biological parameters so that it provides a better environment for plant growth. This compost can be used as;

• **Mulch:** spread a layer of compost 1-3 inches thick around the plants and over bare soil to prevent soil erosion, conserve water and control weed growth.

• **Soil conditioner:** mix about 4-5 inches of compost into soil when starts a nursery, Vegetable garden or plant new trees.

• **Potting mixture:** screen the compost through a ¼ inch mesh. Mix 2 parts of compost with 1 part of sand and 1 part of top soil and use as a potting mixture for plants.

Stable compost can be blended into soil mixes and is suitable for most outdoor planting projects. It is typically mixed with other ingredients such as peat moss, shredded bark, sand, or loamy topsoil when used as an outdoor planter mix. Mixing ratios vary, but 10% compost is considered to be a minimum, 30% optimum, and 50% maximum in planting shrubs and trees. Cured compost is suitable for all planting projects and can be also used in potting soils. Fully cured compost will not burn plants and can be blended directly into the root zone when planting seeds and seedlings. Cured compost is occasionally used as a territory top dressing and for covering fresh grass seed. The top dressing application rate is approximately one cubic yard per 1000 square feet.

Stable and cured compost probably has its greatest value when rototilled directly into the soil. One cubic yard of compost covers 108 square feet at three inches, 216 at two inches, and 324 at one inch (Comp. 2).

2.10 Composting in Bangladesh

Composting in Dhaka

Over ten million people live in Dhaka. The city generates about 5,800 tons of solid waste each day, at least 80% of which is organic and suitable for composting (Comp.6). Yet the Dhaka City Corporation collects less than half of it. The rest remains on roadsides, in open drains and in low-lying areas. This has a negative impact on the city's environment. It is estimated that the population of Dhaka will be 19.5 million by 2015. It will become very difficult to find sites to bury the waste as the city expands, and transport costs to transfer the waste will increase. The volume of waste needs to be reduced to a sustainable level.

Waste Concern initiated the first pilot project of composting in 1995. The process of the composting involves collection and sorting of solid waste in the resource recovery. Plant located within the community. Then the organic waste is heaped into piles under a shade, In addition, the shed protects the compost workers from rain and heat of the sun. The organic waste is piled around a bamboo rack to allow a good circulation of air and beneficial microorganisms to decompose the organic waste efficiently. Pile temperature of 55 °C to 65 °C is optimum for aerobic composting (Comp. 3) Sawdust is mixed with the waste to increase the air content. The pile is turned frequently in order to maintain the temperature and to ensure equal decomposition throughout the pile. Water is used to speed up decomposition. Chicken and cattle manure are added to increase the nitrogen in the compost. This process takes 40 days (Comp. 4).

Composting in Khulna

Khulna City Corporation generates around 455 tons of municipal solid waste per day considering all the sources and the generation rate is 0.5 Kg/capita/day on an average (Comp7). The maximum part is organic waste. Domestic wastes are the main sources. The other important sources of municipal solid wastes are commercial wastes which comprises of markets, hotels, restaurants, hospital/clinical, institutions including schools, colleges and government offices, construction & demolition, municipal services like street sweeping, drain sweeping, treatment plant sites and other wastes (Salequzzaman, Banerjee and Ahmed, 2005)

In Khulna City the main responsibility of solid waste management system is on the Khulna City Corporation. There are two ways of solid waste management in Khulna city area. First is collection and transportation of solid waste to the disposal site and second is resource recovery and composting of solid waste. There are two types of solid waste collection and transportation to the disposal site in Khulna City Corporation region. These are:

i) Conventional System
ii) Participatory System

In the conventional system it is the responsibility of the householders to carry their wastes to the nearest solid waste bins or similar facilities which are provided by the city corporation and deposit wastes there. The city corporation is responsible for the transfer of this waste from the roadside bins to the final disposal site.

In Participatory System Waste generated in the home is stored in a bin, basket or bag and collected every day by a primary collector who transports the waste to nearby transfer points by rickshwa van. Prodipon an NGO has already started composting project at Khulna city (Alamgir, M 2003). The waste is then collected from the transfer points and taken to the final disposal point by a large truck. This is secondary collection and is the responsibility of KCC. The city corporation has 60 bigha own land for dumping the solid waste at the edge of the Khulna city in the Rajbandh.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

The study was performed by means of different proportions inserted in forced and passive aerated reactor. For this purpose organic waste were collected from student's hall and saw dust from local saw mills and paper from office of KUET. Saw wood waste and saw dust was used as bulking agent in composting process. The individual's solid wastes are mixed with such proportion to get a homogenous mixture and to put into the reactors. Before and after experiments the physical tests like moisture content, volatile solid and fixed solid was performed. Two digital thermometers were inserted in both reactors for taking the temperature regularly. Two air pumps were connected to force-aerated reactor for providing oxygen into the reactor. The experiments were done in both forced aeration and passively aeration conditions.

3.2 Source of waste

Food waste was collected separately from different households and from dining room of student hall. Paper was collected from different faculty office of KUET campus. Saw dust was collected from local sawmill.

3.3 Preparation of waste mixture

Food waste was mixed with sawdust and waste paper (cut into small pieces) as shown in Figure 3.1. The waste namely food, paper and sawdust were mixed with selected proportion to have a suitable C/N ratio of ranged from 25 to 30 as suggested by Bari & Koening (2001). The experiments were performed in 6 different conditions. The condition of Exp-1, Exp-3, and Exp-4 are shown in Table 3.1. For most experiment two bin namely passively aerated bin and forced aerated bin are used.

In Exp-2 and Exp-5 are a kind of 2nd stage composting and the mixed compost from both bin after Exp-1 and Exp-4 were used as feedstock. In Table 3.1 proportions of different waste mixture is also given. In Exp-01, the percentage of waste mixture, Food: Vegetable: Paper: Sawdust is 60: 18: 10: 12.

Table: 3.1 Initial waste mixture for different composting experiment

Types of Organic solid waste	% In weight						
	Exp -1		Exp- 3	Exp- 4		Exp-6	
	PAB	FAB	PAB	PAB	FAB	PAB	FAB
Food	60 (12)	60 (12)	55 (9.08)	48 (6.0)	48 (6.0)	33 (6.10)	33 (3.99)
Vegetable	18 (3.6)	18 (3.6)	20 (3.30)	20 (2.5)	20 (2.5)	27 (4.91)	27 (3.27)
Paper	10 (1.8)	10 (1.8)	7.5 (1.24)	7.5 (0.94)	7.5 (0.94)	20 (3.6)	20 (3.6)
Sawdust	12 (2.4)	12 (2.4)	12.5 (2.06)	12.5 (1.56)	12.5 (1.56)	20 (3.6)	20 (3.6)
Saw waste	-	-	5 (0.83)	5 (0.63)	5 (0.63)		
Total in kg	20	20	16.5	12.5	12.5	18.4	12.1

PAB = Passively aerated bin, FAB = Forced aerated bin, Values in ( ) is in Kg, Compost released from Exp-1 and Exp-4 were used as feedstock i.e 2nd stage in Exp- 2 and Exp-5 respectively.

Figure 3.1 Collected different waste mixing at Geo-Environmental Lab of KUET

3.4 Fabrication of two types of composting bin (Reactor)

For both cases (forced aerated composting and passive aerated composting) 50 liters bins were used. The bins were actually plastic covered drum. Some kind of low cost insulator made of cotton was used to keep the heat generated from the biological reaction to increase the temperature upto 50 to 60 °C inside the bins. The insulator was one inch thick as like as quilt. An aquarium aerator for aeration was connected with forced aeration bin A wire net was provided at 10 cm from the bottom, for supporting the waste. This net was also allowed air for proper distribution.

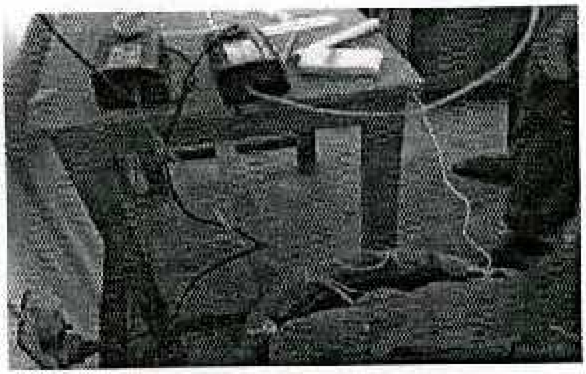

Figure 3.2 Forced aerated composting bin connected with air pump

The passively aerated composting bin was fitted on a M.S frame, in order to facilitate to turn the whole bin. The bin was over turned twice a day. At the time of bin turning the waste inside bin was also over turned. In this way waste was passively aerated through air passing inside the bin. A perforated 2-inch dia PVC pipe was inserted in side the bin from top to bottom. The pipe was fitted at the center of the bin which is considered as general practice. Air was entered in side the bin through perforate pipe.

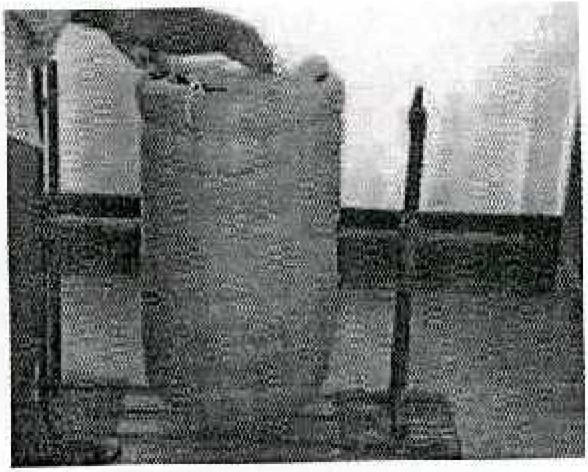

Figure 3.3 Passively aerated composting bin fitted on a M.S frame

Temperature was monitored manually by using digital thermometer. Before and after each composting runs in two bins the waste and/or the compost character such as moisture content, total solids, volatile solids are regularly measured. The runs were mainly continued for 3-5 weeks. After each runs the fresh compost were transferred to another bin for stabilization. Finally stability (maturity) was measured according to self-heating test.

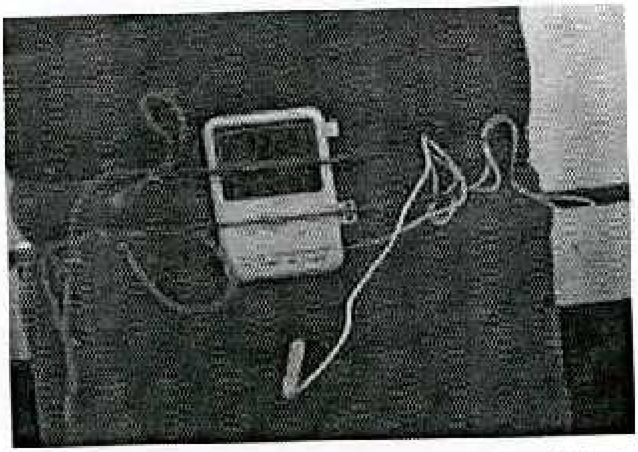

Figure: 3.4 Temperature recorded manually by using digital thermometer

Figure: 3.5 Fresh compost ready for stabilization

3.5 Self -heating test

The fresh compost released from the different Experiments from the both reactor bin transferred to some thermo flask for self-heating tests as shown in Figure 3.6. Temperature developed in the flask was measured manually using thermometer. The moisture content, volatile solid and fixed solid of matured compost were tested at Environmental Engineering laboratory of Department of Civil Engineering, KUET The biological stability of produced compost can be determined through self-heating test.

Figure: 3.6 Self-heating test using thermo flasks

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Bin composting

4.1.1 Introduction

The study was performed by means of forced and passive aerated bin. Temperature variation in bin composting process has been carried out through forced and passive aeration. Degree and extent of degradation upto maturity of compost were identified through different stage of composting process. Simple mass balance analysis was developed for two types of bin composting process. The analysis also helps to characterize the compost.

4.1.2 Temperature variation in different experiments

In Exp-1 both bins run for 30 days. In passively aerated reactor temperature was raised upto max 50.2 °C and in most of the time temperature was got down a few degree after rotation as shown in Figure 4.1. In forced aerated reactor the temperature was raised upto max 50.4 °C as shown in Figure 4.2, which is very close to each other. In passively aerated reactor bin 50 °C temperature was stands for 10 days while in forced aerated bin it was for 3 days. The rate of temperature fall is sharp in this bin. Area under temperature curve before rotation is 8174 °Ch and after rotation it is 6819 °Ch. In forced aerated bin area under temperature curve is 9541 °Ch. The area under temperature curve, °Ch is calculated, multiplying the biological heat generated in °C to duration of the experiments in hours.

