STUDY ON ACCEPTABLE COMPOSTING TECHNOLOGY IN BANGLADESH

by

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A thesis submitted in partial fulfillment of the requirements for the degree of
Master of Science in Civil Engineering

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Declaration

This is to certify that the thesis work entitled as "Study on Acceptable composting Technology in Bangladesh" has been carried out by Khan Md. Mehedi Hasan in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above research work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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- Khan Md. Mehedi Hasan

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To

my parents who taught me morality

and

my beloved younger brother and sisters

ABSTRACT

Composting has several benefits including fast conversion of the organic solid wastes to a biologically stable end product as compared to bio-chemical reactions occurring in landfills and recovery of waste material in the form of compost for utilization in agriculture, horticulture or other applications, as a soil conditioner, potting soil, organic fertilizer, landscaping material etc. Historically the composting is applied in the different civilization including Europe, China and Bangladesh. Despite the huge potential to convert a significant portion of Municipal Solid Waste (MSW) of Bangladesh into compost due to its inherent physical characteristics, the expected success is not seen, moreover, it suffers several setbacks. With the view to overcome existing setbacks, the technology (known elsewhere) suitable for Bangladesh should be evolved. To search an acceptable composting technology for the country, a Demo Compost Plant was built as a part of WasteSafe II research project in cooperation with a NGO named as Samadan, at Khalishpur, Khulna. This study mainly conducted in this plant through necessary field works to develop an acceptable composting technology for Bangladesh.

In this study four types of processes - three are passively aerated and the rest one is forced aerated, used as the aeration system was constructed successfully and hence evaluated practically through constructing series of compost piles. In the first passively aerated compost pile, horizontal bamboo frame was used. In the Second one, perforated vertical PVC pipe was used instead of bamboo frame. The Third compost pile is forced aerated, in which locally fabricated blower was used, while the fourth one is passively aerated as practiced in the Samadan Compost Plant. MSW was collected from the adjacent areas of the plant giving special initiative to minimize the existence of non-biodegradable wastes. As the solid waste comes directly from the kitchen, percentage of rapidly degradable waste is greater than others and toxic substance and metal type waste are less in the used waste for demo compost plant.

Twelve compost piles at three set-up were studied. Physical properties of input MSW such as composition, bulk density, moisture content and particle size distribution were evaluated for all compost piles. Temperature was taken from nine different positions of individual compost piles of two set-up and twenty seven different position of last set-up. Twelve self heating tests were performed in this study. Most of all stability index (SI) is found as IV. Density change during the composting process was measured also for all compost piles of first two set-ups. It is found that density has changed up to about 77% at loose state and about 50% at dense state. It is seen that the production of compost is varied from 25 to 39% of total input waste. The Physical parameters like volatile solids, moisture content, dry matter, pH, salinity, nutrients like total nitrogen, nitrate nitrogen, ammonia nitrogen, potassium, magnesium, phosphorus and heavy metal contamination of the compost were measured taking the help from Bauhaus University Weimar, Germany. The values of the relevant parameters of compost in most of the cases are found in the standard range.

To overcome the disadvantage of practiced screening system, a newly designed and locally fabricated rotary screening system is developed and hence the performance was evaluated. The new system depicted better performance than the existing one in all aspects.

From physical inspection and experimental findings, it is revealed that the passively aerated (horizontal aeration system) composting technique is suitable for Bangladesh. However, some easily affordable and sustainable mechanical device should be incorporated to increase the efficiency and to reduce the health hazards of the compost plant.

CONTENTS

CHAPTER ONE

INTRODUCTION

1.1 General

Human activities generate waste materials that are often discarded because they are considered useless. These wastes are normally solid, and the word waste suggests that the material is useless and unwanted. However, many of these waste materials can be reused, and thus they can become a resource for industrial production or energy generation, if managed properly. Waste management becomes one of the significant problems of our time because enormous amount of waste are produced and most people want to preserve their lifestyle, while also protecting the environment and public health.

Historically, waste management has been an engineering function. It is related to the evolution of a technological society, which along with the benefits of mass production has also created problems that require the disposal of solid waste. Solid waste management means the process of solid waste collection, control, carrying, processing and disposal with considering of public health, social impact, economy, engineering, environmental impact etc. Also the solid waste management is related with proper administration, money, planning and research etc. To manage the waste as environment friendly and cost effectively, the best solution is Integrated Waste Management (IWM). When the functional elements of their waste management services have been evaluated and selected, and all the interfaces and connections between elements have been matched for effectiveness and economy, the concerned stakeholders/authorities/communities are said to have developed an Integrated Waste Management (IWM) system (Alamgir, et. al., 2005). IWM can be defined as the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives and goals (Tchobanoglous and Kreith, 2002). Composting is one element of an integrated solid waste management strategy that can be applied to mixed municipal solid waste (Sarwar, et. al., 2008). The popularity of composting has increased due to several environmental benefits such as:

- fast conversion of the organic solid waste to a biologically stable end product
- recovery of waste material in the form of compost for utilization in Agriculture, horticulture or other applications, as a soil conditioner, organic fertilizer and landscaping material
- stabilization and volume reduction (saves landfill space) of the waste materials prior to environmentally sound final disposal in landfills
- cheap and effective solid waste treatment method (Seasay, et al., 1998, Bari, et al., 2001)

Despite the huge potential to covert a significant portions of MSW of Bangladesh into compost, this sectors suffers several setback.