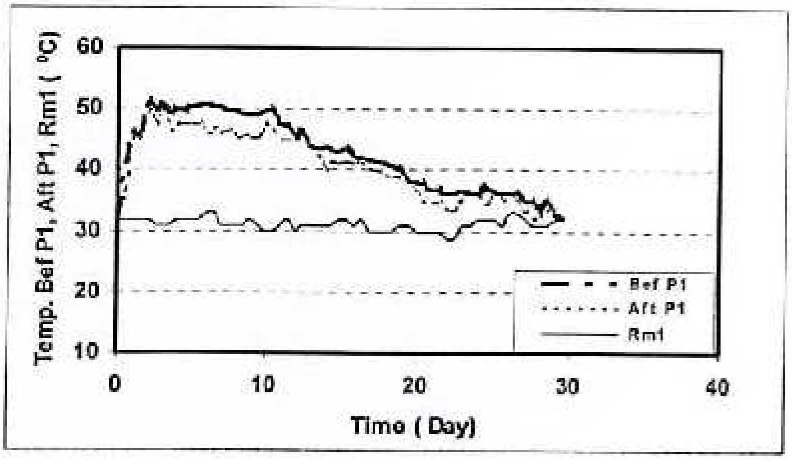

Figure 4.1 Temperature variation in Exp-1, passively aerated turned bin

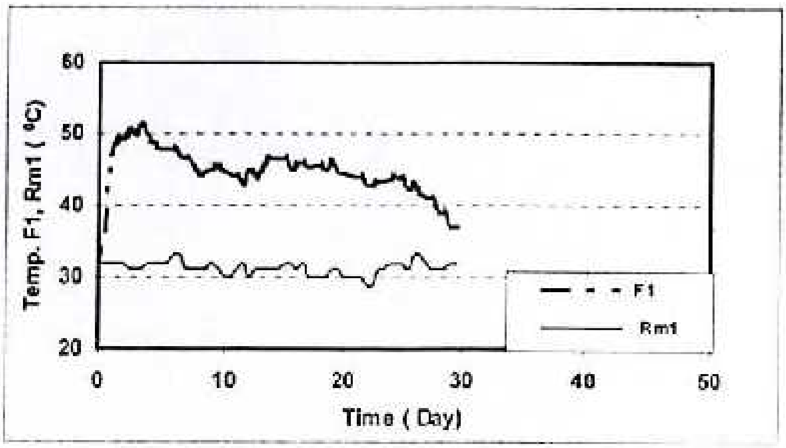

Figure 4.2 Temperature variations in Exp-1, forced aerated bin

Compost released from both bins after 30 days were mixed properly and used as feedstock in Exp-2. Only in forced aerated reactor this feedstock was placed for further degradation. The reactor was run for 40 days and temperature was raised upto max 54 °C as shown in Figure 4.3. In this Exp-2 moisture content was higher. Therefore heat generation as well as degradation was not satisfactory. Some additional saw dust was feeded as bulking agent to minimize this sort of problem. After sometime temperature was raised and degradation was started smoothly. Area under temperature curve is 6110 °Ch.

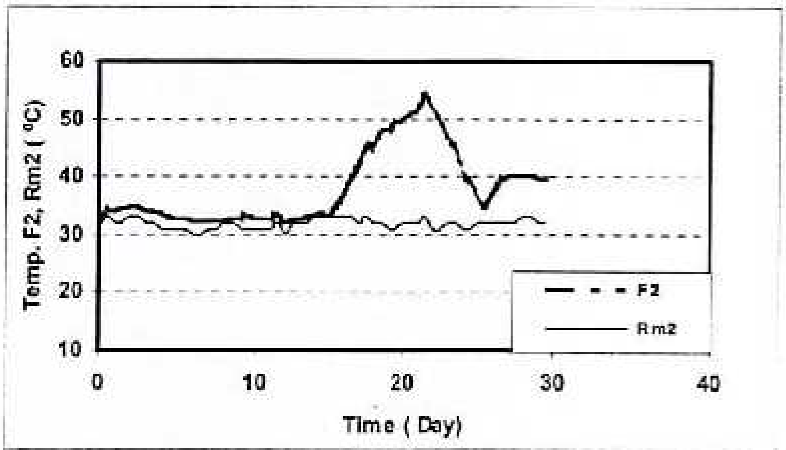

Figure 4.3 Temperature variations in Exp-2, forced aerated bin

In Exp-3 only passively aerated reactor was used to know the ideal condition of waste degradation. The duration of experiment was 34 days. The temperature in side the reactor was raised upto max 50.4 °C as shown in Figure 4.4. The area under temperature curve shows the satisfactory degradation. Area under temperature curve before rotation is 9150 °Ch and after rotation it is 8197 °Ch.

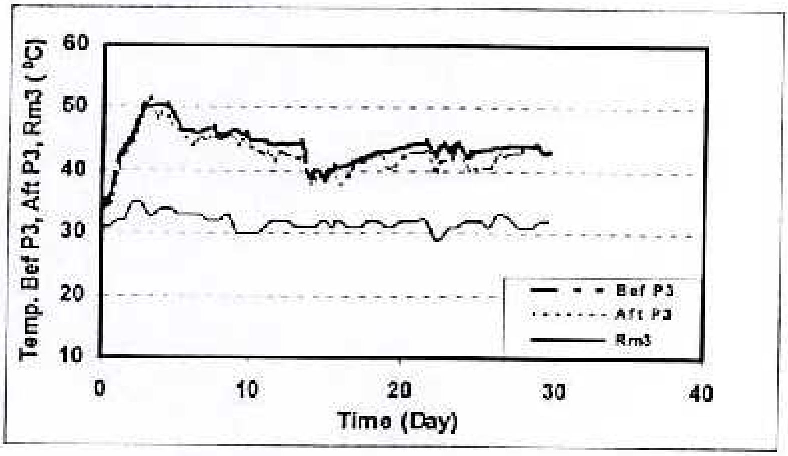

Figure 4.4 Temperature variation in Exp-3, passively aerated turned bin

In Exp-4 both reactor were run 36 days. In passively aerated reactor temperature was raised upto max 48.5 °C and in most of the time temperature was got down a few degree after rotation as shown in Figure 4.5. In forced aerated reactor the temperature was raised upto max 51 °C as shown in Figure 4.6, which is very close to passively aerated reactor bin. In passively aerated bin area under curve with respect to ambient temperature was more than forced aerated bin. Area under temperature curve before rotation is 10584 °Ch and after rotation it is 10065 °Ch. In forced aerated bin area under temperature curve is 10350 °Ch.

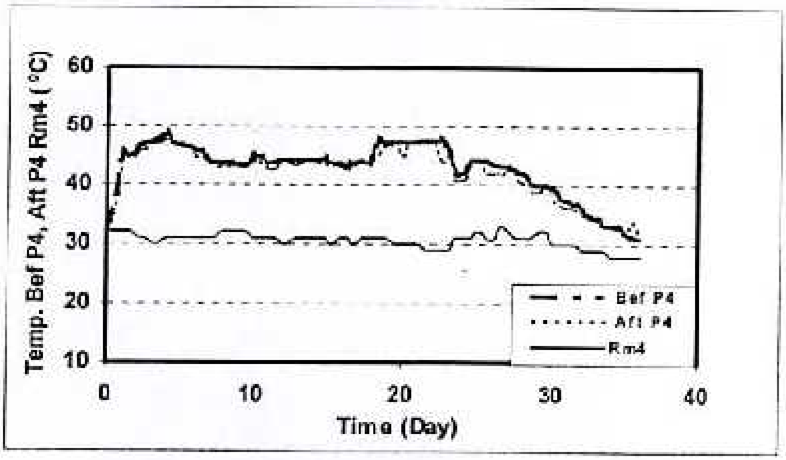

Figure 4.5 Temperature variation in Exp-4, passively aerated turned bin

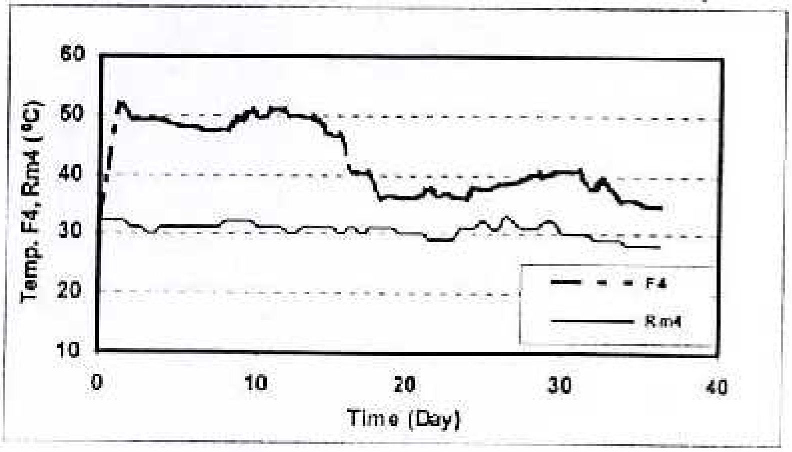

Figure 4.6 Temperature variations in experiment-4, forced aerated bin

Compost released from both reactors in Exp-4, mixed properly and used as feedstock in Exp-5. In only forced aerated reactor this feedstock was placed for further degradation. The reactor was run for 22 days and temperature was raised upto max 47 °C as shown in Figure 4.7. This could be the indication of more heat generation. Area under temperature curve is 6208 °Ch.

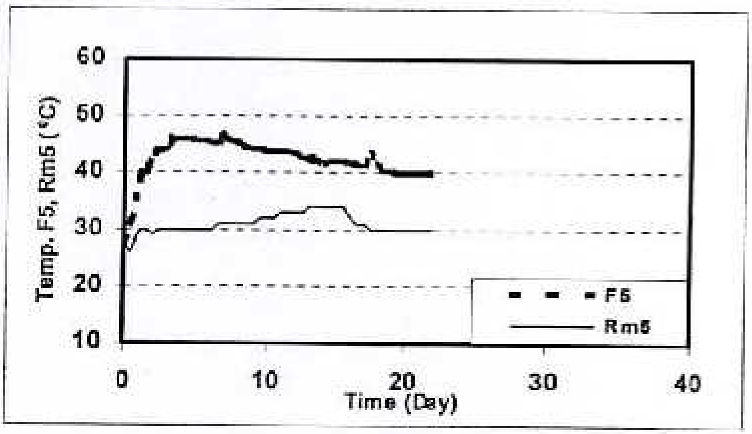

Figure 4.7 Temperature variations in Exp-5, forced aerated bin

In Exp-6 both bin were run for 41 days. This experiments was performed in different condition to find out the effect of frequent waste feeding. Feeding of waste was divided into 9 times. At first day 25% of the total estimated waste was feeded in both bin. In passively aerated bin the temperature raised upto max 42.2°C at 2nd day. The temperature was then got down until the next feeding. Temperature rise and fall was continued upto 27 th i.e last feeding date. Final degradation was obtained in between 27 th and 41 th day that has shown in Figure 4.8.

In forced aerated reactor the temperature was raised upto max 49.7 °C on 32 th day that has shown in Figure 4.9. The area under temperature curve with respect to ambient temperature was more in forced aerated bin. Area under temperature curve before rotation is 12640 °Ch and after rotation it is 12284 °Ch. In forced aerated bin area under temperature curve is 23702 °Ch.

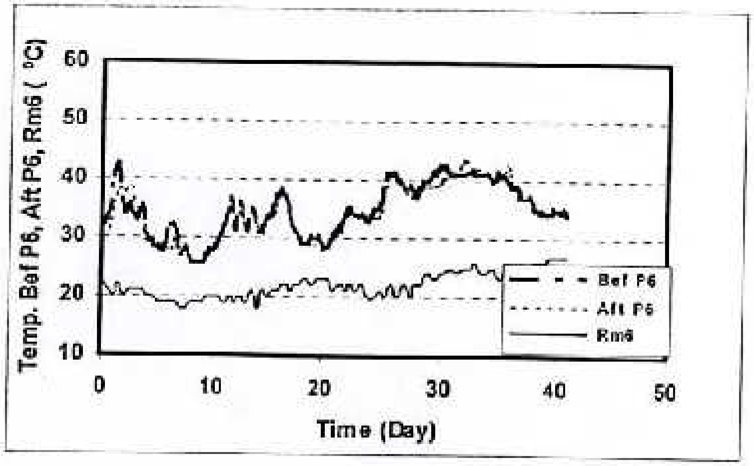

Figure 4.8 Temperature variations in Exp-6, passively aerated turned bin

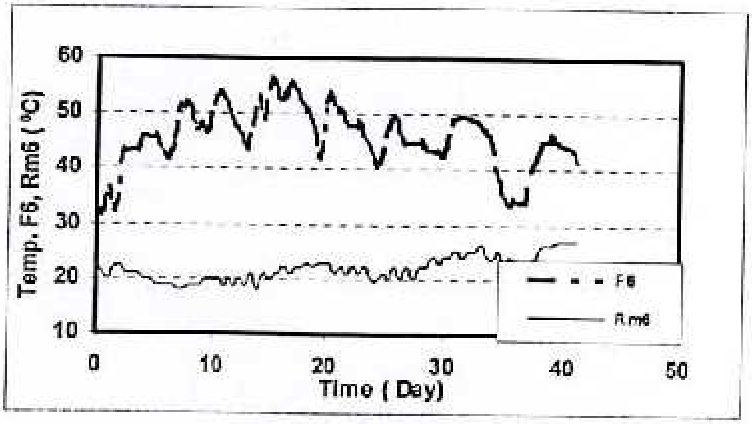

Figure 4.9 Temperature variations in Exp-6, forced aerated bin

4.1.3 Simple mass balances for different experiment

In different types of experiments mainly two types of waste were used, namely food waste (Rice and vegetable) and mixed office waste paper. In addition, saw dust was used as a bulking agent. Moisture content, volatile solid of individual sample used in different experiment are presented in Table 4.1. Moisture content of food waste was in the range of 50% to 79 %.

Changes in total mass, moisture content and volatile solids, fixed solids during different composting test (Initial and final) are presented in Table 4.2. Initial moisture content of the waste mixtures varied between 55 to 80 %. The ranges of initial and final weight of waste poured inside the both (passive and forced aerated) bin for test was 12 to 20 kg and 6 to 12 kg respectively.

The variation of weight as well as change of volatile solid in different types of experiments i.e Exp-1, Exp-2, Exp-3, Exp-4, Exp-5, and Exp-6 is calculated individually. The figure 4.10(a), 4.10(b), and 4.11(a), 4.11(b), shows variation of volatile solid in Exp-1 and Exp-4 respectively.

The Exp-6 was performed in different condition. Specified waste was feeded in reactors bin at certain intervals. This will help to know the optimum frequency of waste feeding specially for household purpose. Total and percentage change in moisture content and volatile solid of different experiment are presented in Table 4.3. Total and percentage change in moisture content and volatile solid of intermittent waste addition in Exp-6 is presented in Table 4.4

In this test solid waste was added in 7 different times with 1-4 days frequency. In first day 7.5 kg and 4.6 kg waste was added in passively and forced aerated bin respectively. Initial moisture content and volatile solid was 77 % and 96 % respectively in both reactors that is presented in Table 4.5. On 25 th day the bin weight was taken 18.4 kg passively aerated bin and 12.10 kg of forced aerated bin with full of bin capacity. Therefore both bin were run for further 15 days for final degradation. Finally the weight of passively aerated bin was 17.4 kg and forced aerated bin was 11.1 kg. Moisture content was observed 62 % in passively aerated bin and 60 % in forced aerated bin. In both bin volatile solid was 92 % and reduced to only a few percentage at final stage.

In Exp-01 after 30 days of experiment MC difference in passively and forced aerated reactor bin is 45 % and 52 % respectively. In this experiment MC difference higher in forced aerated bin. VS difference is in passively aerated bin 45 % and in forced aerated bin 54 %. VS difference was 09 % higher in forced aerated bin rather than passively aerated bin.

In Exp-4 after 36 days of experiment MC difference was higher in forced aerated bin but VS difference was almost same in both bin.

In Exp-6 after 42 days of experiment, MC difference in both bins was few. VS difference was higher in forced aerated bin rather than passively aerated bin. In this experiment main degradation was took place after 25 days

The extent and degree of degradation of different experiment are shown in Table 4.6. In Exp-3, during 30 days period of composting in passively aerated bin the percentage of degradation was max upto 68 %. This may be expressed that in Exp-3 of passively aerated bin, degree of degradation was more with respect to the other experiment. This condition could support the suitability of passively aerated reactor bin rather than forced aerated bin irrespective to other condition. In Exp-4 percentage of degradation in both bin was very similar to each other.

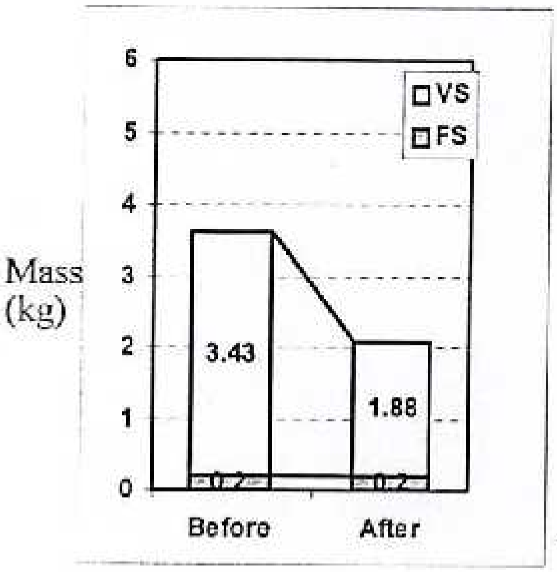

Figure 4.10 (a) Mass variation during Exp-1, passively aerated bin

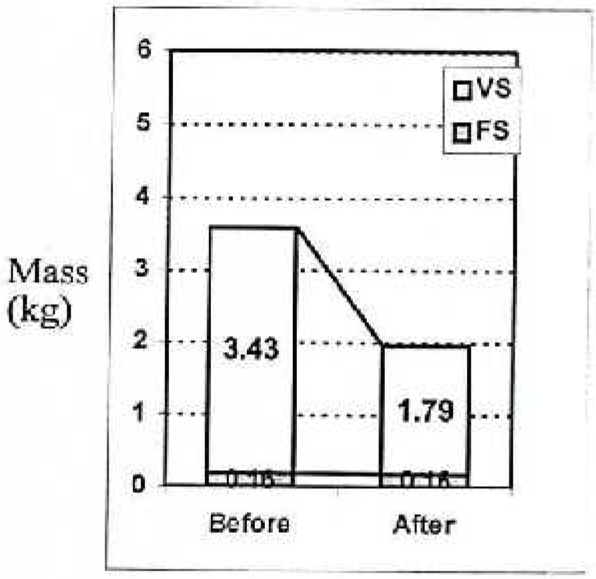

Figure 4.10 (b) Mass variation during Exp-1, forced aerated bin

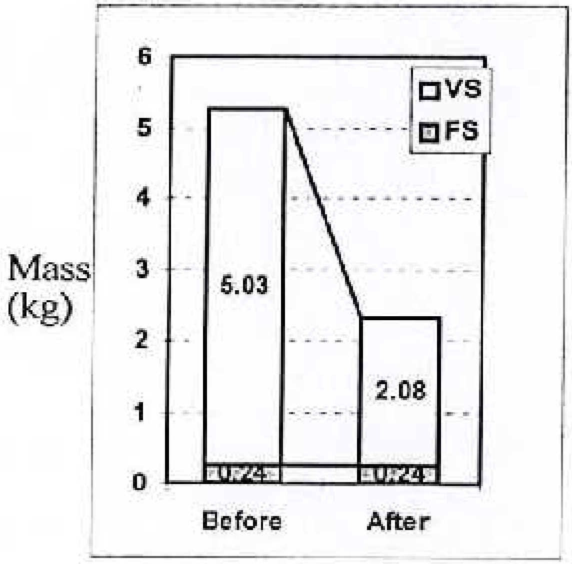

Figure 4.11 (a) Mass variation during Exp-4, passively aerated bin

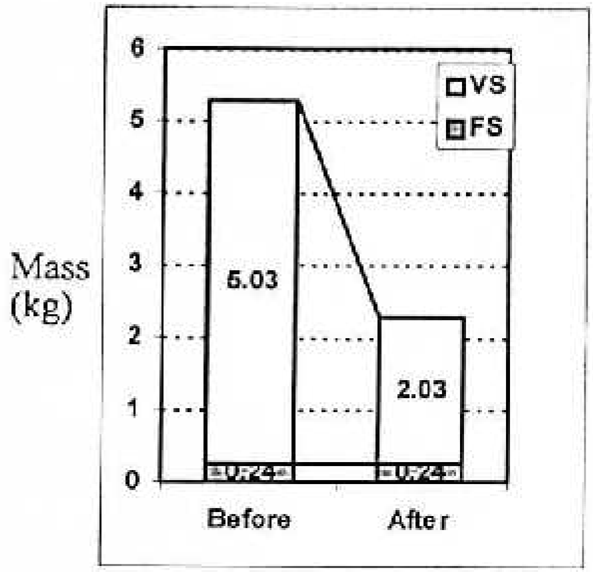

Figure 4.11 (b) Mass variation during Exp-4, forced aerated bin

Table: 4.1 Moisture content, volatile solid of individual sample used in different experiment

Parameter/ Experiment	MC/ VS	Food waste In %	Vegetable Waste in %	Saw dust / Saw wood in %	Waste Paper in %
Exp -1	MC	75.8	94.90	45.72	8.14
	VS	98.02	96.20	98.55	90.49
Exp-3	MC	72.5	85	45.38 / 10.41	9.81
	VS	99.2	86.89	96.09 / 99.26	92.60
Exp-4	MC	55.76	90.63	31	3.47
	VS	90.63	85.96	96.25	87.15
Exp-6	MC	79	88	40	14
	VS	92	92	97	95

In Exp -2 and Exp-5 mixed compost released from both reactors after Exp-1 and Exp-4 were used as feedstock.

Table: 4.2 Change in total mass, moisture content, volatile solid, fixed solid in different experiment

Parameter/ Experiment		Mass in kg		Moisture Content kg / %		Volatile Solid kg / %		Fixed Solid in kg	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
Exp-1	P	20	11	16.40 / 82 %	8.91 / 81 %	3.42 / 95 %	1.88 / 90 %	0.18	0.21
	F	20	9.5	16.40 / 82 %	7.79 / 82 %	3.42 / 95 %	1.57 / 92 %	0.18	0.14
Exp-2	F	16	14	12.80 / 80 %	10.92 / 78 %	2.88 / 90 %	2.80 / 91 %	0.32	0.28
Exp -3	P	16.5	7	11.35 / 68.8 %	5.25 / 75 %	4.96 / 96.4 %	1.65 / 94.2 %	0.19	0.10
Exp-4	P	12.5	9	7.25 / 58 %	6.66 / 74 %	5.03 / 95.84 %	2.08 / 89 %	0.22	0.26
	F	12.5	7	7.25 / 58 %	4.69 / 67 %	5.03 / 95.84 %	2.04/ 88.13 %	0.22	0.27
Exp-5	F	14	10.5	10.5 / 75 %	8.09 / 77 %	3.08 / 88.11 %	2.0 / 83 %	0.41	0.41
Exp-6	P	18.4	17.4	11.4 / 62 %	10.78 / 62 %	6.44 / 92 %	6.02 / 91 %	0.56	0.37
	F	12.1	11.1	7.26 / 60 %	6.66 / 60 %	4.54 / 94 %	4.04/ 91 %	0.35	0.35

Table: 4.3 Total and percentage change in moisture content and volatile solid of different experiment

Parameter/ Experiment		Duration of Exp (in days)	Moisture Content				Volatile Solid			
			Initial in Kg	Final in Kg	Diff in Kg	Diff in %	Initial in Kg	Final in Kg	Diff in Kg	Diff in %
Exp-1	P	30	16.40	8.91	7.49	45 %	3.43	1.88	1.55	45 %
	F	30	16.40	7.79	8.61	52 %	3.43	1.57	1.86	54 %
Exp-2 (2nd stage)	F	40	12.8	10.92	1.88	15 %	2.88	2.80	0.08	2 %
Exp -3	P	30	11.35	5.25	6.10	53 %	4.96	1.65	3.31	68 %
Exp-4	P	36	7.25	6.66	0.59	08 %	5.03	2.08	2.95	58 %
	F	36	7.25	4.69	2.56	35 %	5.03	2.04	2.99	59 %
Exp-5 (2nd stage)	F	22	10.5	8.09	2.41	23 %	3.08	2.00	1.08	35 %