1.2 Compost and Composting

Compost is an organic matter source with a unique ability to improve the chemical, physical and biological characteristics of soils. It improves water retention in sandy soils and promotes soil structure in clayey soils by increasing the stability of soil aggregates. Adding compost to soil increases soil fertility and cation exchange capacity and can reduce fertilizer requirements up to 50%. Soil becomes microbially active and more suppressive to soil-borne and foliar pathogens. Enhanced microbial activity also accelerates the breakdown of pesticides and other synthetic organic compounds. Compost amendments reduce the bioavailability of heavy metals-an important quality in the remediation of contaminated soils.

A definition of Composting as applied to MSW management is as follows: "Composting is the biological decomposition of the biodegradable organic fraction of MSW under controlled conditions to a state sufficiently stable for nuisance-free storage and handling and for safe use in land applications (Golueke, et. al., 1955; Golueke, 1972; Diaz, et. al., 1993).

Figure 1.1 Photograph of Final Compost

Compost is not particularly high in essential nutrients, (N-P-K), and is considered a soil conditioner rather than a fertilizer. However, organic matter is a valuable soil amendment.

Composting is a controlled process to produce compost. Organic substances are decomposed by this process. In ancient day mostly animal manure and agricultural wastes are composted to produce compost and to supplement the organic in the field, which are still popular in Bangladesh.

Benefits of Compost

Benefits of compost are found in the following two ways:

1. Soil / Plant Improvements
2. Pollution Prevention / Remediation

Soil / Plant Improvements

- Improves soil structure
- Improves nutrient holding capacity
- Reduces soil compaction and crusting
- Reduces fertilizer requirements
- Increases ease of cultivation
- Improves root growth and yields
- Improves water infiltration and drought tolerance
- Protects plants from disease
- Increases microbial and earthworm populations

Pollution Prevention / Remediation

- Prevents erosion of embankments, roadsides, and hillsides.
- Binds heavy metals in contaminated soils.
- Degrades many pesticides.
- Absorbs odors and degrades volatile organic compounds.
- Diverts organics from landfills into compost, reducing waste burden and methane production.

1.3 Background of This Study

During the field survey from May 2004 to October 2004, it is found that the composting activities have been initiated as organized base (pilot-scale type) in six cities of Bangladesh by different organizations including city corporation, NGOs and CBOs. Chittagong City Corporation (CCC) and Barisal City Corporation (BCC) do not have any plants until the survey period. In Dhaka City Corporation (DCC), Waste Concern had five and Prodipan had one compost plant. In Khulna City Corporation (KCC), Prodipan had one, PRISM had four and RUSTIC had one compost plant. The capacity of all the plant was one ton per day. In RCC had one organization related to this sector named LOFS, which had one plant with the capacity of 0.4 ton per day. In Sylhet City Corporation (SCC), SP (Sylhet Partnership) and EPCT had two compost plants, which capacity were 2.5 ton and 0.03 ton per day respectively. Mostly the processes adopted in these cities are windows or active pile system. The barrel or small container composting methods is also getting popularity particularly in urban slums, colonies etc. (Alamgir, et. al., 2005).

In all the mentioned compost plant, the compost plant of Sylhet partnership (Sylhet), PRISM (Khulna), PRIZM (Gazipur), RUSTIC (Khulna), Prodipan (Khulna) were found active and well running in January 2005, August 2007, January 2005, January 2005, July 2005, respectively. But in 2007, the plant of Sylhet partnership and PRIZM and in 2008 the plant of PRISM was found closed. In 2007, the plant of Prodipan and in 2008 the plant of RUSTIC was found poorly running.

The composting of organic wastes has a very significant role to play in the MSW management. However, that role is in danger of being compromised by failure to follow well established scientific principals in the location, design and operation of composting plant and by the public reaction to the resulting nuisance and emissions. Another important factor for the failure is economic condition of compost plant.

1.4 Objectives of This Study

1. To identify the present status of composting plants in Bangladesh.
2. To investigate the various aspects of composting such as different ways of passive aeration, possibility of introducing forced aeration system.
3. To examine the suitable options to enrich the quality of compost for the satisfaction of potential buyers/consumers.
4. To establish an acceptable and sustainable composting technology for Bangladesh.

1.5 Organization of the Thesis

This report contains Introduction, Literature Review, Study on Compost Plant, Methodology, Results and Discussion and Conclusion and Recommendation as shown below.

Chapter 1 (One)	:	Includes general introduction, objectives of this study.
Chapter 2 (Two)	:	Literature review covering details of composting, various control parameters, microbiology of composting, present practiced technique in Bangladesh, Compost standards and Composting situation in Bangladesh.
Chapter 3 (Three)	:	A brief description on existing compost plant and its constraints are revealed in this chapter.
Chapter 4 (Four)	:	A brief description of methods and methodology including construction of compost plant and related infrastructure are presented.
Chapter 5 (Five)	:	All the experimental results including analysis of various physical parameters and various issues, which are found in this study, are presented here.
Chapter 6 (Six)	:	Conclusion and a number of recommendations for future study are provided in this chapter.
Reference	:	At the end of the main chapters the references are added, which is used in this study thesis and may also be used in any further study in this contest.