Table: 4.4 Total and percentage change in moisture content and volatile solid of intermittent waste addition Exp-6

Parameter/ Experiment		Duration of Exp (in days)	Moisture Content				Volatile Solid			
			Initial in Kg	Final in Kg	Diff in Kg	Diff in %	Initial in Kg	Final in Kg	Diff in Kg	Diff in %
Exp-6	P	42	18.4	17.4	1.00	6 %	7.78	5.34	2.44	31 %
	F	42	12.1	11.1	1.00	8 %	5.12	2.04	3.08	60 %

Table: 4.5 Change in total mass, moisture content, volatile solid in different stage of intermittent waste feeding in Exp-6

Day of waste feeding	Passively aerated bin						Forced aerated bin					
	Total mass in kg		MC %		VS %		Total mass in kg		MC%		VS%	
	Ini	Fi	Ini	Fi	Ini	Fi	Ini	Fi	Ini	Fi	Ini	Fi
First day	7.5	-	77		96	-	4.6	-	77	-	96	-
3rd day	9.75	7.5	67	75	95	94	6.3	4.4	67	74	98	96
6 th day	12.5	9.75	53	70	94	94	7.9	6.3	53	70	94	94
8 th day	14.7	12.5	60	69	95	93	9.4	7.8	60	69	95	93
12 th day	16.1	14.6	52	67	95	92	10.1	8.6	52	67	94	92
16 th day	18.1	16.1	56	65	95	92	11.4	9.8	56	66	95	93
19 th day	18.4	18.1	54	64	95	92	12.8	11.3	54	64	95	94
23 rd day	18.4	18.1	46	63	91	92	12.1	12.1	46	61	91	94
25 th day	18.4	18.2	54	62	92	92	12.1	12.1	54	60	92	94
42 th day		17.4	-	62	-	91	-	11.1	-	60	-	91

Ini = Initial and Fi = Final

Table: 4.6 Extent and degree of degradation of different composting experiments

Experiment Type	Type of bin	Duration of Exp run (in days)	Degree of Degradation (in percentage)
Exp-1	P	30	45 %
	F	30	54 %
Exp-2 (2nd stage)	F	40	2 %
Exp -3	P	30	68 %
Exp-4	P	36	58 %
	F	36	59 %
Exp-5 (2nd stage)	F	22	35 %
Exp-6 (intermittent waste addition)	P	42	31 %
	F	42	60 %

4.2 Self-heating test

4.2.1 Introduction

The self-heating test is an widely applied procedure to determine the biological stability of compost. Self-heating test could be used to determine the stability index of the compost as well as to estimate the respirometric activity. This test is simple and required data are easily obtainable.

4.2.3 Procedure of the test

A number of self-heating tests were conducted to assess the stability of compost produced after bin composting process. The self-heating tests were conducted according to the procedure recommended by LAGA (1985) and BGK (1994) as cited by (Koning & Bari 1999). In this study normal thermo-flasks were used as reactor. Each flask is one-liter capacity. Thermometer was inserted in each of the flask for measuring temperature in the flask. Compost released from both bins in different experiment was used as sample in self-heating test run. Based on the results of the self-heating test, the waste is classified according to degree of biological stability.

4.2.3 Temperature variation in different self-heating test

Temperature variation was recorded by thermometer. From starting to end of the experiment the thermometer was inserted in the flask for taking reading manually. In all tests separate thermometers were used. Ambient temperature was recorded separately at all the time during temperature recording. In self-heating test R1, 4- flasks were used for 20 days. In R1, 2-flask was filled by the compost released from the passively aerated bin and another two lasks were filled by the compost from forced aerated bin. Temperature was raised upto max 54 ^{0}C in the flask with compost from passively aerated bin. Temperature was raised upto max 47 ^{0}C in the flask with compost of forced aerated bin. This temperature variation has shown in Figure 4.12. It could be assumed from temperature variation condition that the compost from passively aerated reactor needs more degradation.

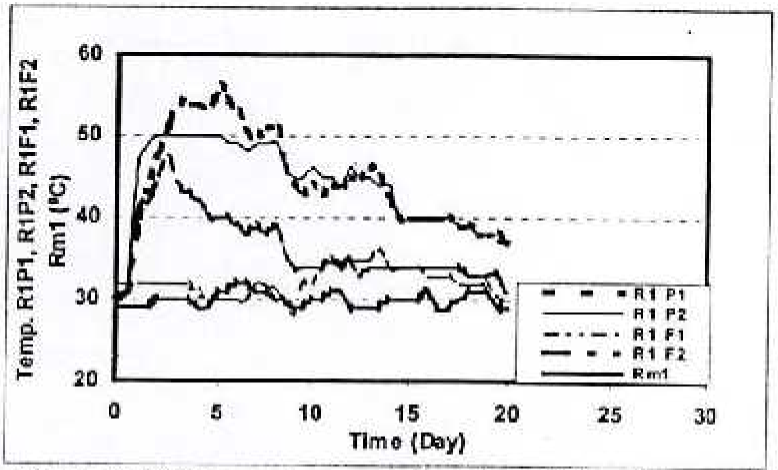

Figure 4.12 Temperature variations in self-heating test of R1 compost from both bins of Exp-1

In self-heating test R2, 2-flasks were run for 29 days. In R2, 2-flask was filled by the mixed compost released from forced aerated bin after Exp-2. Temperature was raised upto max 46 ^{0}C within 8 th day of test run, as shown in Figure 4.13. The temperature was fall gradually.

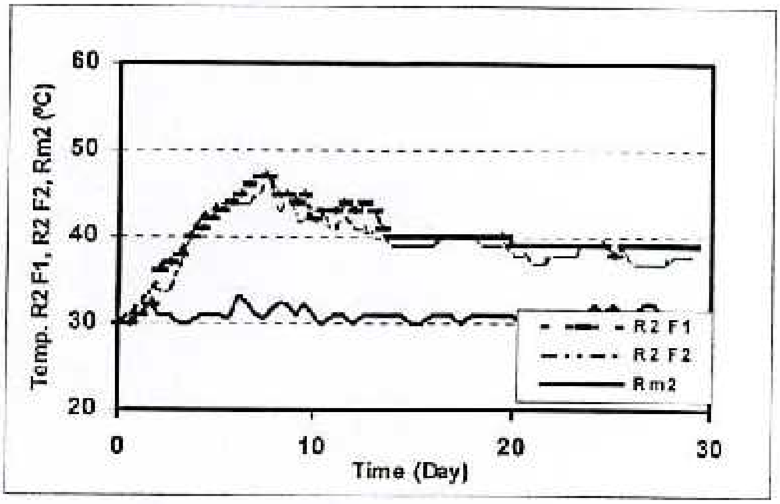

Figure 4.13 Temperature variation in self-heating test R2 with compost from forced aerated bin in Exp-2

In self-heating test R3, one reactor flask was run for 18 days. In R3, flask was filled by the mixed compost released from passively aerated reactor bin after Exp-3. Temperature was raised upto max 47 ^{0}C is presented in Figure 4.14.

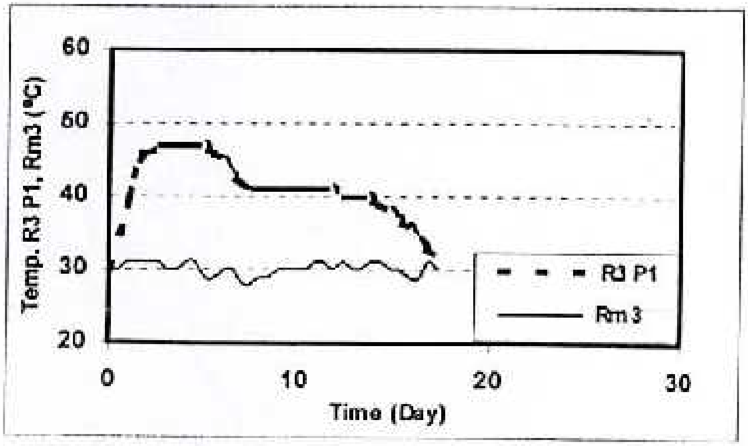

Figure 5.14 Temperature variations in self-heating test R3 with compost from passively aerated bin in Exp-3

In R4, 4-reactor flasks were run for 22 days. In R4, 2 flasks was filled by the compost released from the passively aerated bin and another two flask were filled by the compost from forced aerated bin. Temperature was raised upto 51 ^{0}C in flask with compost from passively aerated bin. Temperature was raised upto 42 ^{0}C in the flask reactor carrying compost of forced aerated bin. This temperature variation has shown in Figure 4.15. It could be assumed from temperature variation condition that the compost from passively aerated reactor needs more degradation.

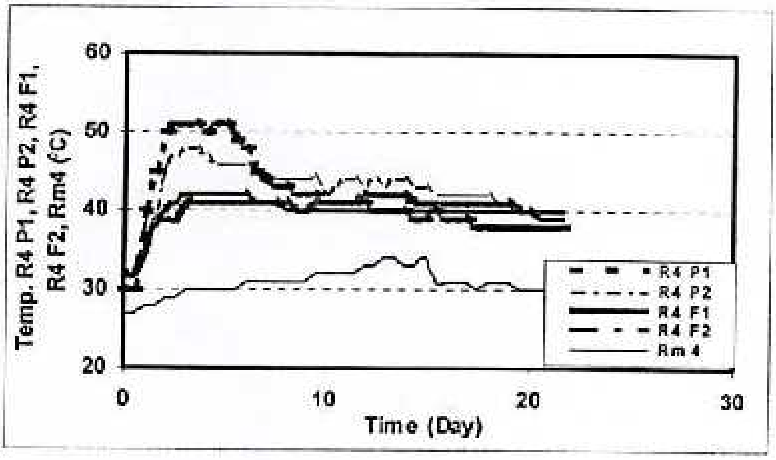

Figure 4.15 Temperature variation in self-heating test R4 with compost from both bins

In self-heating test R5, one flask was run for 24 days. In R5, the mixed compost released from forced aerated reactor bin of Exp-5 was filled in one flask. Temperature was raised upto 41 °C and temperature was in static state in maximum days of test run is presented in Figure 4.16.

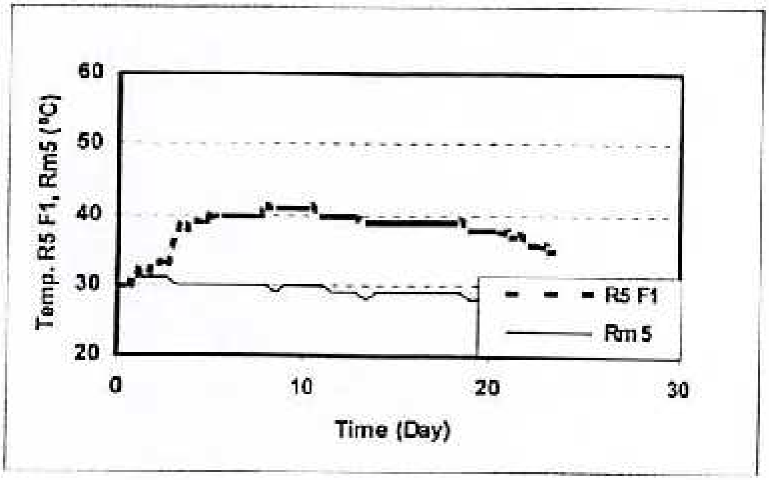

Figure 4.16 Temperature variations in self-heating test R5 with compost from forced aerated bin of Exp-5

In R6, 4-flasks were run for 22 days. In R6, 2 flasks was filled with the compost released from the passively aerated bin and another two flasks were filled by the compost from forced aerated bin. Temperature was raised upto max 51 °C in reactor flask carrying compost from passively aerated reactor bin. Temperature was raised upto 52 °C in the flask with compost of forced aerated bin. This temperature variation has shown in Figure 4.17.

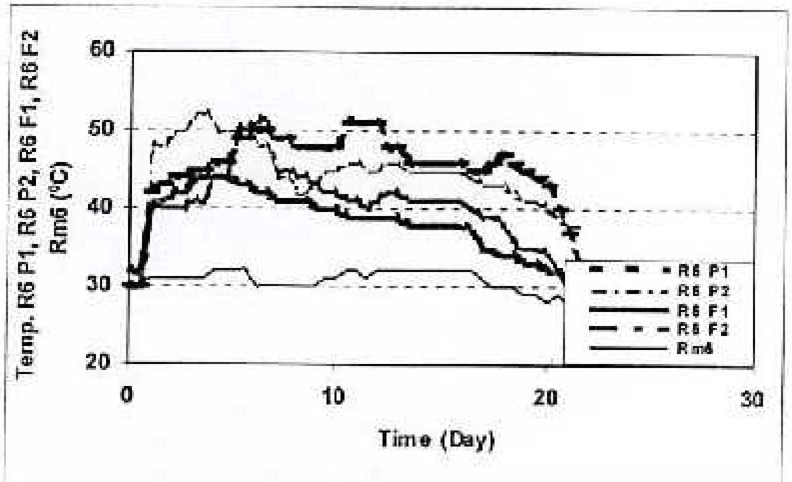

Figure 4.17 Temperature variations in self-heating test R6 with compost from both bin of Exp-6

4.2.4 Simple mass balance of different self-heating test

In different types of self-heating test were performed to determine the maturity index of compost released from both bins. Changes in total mass, moisture content and volatile solids, during self-heating test (Initial and final) are presented in Table 4.7. The ranges of initial weight of waste poured inside the flasks for self-heating test was 336 gm to 540 gm. After self-heating tests finally this range become 308 gm to 420 gm respectively. The variation of weight as well as volatile solid of compost in different types of self-heating tests i.e Run-1, R2, R3, R4, R5 and R6 is analyzed according to standard methods. The Figures 4.18 (a) to 4.18 (d) and, 4.19 (a) to 4.19 (d) are graphical representation of volatile solid variation in Self-heating tests R1 and R4 respectively.

In R1 after 20 days of test moisture content difference was 10 % to 26 % of waste from passively aerated bin while this MC difference is 32 % to 50 % of waste from forced aerated bin. Similarly volatile solid difference was more in waste from forced aerated bin rather than waste from passively aerated bin as presented in Table 4.8.

In R2, sample was taken from Exp-2 in two flasks. This run was conducted with a for duration of 29 days. The moisture content difference was observed upto maximum 29 % and volatile difference was observed 51%.

The duration of R3 was 18 days. Moisture content difference was observed 24 % and VS difference was observed 23 %.

R4 was conducted in the same way of R1. Duration of this test was 22 days. In this run MC and VS difference was more in the waste from forced aerated bin than the waste from passively aerated bin.

Duration of R5 test was 24 days. MC and VS difference was observed 1% and 17 % respectably.

In R6, after 22 days of test moisture content difference was 15 % to 16 % of waste from passively aerated bin while this MC difference is 10 % to 15 % of waste from forced aerated bin. It is observed that volatile solid difference was also more in waste from passively aerated bin rather than waste from forced aerated bin.

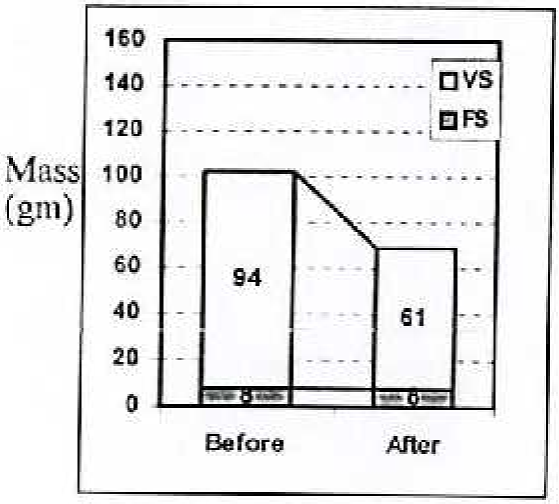

Figure 4.18 (a) Mass variation self-heating test R1 P

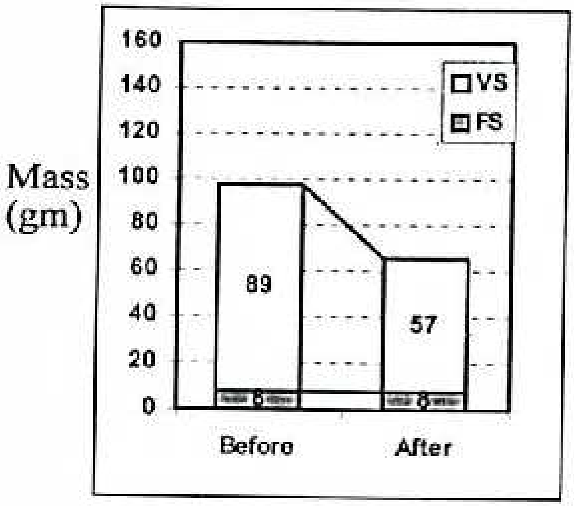

Figure 4.18 (b) Mass variation self-heating test R1 P

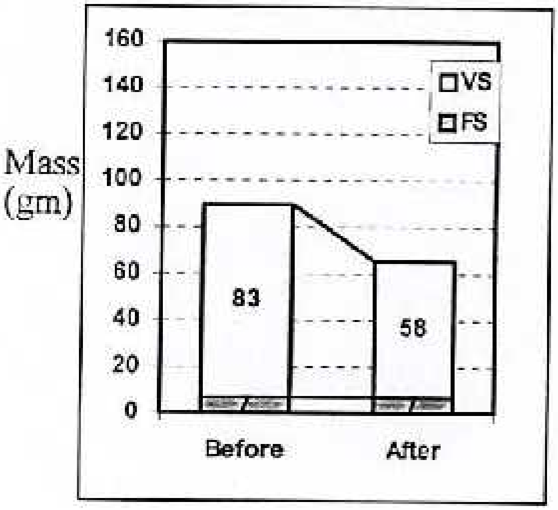

Figure 4.18 (c) Mass variation self-heating test R1 F

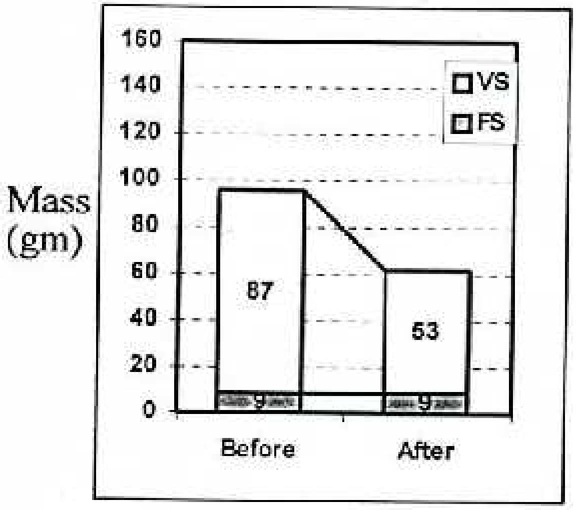

Figure 4.18 (d) Mass variation self-heating test R1 F

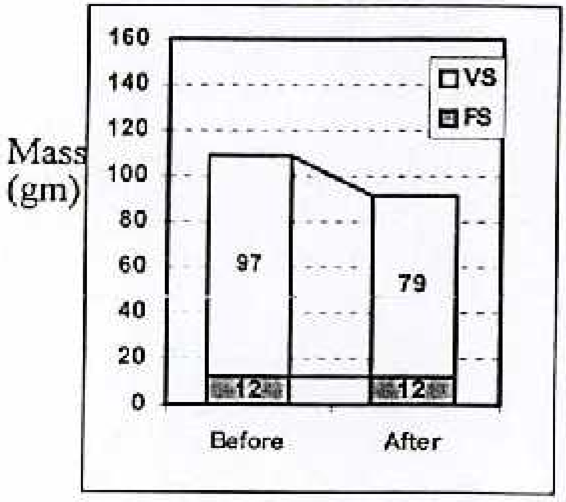

Figure 4.19 (a) Mass variation self-heating test R4 P

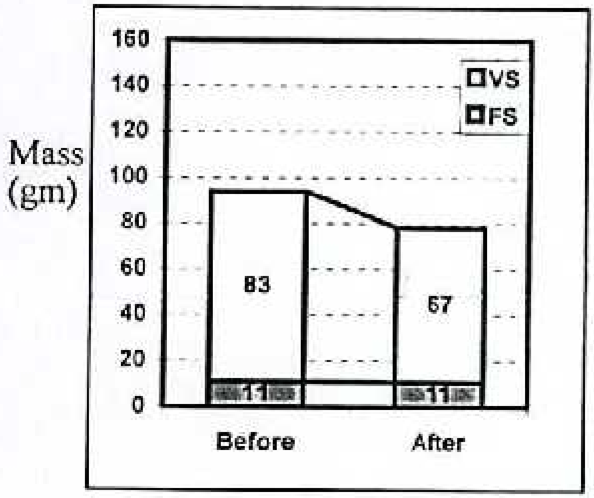

Figure 4.19 (b) Mass variation self-heating test R4 P

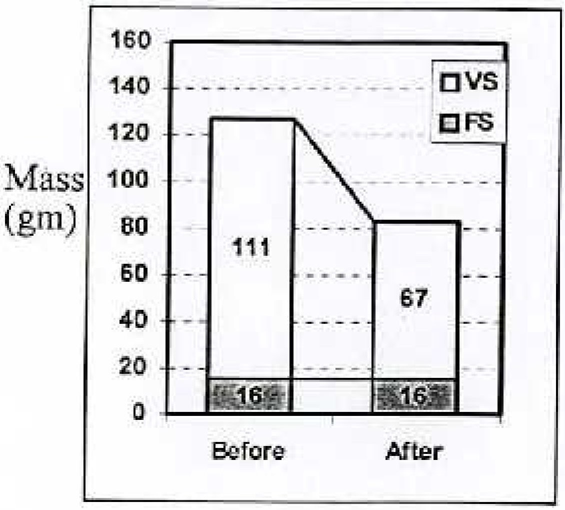

Figure 4.19 (c) Mass variation self-heating test R4 F

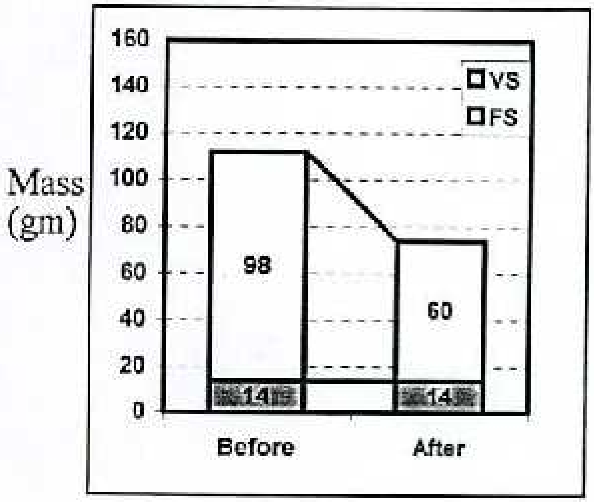

Figure 4.19 (d) Mass variation self-heating test R4 F

Table 4.7 Change in total mass, moisture content, volatile solid, fixed solid in different self heating test

Parameter/ Run	Flask	Mass in gm		Moisture Content gm / %		Volatile Solid gm / %		Fixed Solid in gm	
		Initial	Final	Initial	Final	Initial	Final	Initial	Final
R1	P	540	420	437 / 81 %	353 / 84 %	94 / 91 %	61 / 91 %	08	08
	P	515	373	417 / 81 %	310 / 83 %	89 / 91 %	57 / 91 %	08	08
	F	478	325	387 / 81 %	263 / 81 %	83 / 91 %	58 / 94 %	07	07
	F	495	265	400 / 81 %	202 / 76 %	87 / 92 %	53 / 85 %	09	09
R2	F	344	226	258 / 75 %	183 / 81 %	70 / 86 %	34 / 81 %	16	09
	F	379	270	276 / 73 %	213 / 79 %	88 / 86 %	53 / 93 %	16	04
R3	P	428	322	312 / 73 %	238 / 74 %	98 / 85 %	75 / 90 %	18	9
R4	P	418	373	309 / 74 %	283 / 76 %	97 / 89 %	79 / 88 %	12	12
	P	360	308	266 / 74 %	231 / 75 %	83 / 89 %	67 / 87 %	11	11
	F	381	289	255 / 67 %	205 / 71 %	111 / 88 %	67 / 82 %	16	16
	F	336	269	225 / 67 %	194 / 72 %	98 / 88 %	60 / 80 %	14	14
R5	F	474	450	365 / 77 %	360 / 80 %	106 / 97 %	88 / 98 %	05	05
R6	P	502	428	311 / 62 %	261 / 61 %	175 / 92 %	152 / 91 %	16	15
	P	490	422	303 / 62 %	257 / 61 %	171 / 92 %	150 / 91 %	16	15
	F	466	398	280 / 60 %	234 / 59 %	171/ 92%	148 / 91%	16	16
	F	508	429	304 / 60 %	253 / 59 %	187 / 92 %	160/ 91 %	17	16