CHAPTER TWO

LITERATURE REVIEW

2.1 General

Since the beginning, humankind has been generating waste, be it the bones and other parts of animals that they slaughter for their food or the wood that they cut to make their carts. With the progress of civilization, the waste generated became of a more complex nature. At the end of the 19th century the industrial revolution saw the rise of the world of consumers. Not only the air gets polluted but the earth itself became more polluted with the generation of solid waste. The rapid increase of population and urbanization is largely responsible for the increase of solid waste (edugreen.teri.res.in).

2.2 Historical Overview

Occasionally, curious individuals want to know the origins of composting. It is difficult to attribute the birth of composting to a specific individual or even one society but it is believed that composting began shortly after humans started to cultivate food. The ancient Akkadian Empire in the Mesopotamian Valley referred to the use of manure in agriculture on clay tablets 1,000 years before Moses was born. There is evidence that Romans, Greeks and the Tribes of Israel knew about compost. The Bible and Talmud both contain numerous references to the use of rotted manure straw, and organic references to compost are contained in tenth and twelfth century Arab writings, in medieval Church texts, and in Renaissance literature. Notable writers such as William Shakespeare, Sir Francis Bacon, Sir Walter Raleigh all mentioned the use of compost.

On the North American continent, the benefits of compost were enjoyed by both native Americans and early European settlers of America. Many New England farmers made compost as a recipe of 10 parts muck to 1 part fish, periodically turning their compost heaps until the fish disintegrated (except the bones). One Connecticut farm, Stephen Hoyt and Sons, used 220,000 fish in one season of compost production. Other famous individuals that produced and promoted the use of compost include George Washington, Thomas Jefferson, James Madison, and George Washington Carver.

The early 20th century saw the development of a new "scientific" method of farming. Work done in 1840 by a well-known German scientist, Justus von Liebig, proved that plants obtained nourishment from certain chemicals in solution. Liebig dismissed the significance of humus, because it was insoluble in water. After that discovery, agricultural practices became increasingly chemical in nature. Combinations of manure and dead fish did not look very effective beside a bag of fertilizer. For farmers in many areas of the world, chemical fertilizers replaced compost.

Sir Albert Howard, a British agronomist, went to India in 1905 and spent almost 30 years experimenting with organic gardening and farming. He found that the best compost consisted of three times as much plant matter as manure, with materials initially layered in sandwich fashion, and then turned during decomposition (known as the Indore method). In 1943, Sir Howard published a book, *An Agriculture Testament*, based on his work. The book renewed interest in organic methods of agriculture and earned him recognition as the modern day father of organic farming and gardening.

J.I. Rodale carried Sir Howard's work further and introduced American gardeners to the value of composting for improving soil quality. He established a farming research center in Pennsylvania and the monthly *Organic Gardening* magazine. Now, organic methods in gardening and farming are becoming increasingly popular. A growing number of farmers and gardeners who rely on chemical fertilizers are realizing the value of compost for plant growth and restoring depleted soil (http://web.extension.uiuc.edu).

2.3 Biological Succession of Composting

Composting is a biological process in which organic wastes are converted into stabilized humus by the activity of complex organisms naturally present in the wastes. These include microorganisms such as bacteria, fungi, and protozoa, and may also involve invertebrates such as nematodes, earthworms, mites, and various other organisms (Figure 2.1).

The organic wastes are initially decomposed by the first level consumers such as bacteria, fungi (molds), and actinomycetes. Waste stabilization is accomplished mainly through the bacterial reactions. Mesophilic bacteria are the first to appear. Thereafter, as the temperature rises, thermophilic bacteria, which inhabit all parts of the compost heap, appear. Thermophilic fungi usually grow after 5-10 days of composting. If the temperature becomes too high, i.e. greater than 65-70^{0}C, fungi, actinomycetes, and most bacteria become inactive and only spore forming bacteria can develop. In the final stages, as the temperature declines, members of the actinomycetes become the dominant group which may give the heap surface a white or grey appearance.

Thermophilic bacteria mostly *Bacillus* spp. (Storm, 1985), play a major role in the decomposition of proteins and other carbohydrate compounds. In spite of being confined primarily to the outer layers of the compost piles, and becoming active only during the latter part of the composting period, fungi and actinomycetes play in decomposing cellulose, lignins, and other more resistant materials, which are attacked after the readily decomposed materials have been utilized. The common species of actinomycetes are reported to be *Streptomyces* and *Thermoactinomycetes*, while *Aspergillus* is the common fungus species (Strom, 1985).

After these stages the first level consumers become the food of second-level consumers such as mites, beetles, nematodes, protozoa, and rotifers. Third-level consumers such as centipedes rove beetles, and ants prey on the second-level consumers. A schematic diagram showing the growth patterns of different-level consumers, with composting time and temperature, is presented in figure 2.1.

In order for the composting process to function effectively a suitable number of organisms must be presented which are capable of attacking the types of wastes to be stabilized. These organisms are naturally present in the waste such as nightsoil, animal manure, and wastewater sludge; hence compost seeding is usually not necessary. Although packages of compost inculum are commercially available, controlled scientific tests showed no increased benefits over natural source of organisms (Dindal, 1978). However, some types of agricultural waste, such as rice straw, leaves, and aquatic weeds, which do not readily have these organisms, may require the seeding of nightsoil, or sludge at the starting period.