Table 4.8 Total and percentage change in moisture content and volatile solids in different self-heating test

Parameter/ Run	Flask	Duration of Exp run (in days)	Moisture Content				Volatile Solid			
			Initial in gm	Final in gm	Diff in gm	Diff in %	Initial in gm	Final in gm	Diff in gm	Diff in %
R1	P	20	437	353	84	10 %	94	61	33	35 %
	P	20	417	310	107	26 %	89	57	32	36%
	F	20	387	263	124	32 %	83	58	25	30 %
	F	20	400	202	198	50 %	87	53	34	39 %
R2	F	29	258	183	75	29 %	70	34	36	51 %
	F	29	276	213	63	23 %	88	53	35	40 %
R3	P	18	312	238	74	24 %	98	75	23	23 %
R4	P	22	309	283	26	08 %	97	79	18	19 %
	P	22	266	231	35	13 %	83	67	16	19 %
	F	22	255	205	50	20 %	111	67	44	40 %
	F	22	225	194	31	14 %	98	60	38	39 %
R5	F	24	365	360	5	01 %	106	88	18	17 %
R6	P	22	311	261	50.16	16 %	175	152	23.60	13 %
	P	22	303	257	46.38	15 %	171	150	21.54	12 %
	F	22	280	234	44.78	15 %	171	148	22.99	13 %
	F	22	304	253	51.69	10 %	187	160	26.88	14 %

4.2.5 Biological maturity index of compost

In composting biological maturity or stability of compost is a significant issue. The Self-heating test is widely adopted in solid waste composting process. There are many problems encountered when attempting to specifically define stability (or maturity) of compost (Iannotti et. al, 1993; Ibrahim, 1967; Inbar et.al., 1990). Self-heating tests are relative test, which depends on how it is measured (Becker & Köter, 1995). Surface spread raw compost does not heat in the soil (even though it may release large quantities of energy). On the other hand, stable compost, if placed in a large-enough pile, can heat up considerably (Parnes, 1989). Learning to identify this behavior with a self-heating test can be very useful. Self-heating test is important because it drives the compost process, and regardless of other behavior, the presence of heat in compost is widely held to be a sign of immaturity (Gallenkamper et. al, 1993). Self-heating in finished composts can be dangerous after packaging and shipping of large volumes of material, because of the tendency of large containers or pallets to heat up during shipment (Comp.5).

A compost self-heating test may be compared for illustration purposes to a calorie-bomb analysis, used widely to calculate energy content of food-stuffs. In a calorie bomb, organic matter is ignited in the presence of oxygen, and the total temperature rise precisely recorded. The amount of energy (calories) present in the material is computed from the result. Theoretically, compost could be analyzed this way, but the results would, of course, be impractical.

In this study the indirect respirometric activity of the compost was determined using available data from self-heating test. Based on the results of the self-heating test, the compost is classified according to degree of biological stability as shown in Table 4.9 (LAGA 1985) as cited by (Koning & Bari 1999), where T_{max} = maximum temperature, I_{max} = maximum temperature increase; A_{72} = area under temperature curve after 72 hours. Initial masses and change in physico-chemical parameters during different self-heating test are presented in Table: 5.4 The calculated and estimated parameters of all kind of self-heating tests of all runs, $T_{max,}$ I_{max}, A_{72}, K_c, $H_{1,}$ r_a, RA and the stability index (SI) are presented in Table4.10 Based on the values of $T_{max,}$ I_{max}, A_{72} of all runs, the stability index (SI) of all composts was determined, respectively. The specfic heat transfer coefficient K_c was considered as 0.020 h^{-1} (Bari, Q.H. 1999).The range of estimated heat energy generated by the degradation of VS was 12000 to 15000 J/g, remarkably close to reported values for food waste and waste paper. The higher value of r_a refers more moisture evaporation. The higher value of RA refers unstable compost while lower value refers stable compost as shown in Table 4.11.

According to the six self-heating test, in R2, the compost after the test Exp-2 (i.e 2^{nd} stage test) had an SI of III to IV, indicating stable compost while it was unstable compost with an SI of I to II after Exp-1 (i.e ist stage test). In R5, the compost after the test Exp-5 (i.e 2^{nd} stage test) had an SI of IV, indicating stable compost while it was closed to unstable compost with an SI of II to III after Exp-4 (i.e ist stage test). In these circumstances it may be mentioned that for stability, compost needs to 2^{nd} stage degradation and forced aeration. In forced aeration composting bin additional power source is required which may expensive on unavailable some time. While passively aerated composting bin is easy for use and suitable.

In R6, the compost after the test Exp-6 has SI of V in both passively and forced aerated bin. This condition may be indicating that frequently wastes feeding with certain duration need not 2^{nd} stage degradation for providing stable compost.

Table: 4.9 Classification of compost according to degree of biological stability

Degree of Biological Stability (Stability Index SI)	V Stable	IV	III	II	I	I Unstable
T_{max} in °C	20-30	30-40	40-50	50-60	60-70	>70
I_{max} in °C/h	<0.3	0.3-0.45	0.45-0.8	0.8-1.4	1.4-2.0	>2.0
Area A_{72} in °C.h	<1700	1700-2000	2000-2500	2500-3000	3000-3500	>3500
RA in mg O_2/g VS-h	0-0.5	0.5-1.0	1.0-1.5	1.5-2.0	>2.0	

RA =respirometric activity; [a]Based on Iannotti et al.[1994] as cited by Epstein [1997]

Table: 4.10 Initial masses and change in physico-chemical parameters during different self-heating test

Test No	Test Type	$Mass_i$	ΔMass	MC_i	ΔH_2O	TS_i	VS_i	VS_i	ΔVS	ΔV
		g	g	%	g	g	%	g	g	%
R1	P	540	120	81	84.60	102.60	91.00	93.37	32.21	34.50
	P	515	142	81	107.56	97.85	91.00	89.04	31.34	35.20
	F	478	153	81	136.93	90.82	91.00	82.65	12.38	14.98
	F	495	230	81	199.55	94.05	92.00	86.53	32.47	37.52
R2	F	344	118	75	74.94	42.9	50.07	73.96	39.61	53.55
	F	379	109	73	63.37	56.7	44.59	88.00	35.27	40.08
R3	P	428	106	73	74.16	115.56	85.00	98	22.88	23.29
R4	P	418	45	74	25.84	108.68	89.00	96.73	17.95	18.56
	P	360	52	74	35.40	93.60	89.00	83.30	16.31	19.58
	F	381	92	67	50.08	125.73	88.13	110.8	42.08	37.98
	F	336	67	67	31.44	110.88	88.13	97.72	37.46	38.34
R5	F	474	44	77	20.98	109.02	97.00	105.7	21.47	20.30
R6	P	502.0	8.0	62	50.16	190.76	92.00	175.50	23.60	13.45
	P	490.0	10.0	62	46.38	186.20	92.00	171.30	21.54	12.57
	F	466.0	68.0	60	44.78	186.40	92.00	171.49	22.99	13.41
	F	508.0	79.0	60	51.69	203.20	92.00	186.94	26.88	14.38

I= initial; Δ= change over time; MC= moisture contant; TS= total solids

Table 4.11 Estimated respirometric activity, stability index, and other self-heating test parameters

Test No	Test	Tmax °C	Imax °C/h	A_{72} °C.h	eH_2O g	K_c h^{-1}	H_1 KJ/kg	r_a	RA	SI
R1	P	56	0.83	3240	100.71	0.020	14741	1.97	1.19	II
	P	50	1.36	3336	125.16	0.020	15518	2.28	2.27	I
	F	47	0.94	2292	144.42	0.020	16612	4.05	2.66	I
	F	36	1.33	3000	218.31	0.020	16681	6.93	6.56	I
R2	F	47	0.75	2448	94.75	0.020	9393	2.66	1.42	III
	F	46	0.47	2424	81.01	0.020	9667	2.40	0.80	IV
R3	P	47	1.25	3120	85.60	0.020	14613	2.62	2.28	I
R4	P	42	1.06	2700	34.82	0.020	12415	1.60	1.15	III
	P	42	1.04	2748	43.56	0.020	11581	1.96	1.41	III
	F	51	1.25	3204	71.21	0.020	8095	2.23	1.89	II
	F	48	1.08	3000	50.17	0.020	7941	1.69	1.12	III
R5	F	41	0.53	2376	31.72	0.020	12508	1.43	0.55	IV
R6	P	44	0.60	2892	61.96	0.020	12985	1.98	0.74	V
	P	51	0.60	2796	57.15	0.020	13338	1.95	0.76	IV
	F	51	0.57	2976	56.27	0.020	13453	1.81	0.67	IV
	F	52	0.50	3336	65.13	0.020	14003	1.74	0.55	IV

eH_2O = Total H_2O evaporation ($\Delta H_2O + \Delta VS.fvs$); k_c= test specific heat transfer cofficient; H_1 = heat energy generated by the degradation of VS; RA = MgO_2/gVS-h; r_a = adjustment factor (ratio of total biological heat generation to loss of sensible heat to surroundings)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on the result of this study the following conclusions are drawn:

1. Similar set of composting using similar initial waste mixture shows almost similar area under temperature curve, that is the area is almost same for forced and passively aerated composting. In first experiment (Exp-1) of this type the areas are 8174 °Ch and 9541 °Ch for passively and forced aerated bin respectively. In another experiment (Exp-4) of this type the areas are 10584 °Ch and 10350 °Ch for passively and forced aerated bin respectively.

2. In two 2nd stage forced aerated bin composting, the area under temperature curve was observed 6110 °Ch and 6208 °Ch respectively. It indicades that the volatile solids in 2nd stage was less and ther by less heat energy was released as the area under temperature curve in 2nd stage is less than first stage.

3. The range of volatile solid degradation for passively aerated bin was 45-68 % with range of area under temperature curve 8000-9000 °Ch and for forced aerated bin range of volatile solid degradation was 54-59 % with range of area under temperature curve 9000-10000 °Ch. It seems that the degradation is almost similar in both processes.

4. For composting experiment with intermittent waste addition, the volatile solid degradation for passively and forced aerated bin were 31 % and 60 % with area under temperature curve 12000-23000 °Ch. For practical purpose with intermittent waste addition, forced aerated bin composting process can be suggested. However more experiment is needed.

5. Since the range of degradation and area under temperature curve for both process is almost same, therefore the passively aerated bin composting is suggested for batch purpose. It does not need external energy for aeration. In forced aerated bin composting 0.06 kw/h energy is needed for aeration for single aquarium aerator.

6. In self-heating test of the compost taken from intermittent waste addition composting, duration of degradation was 22 days. VS difference and SI index was 13% and V respectively of compost from passively aerated bin while VS difference and SI index 14% and IV respectively of compost from forced aerated bin.

7. Almost no leachate and offensive odor were detected during all bin composting experiments. This can be taken as effectiveness of the bin composting process.

8. Most of the mass balance shows the general trend of volatile solid reduction from beginning to end of the composting process. This creates a physical feeling of mass reduction in composting process.

5.2 Recommendations for future studies

1. The carbon nitrogen ratio of raw waste is to be evaluated properly before starting composting process. It can also check during the composting process.

2. The pathogenic bacteria are to be tested initially and during different stage of composting.

3. For precise measurement, data logging system should be applied for future study.

4. Horizontal or inclined rotating bin composting can be applied.

5. The suitable size of composting bin and real demand of compost for house hold purpose should be evaluated properly.

6. Composting experiments with intermittent waste addition, spcial attention should be given to achieve optimum composting degradation from passively aerated bin composting in future study.