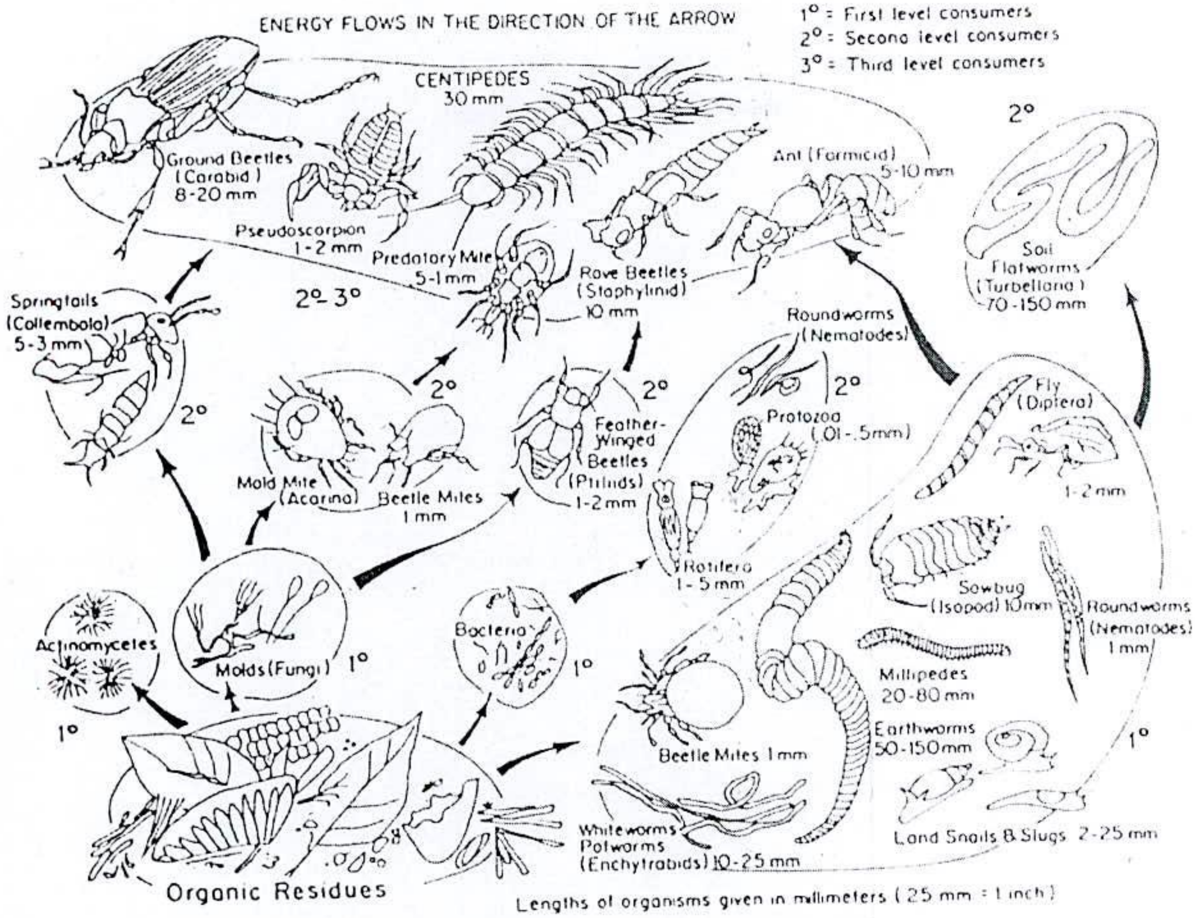


Figure 2.1 Food web of the compost pile (Dindal, 1978)

2.4 Biochemical Reaction of Composting

Organic wastes suitable for composting vary from the highly heterogeneous materials present in municipal refuse and sludge to virtually homogeneous wastes from food processing plants. The courses of biochemically breaking down these wastes are very complex, encountering several intermediates and pathways. For, example, the breaking down of proteins includes the following pathways:

Proteins → peptides → amino acids → ammonium compounds → bacterial protoplasm and atmospheric nitrogen or ammonia

For carbohydrates:

Carbohydrates → simple sugars → organic acids → CO_2 and bacterial protoplasm

The precise details of the biochemical changes taking place during the complex process of composting are still lacking. The phases which can be distinguished in the composting processes according to temperature patterns are (Wiley, 1989):

a) Latent phase, which corresponds to the time necessary for the microorganisms to acclimatize and colonize in the new environment in the compost heap.
b) Growth phase, which is characterized by the rise of biologically produced temperature to mesophilic level.
c) Thermopholic phase, in which the temperature rises to the highest level. This is the phase where waste stabilization and pathogen destruction are most effective.
d) Maturation phase, where the temperature decreases to mesophilic and, consequently, ambient levels. A secondary fermentation takes place which is slow and favors humification; that is, the transformation of some complex organics to humic colloids closely associated with minerals (iron, calcium, nitrogen, etc.) and finally to humus. Nitrification reactions, in which ammonia (a by-product from waste stabilization) is biologically oxidized to become nitrite (NO_2^-) and finally nitrate (NO_3^-), also take place (Metcalf and Eddy, 1979);

$$NH_4^- + \frac{3}{2}O_2 \xrightarrow[Bacteria]{Nitrosomonas} NO_2^- + 2H^- + H_2O \tag{2.1}$$

$$NO_2^- + \frac{1}{2}O_2 \xrightarrow[Bacteria]{Nitrobactor} NO_3^- \tag{2.2}$$

Combining eqs (2.1) and (2.2), the overall oxidation reaction for nitrification is:

$$NH_4^- + 2O_2 \rightarrow NO_3^- + 2H^- + H_2O \tag{2.3}$$

Since NH_4^+ is also synthesized into cell tissue, a representative reaction for cell synthesis is:

$$NH_4^- + 4CO_2 + HCO_3^- + H_2O \rightarrow C_5H_7O_2N + 5O_2 \tag{2.4}$$

The overall nitrification reaction, combining eqs (2.3) and (2.4) is:

$$22NH_4^- + 37O_2 + 4CO_2 + HCO_3^- \rightarrow 21NO_3^- + C_5H_7O_2N + 20H_2O + 42H^- \tag{2.5}$$

The nitrifying bacteria responsible for nitrification consist of two main groups, i.e. the *Nitrosomonas* which converts NH_4^+ to NO_2^-, and the *Nitrobacteria* which convert NO_2^- to

NO_3^-. The nitrifying bacteria have a relatively slow growth rate and are inactive at temperatures greater than 40^0C (Alexander, 1961), hence the will become active normally after the reactions of organic waste decomposition (the growth phase and thermophilic phase) are complete. Since NO_3^- is the form of N which is readily available for crop uptake, the maturation phase thus becomes an essential step in composting to produce good quality compost for use as fertilizer and soil conditioner.

At this stage the organisms classified as second- and third-level consumers, such as protozoa and beetles, will grow and will feed on the first-level consumers (e.g. bacteria, fungi, actinomycetes).

The composted products after maturation can be used as fertilizer and soil conditioners to crops. In this way the nutrients returned as compost are in the form of microbial protoplasm and/or organic compounds that break down slowly. Other nutrients present in the compost, such as nitrates, are readily available to crops.

In the aerobic composting systems the degradation of organic matter depends on the presence of oxygen. Oxygen serves two functions in the metabolic reactions: as the terminal electron-acceptor in aerobic respiration; and as substrate required for the operation of the class of enzymes called oxygenase (Finstein, et. al., 1980).

Organic matter generally degrades more rapidly and more completely if oxygen is plentiful. This can be explained by the presence of the large amount of free energy produced for microbial growth where the prominent electron-acceptor is oxygen. Oxygen can be incorporated into molecules devoid of this element through the action of the widely distributed, non-substrate-specific and inducible enzymes, 'oxygenases'. This is often the first necessary step in metabolic sequences leading to the degradation of molecules resistant to biological attack. Classes of organic micro-contaminants acted upon by oxygenases include saturated alkanes, aromatic hydrocarbons, and halogenated hydrocarbon; anaerobic environments lack this mechanism (Finstein, et al., 1980). In anaerobic composting the free energy (heat) produced is much less than that of aerobic composting, and therefore a longer time is required for organic decomposition and pathogen inactivation.

The kinetic of composting systems is a subject of vital interest to the design engineer, who must determine the type and size of composting plants and the detention time required to achieve a certain degree of organic stabilization and pathogen inactivation. Haug (1980) conceptually described the various rate-controlling phenomena occurring during aerobic composting—these include:

1. Release of extracellular hydrolytic enzymes by the cell and transport of the enzymes to the surface of the substrate;
2. Hydrolysis of substrate molecules into lower molecules into lower molecular weight, soluble fractions;
3. Diffusion transport of solubilized substrate molecules to the cell;
4. Diffusion transport of substrate into the microbial cell, floc or mycelia;
5. Bulk transport of oxygen (usually in air) through the voids between particles;
6. Transport of oxygen across the gas-liquid interface and the unmixed regions which lie on either side of such an interface;
7. Diffusion transport of oxygen through the liquid region;
8. Diffusion transport of oxygen into the microbial cell, floc or mycelia;
   And
9. Aerobic oxidation of the substrate by bio-chemical reaction within the organism.

In practice the design of a composting plant is based on such criteria as: type and quantity of materials to be composted, time required for waste stabilization and pathogen inactivation, degree of compost maturity, type of composting process to be employed, and area and location of the composting plant. Data from laboratory and pilot scale investigation, together with knowledge of past experiences, greatly help in designing an efficient composting plant.

2.5 Classification

The compost process can be classified in terms of distinguishing cultural condition and in terms of technology. This study deals with classification in terms of cultural condition (i.e., aerobic vs. anaerobic and mesophylic vs. thermophylic).

Aerobic vs. Anaerobic

Originally, composting was classified into aerobic vs. anaerobic and many arguments were offered in favor of one or the other. Aerobic processes are those carried out in the presence of oxygen. Anaerobic processes are those carried out in the absence of oxygen. However, in time, the aerobic approach became the usual one, and anaerobic composting fell into disfavor. In fact, a tendency has developed in recent years to define composting as "aerobic decomposition," thereby invalidating the terms "anaerobic composting". Nevertheless, many practitioners especially those well versed in composting are not following the trend. Regardless of one's views on the matter, maintenance of completely aerobic conditions in a composting mass would be exceedingly difficult and certainly impractically expensive. In recognition of foul odors associated with anaerobiosis, a more realistic approach is to design the composting system such that aerobiosis is promoted and anaerobiosis is minimized as much as is feasible.