REFERENCE

Ahmed M.F and Rahman M.M. (2000) Water supply and sanitation. ITN- Center for water supply and waste management, BUET, Dhaka, Bangladesh.

Alamgir, M. (2003) Current status of waste containment in Bangladesh, Paper presented in the the intennational seminar and workshops on Geoenvironmental Engineering, April 2003, BIT Khulna, Bangladesh.

Bari, Q.H, Koenig A and Tao G.H.(2000) Kinetic Analysis of Forced Aeration Composting-1. Reaction Rate and Temperature. Waste Management and Research, 18, pp .303-312.

Brinton, J. William F. Evans E. and Jonathan W.Q. Collinson. (1993) On-farm Composting Guidelines for Use of Dairy and Poultry manures in Composting Formulations. Woods End Research Laboratory, Maine.

Brinton, J. William F. Evans E., M.L. Droffner and R.B. Brinton (1995). Standardized Test for Evaluation of compost Self-Heating. BioCycle, 36:11, 64-68.

BGK (1994) Determination of degree of stability by self-heating test (in German). In methodenhandbuch zur Analyse von Kompost (Methods for the analysis of compost). Bundesguetegemeinschaft Kompost e. V., Kkoeln, Germeny (Cited by Bari 1999)

Bari, Q.H. (1999) Effect of Different Modes of Aeration on Composting of Solid Waste in a closed system. Ph.D. Thesis, Depatment of Civil Engineering, The University of Hong Kong.

BRAC (1997), Fertilizer recommendation Guide-1997 Bangladesh Agricultural Research Council, Soil Publication No.41

Becker, G. and Köter (1995) A Standard Measurement for Compost Maturity, Conference Proceedings, Biological Waste Management

Comp. 1, Part 637 Environmental Engineering, National Engineering Handbook. Resources Conservation Service, United States Department of Agriculture.

Feldman, K. (1995) Stability Index Determination. BioCycle, 36:11, 68-69.

Golueke, C.G. (1972), Composting Rodale Press, Inc., Emmaus, Pa, USA.

Gallenkamper, B., G. Becker, A. Kötter (1993) Criteria for judging the decomposition maturity of biowaste compost (conference report, Ministry for Research and Development (BMFT), 22-23 Nov.1993, Hamburg.

Hung, R. T.1993 The practical Handbook of Compost Engineering. Lewis Publishers, Boca Raton, p.111. (Cited by Bari 1999)

Koening, A and G. H. Tao 1996. Accelerated Forced Aeration Composting of Solid Waste. In Proceeding of the Asia-Pacific Conference on Sustainable Energy and Environmental Technology.World Scinitific Publishing, Singapore, pp.450-457. (Cited by Bari 1999)

Iannotti, D. A., T.Pang, B. L.Toth, D. L.Elwell, H. M. Keener and H. A. J.Hoitink (1993) A Quantitative Respirometric Method for Monitoring Compost Stability, Compost Science & Utilization, 1(3): 52-65

Inbar, Y., Y. Chen, Y. Hadar and H. A .J. Hoitink (1990) New Approaches to Compost Maturity, Biocycle, Dec. 1990

Jackson, M.A (2003) Chemical analysis of soil, McGraw Hill Publication Company.

Lasardi, K. E and E. I. Stentiford (1998) A Simple Respirometric Technique for Assessing Compost Stability Water Research, 32:12, 3717-3723.

LAGA (Laenderarbeitsgemeinschaft Abfallbeseitigung),(1985) Menmorandum M 10 Quality criteria and recommendation for application of compost from solid waste (in Germeny). In kumpf, et al (eds.). Muell-Handbuch Kennzahi. Kennzahi 6856, Lieferung 1/85, Erich Schmidt Verlag, Berlin.(Cited by Bari,1999)

Moqsud, M. A. and Rahman, M. H. (2004) A study on Biochemical Quality of Compost from Kitchen Garbage in Bangladesh, Dhaka.

Marshall, T.J. and J.W. Holmes. 1979 Soil Physics. Cambridge University Press, Cambridge, UK, 277.(Cited by Bari,1999)

Parks, C.L Atlas, M.R Brown, E.A (1988) Laboratory Manual of Experimental Microbiology, A times Mirror Company, USA

Switzenbaun, M.S.,L.H. Moss, E. Epstein, A.B. Pincince and J. F. Donovan. (1997) Defining Biosolids Stability: A Basis for Public Regulatory Acceptance. In Project 94-REM-1, Water Environment Research Foundation, Alexandria, VA.

Salequzzaman, M.; Banerjee, P. and Ahmed, M.K. (2005) Integrated and Sustainable Solid Waste Management in Khulna City Corporation (KCC), Bangladesh

Salequzzaman, M. (2000) Perceptions of Vehicle Air Pollution in Khulna, Bangladesh, Proceedings of the Habitus 2000 Conference in Perth, Western Australia on05-09 September, 2000.

Tchobanoglous, G. (1977) Solid Waste Engineering Principles and Management Issue, McGraw Hill Publications Company.

Tchobanoglous, G. (1993), Integrated Solid Waste Management, McGraw Hill Publications Company.

Vermont State Agency of Natural Resources Center, 1992

WasteSafe (2005) Draft Report on Integrated and Safe Disposal of Municipal solid waste in LDACs. Department of Civil Engineering KUET and Asia Pro Eco Programme, EC

Zimmerman, R. A.(1991) Oxygen Utilization as an indicator of Municipal Solid Waste Compost Stability: In proceedings of the 7 th International Conference on Solid Waste Management and Secondary Materials, Philadelphia, PA, USA.

Comp. 2 www.deq.state.mi.us/documents/deq-whm-stsw-Mulchingand Backyard Composting Guidebook. PDF.

Comp.3www.iges.or.jp/kitakyushu/mtgs/seminars/theme/swm/Supplementary/Solid Waste Management

Comp. 4 www. waste concern.org

Comp. 5 www.woodsend.org

Comp. 6 www.ashoka.org

Comp.7www.adb.org/Documents/Events/2005/Awarness-Motivation-Phase2/Khula/mrahman.pdf

APPENDIX-A

Changes in total mass, moisture content and volatile solids, fixed solids during different bin composting experiments (Initial and final)

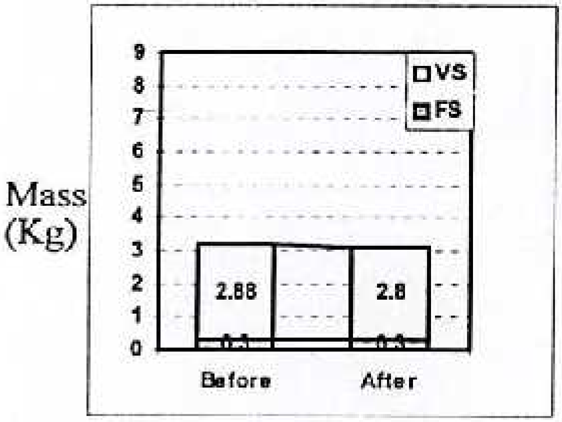

Figure A.1 Mass variation during Exp-2, forced aerated bin

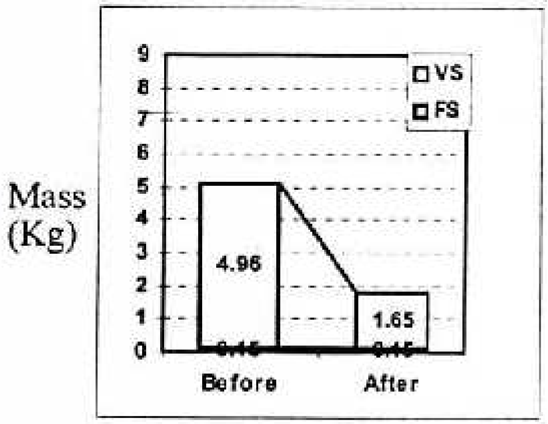

Figure A.2 Mass variation during Exp-3, passively aerated bin

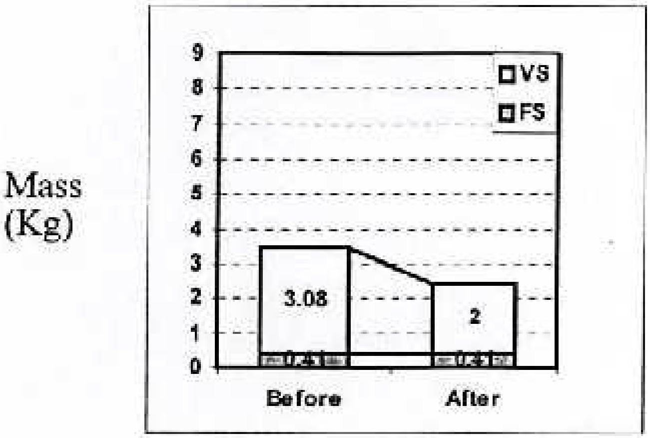

Figure A.3 Mass variation during Exp-5, forced aerated bin.

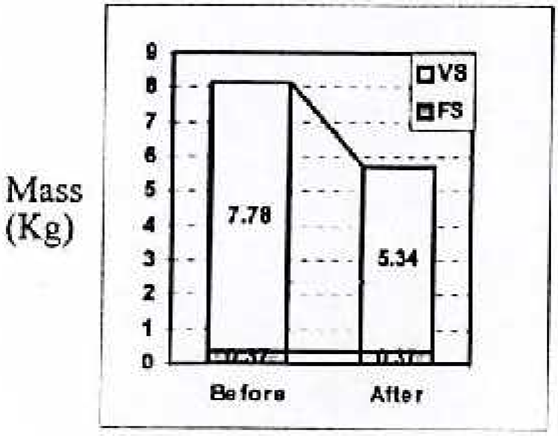

Figure A.4 Mass variation during
Exp-6, passively aerated bin

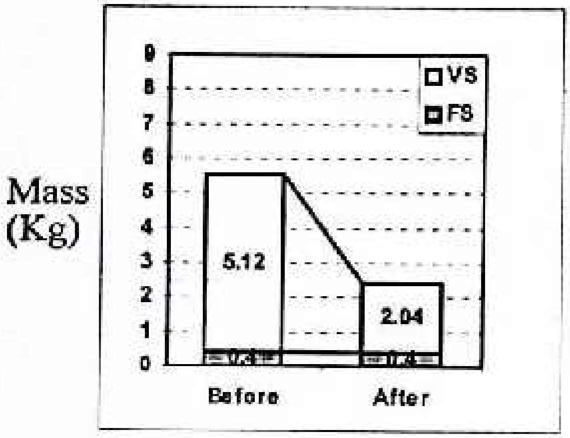

Figure A.5 Mass variation during
Exp-6, forced aerated bin

Changes in total mass, moisture content and volatile solids, fixed solids during different Self- heating tests (Initial and final)