Mesophylic vs. Thermophylic

In modern compost practice, the question of relative advantages of an all-thermophylic vs. an all-mesophylic process is moot because, with few exceptions modern composting incorporates the rise and fall of temperature levels that normally occur unless positive measures are taken to circumvent the process. Mesophylic is the temperature range from about 5 to 45^0C. Thermophylic is the temperature range from about 45 to 75^0C.

2.6 Basic Process

Considerable improvement in the rate of composting of amenable wastes can be brought about by the choice of good operating conditions in terms of adequate concentrations of nutrients, particle size, homogeneity, moisture content, temperature, agitation and aeration. Because composting is the sum total of the metabolic processes of an enormous population of mixed micro-organisms degrading the organic waste, the choice of an amenable environment for these microbes is vital. The basic composting process is shown in the following figure 2.2, where from sorting step to mixing is in preprocessing, from aerobic composting to maturation is in decomposition and from screening to salable product is in post processing.

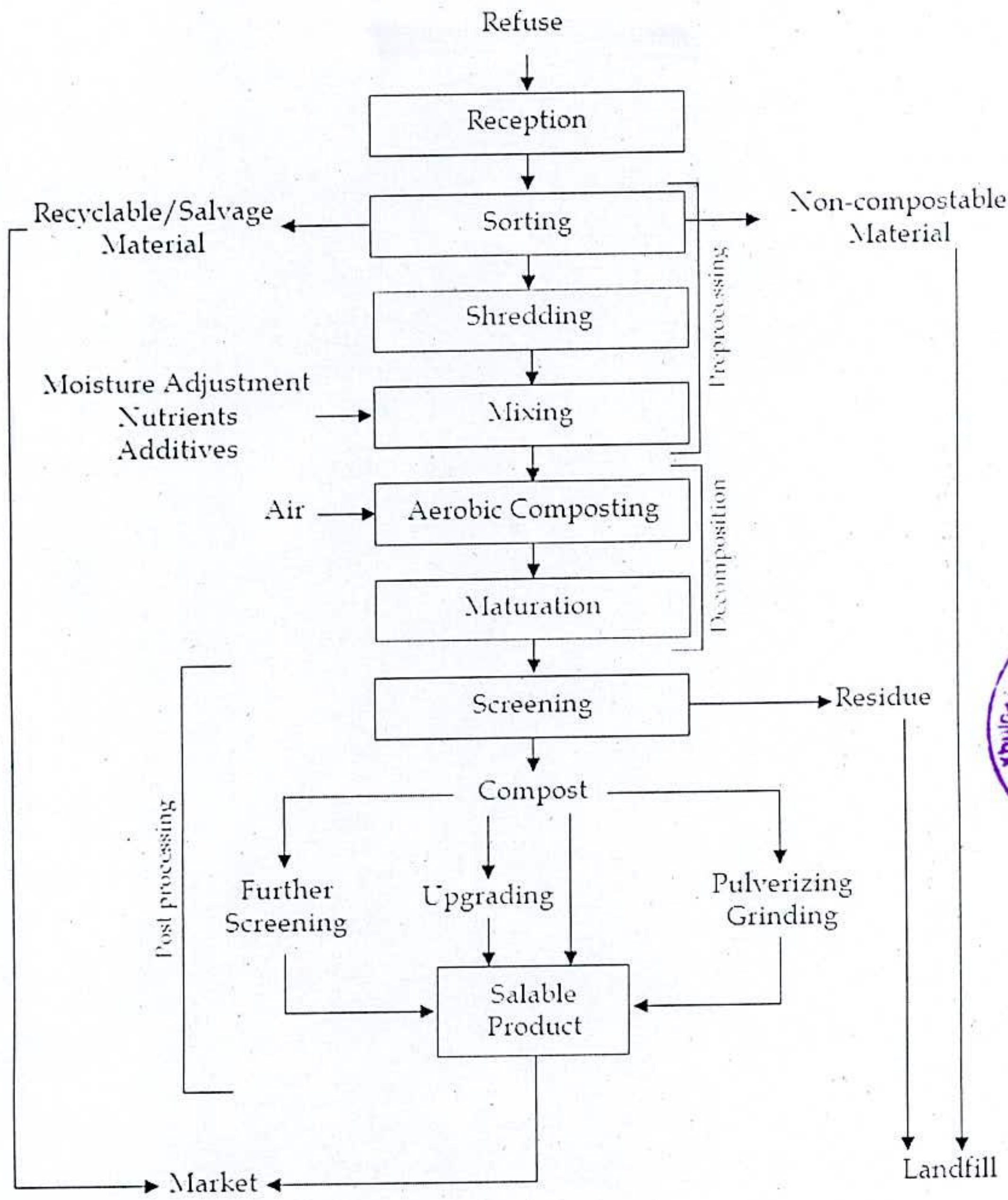


Figure 2.2 Flow diagram showing the basic process of aeróbic composting in a plant

2.7 Compost Phases

Composting characteristically is an ecological succession of microbial populations almost invariably present in wastes. The succession begins with the establishment of composting conditions. "Resident' (indigenous) microbes capable of utilizing nutrients in the raw waste immediately begin to proliferate. Owing to the activity of this group, conditions in the composting mass become favorable for other indigenous populations to proliferate. Plotting the effect of the succession of total bacterial content of the mass would result in a curve, the shape of which would roughly mirror those of the normal microbial growth curves and of the rise and fall of temperature during composting (figure 2.3). Judging from the curve, composting proceeds in three stages, namely (1) an initial lag period ("Lag phage"), and (2) a period of exponential growth and accompanying intensification of activity ("active phase") that (3) eventually tapers into one of final decline, which continues until ambient levels are reached ("curing phase" or "maturation phase"). In practice, this progression of phases is manifested by a rise and fall of temperature in the composting mass. A plot of the temperature rise and fall would result in curve, the shape of which would be roughly identical with that of the growth curve.

The course of the process in all its aspects and the characteristics of its product are all determined by the environmental factors to which the process is exposed, by the operational parameters being followed, and by the technology employed. An abrupt deviation during any of the phase (e.g., sharp drop in temperature) betokens a malfunction. The phase resumes upon the elimination of the malfunction.

Lag Phase

The lag phase begins as soon as composting conditions are established. It is a period of adaptation of the microbes characteristically present in the waste.

Microbes begin to proliferate, by using sugars, starches, simple cellulose and amino acids present in the raw waste. Breakdown of waste to release nutrients begins. Because of the accelerating activity, temperature begins to rise in the mass. Pseudomonades have been routinely identified as being among the more numerous types of bacteria. Protozoa and fungi, if present, are not discernible. The lag period is very brief when highly putrescible materials and/or herbaceous yard wastes are involved. It is some what longer with mixed MSW and woody yard waste and is very protracted with leaves and resistant waste such as dry hay, straw, rice hulls and sawdust.

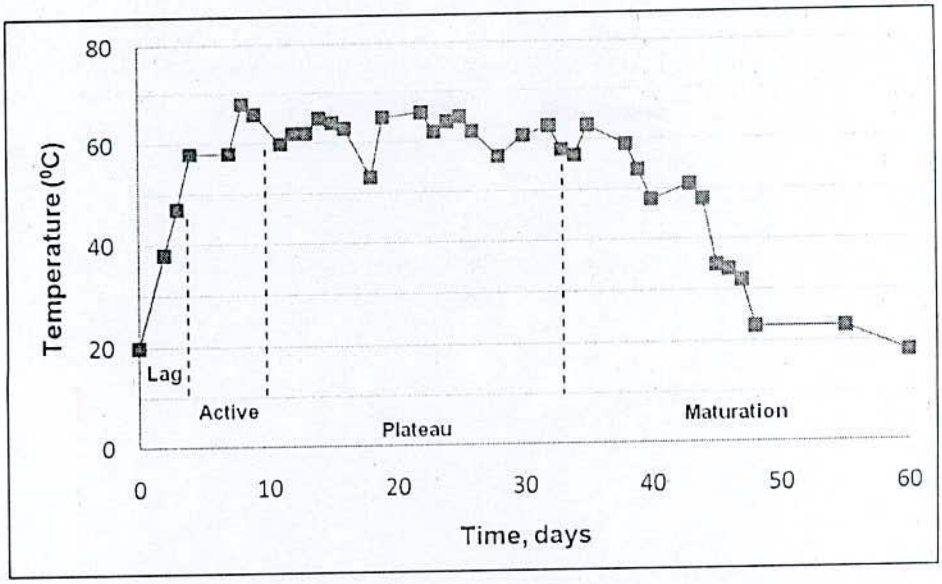


Figure 2.3 Typical temperature curve observed during the various compost phases

Active Phase

The transition from lag phase to active phase is marked by an exponential increase in microbial numbers and a corresponding intensification of microbial activity. This activity is manifested by a precipitous and uninterrupted rise in the temperature of the composting mass. The rise continues until the concentration of easily decomposable waste remains great enough to support the microbial expansion and intense activity. Unless countermeasure are taken, the temperature may peak at 70^0C or higher.

The activity remains at peak level until the supply of readily available nutrients and easily decomposed materials begins to dwindle. In a plot of the temperature curve, this period of peak activity is indicated by a flattening of the curve (i.e., by a plateau). This "plateau" phase may be as brief as a few days or, it the concentration of resistant material is high, as long as a few weeks. The duration of the entire active stage (exponential plus plateau) varies with substrate and with environmental and operational conditions. Thus, it may be as brief as five or six days or as long as two to five weeks. It should be pointed out that a sudden drop in temperature during the active stage is an indication of some malfunction that requires immediate attention (e.g., insufficiency of oxygen supply, excess moisture). Temperature drop due to turning is of brief duration.

Maturation or Curing Phase

Eventually, the supply of easily decomposable material is depleted and the maturation stage begins. In the maturation phase, the proportion of material that is resistant steadily rises and microbial proliferation correspondingly declines. Temperature begins an inexorable decline, which persists until ambient temperature is reached. The time involved in maturation is a function of substrate and environmental and operational conditions (i.e., as brief as a few weeks to as long as a year or two).