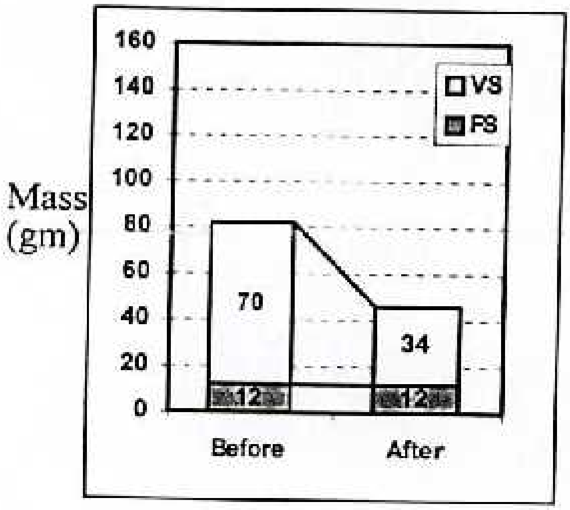

Figure A.6 Mass variation during self-heating R2 F

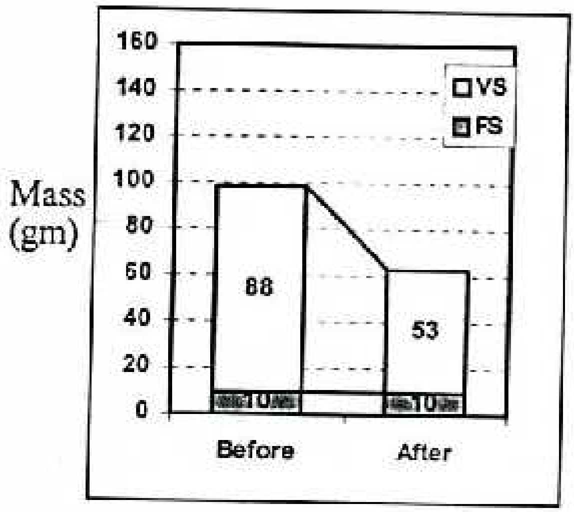

Figure A.7 Mass variation during self-heating R2 F

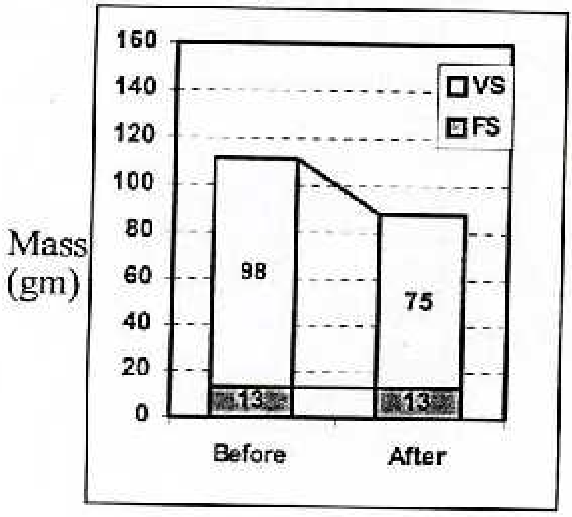

Figure A.8 Mass variation during self-heating R3 P

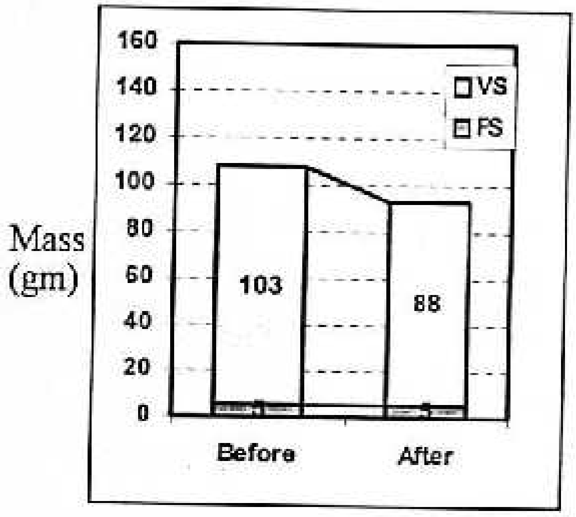

Figure A.9 Mass variation during self heating R5 F

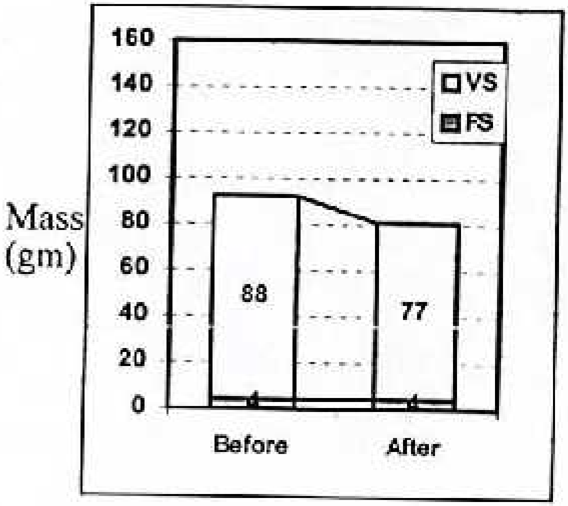

Figure A.10 Mass variation during self-heating R6 P

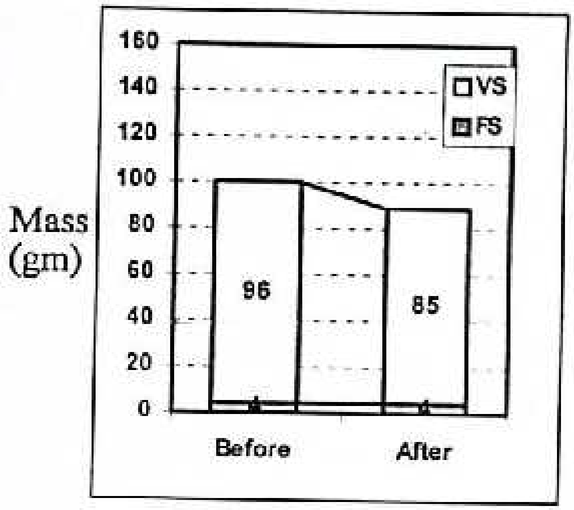

Figure A.11 Mass variation during self-heating R6 P

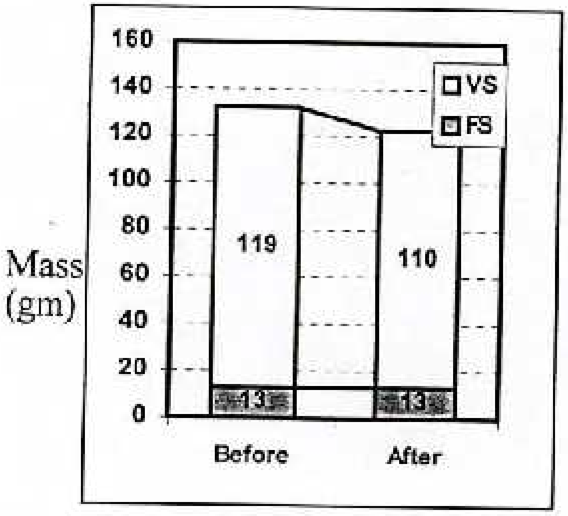

Figure A.12 Mass variation during self-heating R6 F

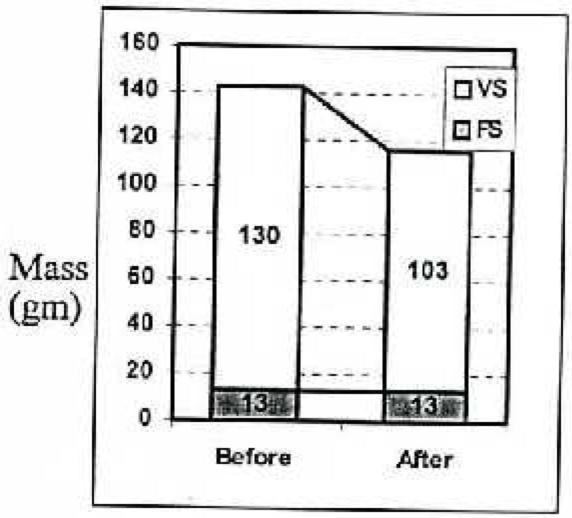

Figure A.13 Mass variation during self-heating R6 F

Table A.1 Data for time and temperature of bin composting Exp-4 (19/08/06 - 23/09/06)

Time in Day	Temperature Bef R	Temp Aft R	Room Temp
0	32	32	32
0.5	37.8	36.2	32
1	45.1	44.8	32
1.5	44.9	45.2	32
2	46	45.4	31
2.5	47	46	31
3	47.3	47	30
3.5	47.8	47.4	30
4	48.5	48	31
4.5	47.3	47	31
5	47	47	31
5.5	46.6	46.5	31
6	46.1	45	31
6.5	45.5	45	31
7	43.8	43.8	31
7.5	43.9	43.2	31
8	43.9	43.5	32
8.5	43.8	43	32
9	43.4	43.3	32
9.5	43.5	43	32
10	44.5	43.7	31
10.5	44.7	44	31
11	43.8	43	31
11.5	43.9	42.8	31
12	44	44	30
12.5	44.2	44	30
13	44	43.5	31
13.5	44.1	44	31
14	44.3	44	31
14.5	44.3	44	31
15	44.5	43.8	31
15.5	43.8	43.5	30
16	43.8	43.5	31
16.5	43.1	42.6	31
17	43.8	43.5	30
17.5	44.2	44	31
18	44	44	31
18.5	47.2	45.2	31
19	47.2	47	31
19.5	47.3	47	30
20	47.4	44.8	30

Time In Day	Temperature Bef R	Temp Aft R	Room Temp
20.5	47.4	47.1	30
21	47.4	47.2	30
21.5	47.5	47.3	29
22	47.5	47	29
22.5	47.5	44.2	29
23	46	45	29
23.5	42	41	31
24	42	41	31
24.5	44	44	31
25	44.2	43.8	32
25.5	44.3	42.2	31
26	43.5	42.1	31
26.5	43.1	41.8	33
27	43.1	43	32
27.5	42.5	40.9	31
28	41.6	40.5	31
28.5	40.5	39	31
29	40	38.9	32
29.5	40	39.7	32
30	39.2	37.4	30
30.5	38	36.9	30
31	37.3	36.2	30
31.5	36.8	36.1	30
32	36	36	29
32.5	35	34.8	29
33	34.4	34.2	29
33.5	33.5	33	29
34	33	33	28
34.5	33	[illegible]	28
35	31.9	31.8	28
35.5	31.5	33.5	28
36	31	31	28

Table A.2 Data for time and temperature of Self-heating test R4 (05/08/06 - 03/09/06)

Time in Day	Flask1	Flask2	Flask 3	Flask 4	Rm Tp					
0	30	30	32	32	27					
0.5	30	30	32	32	27	360	360	384	384	324
1	40	39	35	36	28	480	468	420	432	336
1.5	45	40	39	38	28	540	480	468	456	336
2	50	46	39	40	29	600	552	468	480	348
2.5	51	47	39	41	29	612	564	468	492	348
3	51	48	41	42	30	612	576	492	504	360
3.5	51	48	41	42	30	612	576	492	504	360
4	50	47	41	42	30	600	564	492	504	360
4.5	51	46	41	42	30	612	552	492	504	360
5	51	46	41	42	30	612	552	492	504	360
5.5	49	46	41	42	30	588	552	492	504	360
6	48	46	41	42	31	576	552	492	504	372
6.5	45	45	41	41	31	540	540	492	492	372
7	44	45	41	41	31	528	540	492	492	372
7.5	43	44	41	41	31	516	528	492	492	372
8	43	44	41	40	31	516	528	492	480	372
8.5	42	44	40	40	31	504	528	480	480	372
9	42	44	40	40	31	504	528	480	480	372
9.5	42	44	41	40	32	504	528	492	480	384
10	41	42	41	40	32	492	504	492	480	384
10.5	41	43	41	40	32	492	516	492	480	384
11	41	44	41	40	32	492	528	492	480	384
11.5	41	44	41	40	32	492	528	492	480	384
12	41	43	42	40	33	492	516	504	480	396
12.5	40	44	42	40	33	480	528	504	480	396
13	40	43	42	40	34	480	516	504	480	408
13.5	40	44	42	40	34	480	528	504	480	408
14	40	44	42	40	33	480	528	504	480	396
14.5	39	43	41	40	33	468	516	492	480	396
15	39	43	41	40	34	468	516	492	480	408
15.5	40	42	41	40	31	480	504	492	480	372
16	39	42	41	40	31	468	504	492	480	372
16.5	39	42	41	40	31	468	504	492	480	372
17	39	42	41	40	31	468	504	492	480	372
17.5	38	42	41	40	30	456	504	492	480	360
18	38	42	41	40	31	456	504	492	480	372
18.5	38	41	41	40	31	456	492	492	480	372
19	38	41	41	40	31	456	492	492	480	372
19.5	38	40	40	40	30	456	480	480	480	360
20	38	40	40	40	30	456	480	480	480	360
20.5	38	39	40	39	30	456	468	480	468	360

Time in Day	Flask1	Flask2	Flask 3	Flask 4	Rm Tp					
21	38	39	40	39	30	456	468	480	468	360
21.5	38	39	40	39	30	456	468	480	468	360
						21720	22164	20880	20652	15948
						5772	6216	4932	4704	

Table A.3 A_{72}, T_{max}, I_{max} identification.

	F1	F2	F3	F4	
	360	360	384	384	
	480	468	420	432	
	540	480	468	456	
	600	552	468	480	
	612	564	468	492	
	612	576	492	504	
Area Under A_{72}	**3204**	**3000**	**2700**	**2748**	
T_{max}	**51**	**48**	**42**	**42**	
I_{max}	**1.25**	**1.08**	**1.06**	**1.04**	