2.8 Composting Parameters

There are several important parameters which have to be in desirable conditions for efficient aerobic composting to occur at high temperatures. The parameters are:

1. Carbon-Nitrogen ratio
2. Particle Size
3. Oxygen Uptake
4. Temperature
5. Moisture Content
6. pH
7. Odor
8. Color

First two parameters can be said initial parameter on which the rate of composting process depends. Remaining parameters can be said monitoring parameters, which indicate, composting process is going well or not and on which the characteristics of final compost depends These parameters are discussed below.

Carbon-to-Nitrogen Ratio

The available carbon to available nitrogen ratio (C/N) is the most important of the nutritional factors, inasmuch as experience shows that most organic wastes contain the other nutrients in the required amounts and ratios for composting.

The ideal C/N ratio is between 30:1 and 35:1. Haug (1993, p.248) has argued that the optimum C:N ration is 30, based on theoretical analysis of cell synthesis for an average cell formation of $C_5H_7O_2N$ with the reaction given as:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + H_2O + \text{energy} \quad (2.6)$$

But this Reaction is govered by the energy provided by the cellulosic substrate for the microbe and this can be represented as:

$$X(C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}) \quad (2.7)$$

$$5CO_2 + 2H_2O + NH_3 + \text{energy} \rightarrow C_5H_7O_2N + 5O_2 \quad (2.8)$$

Here, ammonia is the source of cell N.

The maximum yield of cells is limited by thermodynamics to 0.4 cells/g glucose. With an assumed net yield (yield coefficient) of 0.1 cell/g glucose, the moles of energy reaction required per mole of synthesis is calculated as

$$1/\{X(180)\} = 0.1/113$$

Where 180 is the molecular weight of gloucose and 113 is that the cell formation. This gives X = 6.3 or equivalent to 6 moles/mol.

Therefore the combined energy reaction of 2.7 and 2.8 is given as

$$6C_6H_{12}O_6 + 31O_2 + NH_3 \rightarrow C_5H_7O_2N + 31CO_2 + 34H_2O \quad (2.9)$$

Here, 36 mol of C is used for each 1 mol of N. this gives the C:N ration as 36(12)/1(14) = 30.9.

The ideal ratio is about 30 to 35 parts of available carbon to 1 of available nitrogen. The nitrogen content and C/N of several wastes are given in Table 2.1.

Table 2.1 Percent N, C/N and Moisture of Selected Materials

Materials	%N (dry wt.)	C/N (weight to weight)	% moisture (wet wt.)
Fruit wastes	0.9-2.6	20-49	62-88
Rice hulls	0.0-0.4	113-1120	7-12
Vegetable wastes	2.5-4.0	11-13	*
Poultry litter (broiler)	1.6-3.9	12-15	22-46
Cattle manure	1.5-4.2	11-30	67-87
Garbage (food wastes)	1.9-2.9	14-16	69
Paper (from domestic refuse)	0.2-0.25	127-178	18-20
Refuse	0.6-1.3	34-80	
Grass clippings	2.0-6.0	9-25	
Leaves	0.5-1.3	40-80	
Shrub trimmings	1.0	53	15
Tree trimmings	3.1	16	70
Sawdust	0.06-0.8	200-750	19-65

* Not Reported

Source: From Rynk (1992)

A C/N higher than 20/1 or 30/1 can show the compost process. A C/N that is too low (less than 15/1 to 20/1) leads to loss of nitrogen as ammonium N. the additional of a nitrogenous waste can lower an unfavorably high C/N, whereas the addition of carbonaceous waste can raise an undesirable low C/N. Examples of nitrogenous wastes are grass clippings, green vegetation, food wastes, sewage sludge and commercial chemical fertilizers. Examples carbonaceous wastes are hay, dry leaves, paper and chopped twigs.

The requirement that the carbon be in an available form minimizes or even eliminates wood and woody materials as a carbon source in the composting of sewage sludge. Thus sawdust, woodchips or woody shavings used to bulk sewage sludge should not be regarded as a carbon source. Although the carbon in paper, dry leaves and chopped twigs is relatively slowly available, the materials can serve as carbon sources only to a limited extent. Furthermore, because the carbon in the latter materials is only slowly available, their use can raise the permissible upper C/N to as high as 35 to 40/1.

Animal manures, sewage sludge and commercial (agricultural) fertilizers are adequate sources of nitrogen and any other element that may be needed. For example, experience indicates that the unfavorably high C/N ratio of the organic fraction of refuse can be advantageously lowered through the addition digested sludge (Diaz, et. al., 1977).

Particle Size

Theoretically, the smaller the particle size, the more rapid the rate of microbial attack. In practical composting, however, there is a minimum size below which it is exceedingly difficult to maintain an adequate porosity in a composting mass. This size is the "minimum particle size" of the waste material. In composting, the practical "optimum" is a function of the physical nature of the waste material. With a rigid or not readily compacted material such as fibrous waste, twigs, prunings and corn stover, the suitable size is from ½ inch (13 mm) to about 2 inch (50 mm). The particle size of the greater part of a green plant mass such as vegetable wastes, fruit wastes and lawn clippings should be no less than 2 inch (50 mm). On the other hand, depending upon their overall decomposability, their maximum particle size can be as large as 6 inch (0.15 m) or even large.

Oxygen Uptake

Oxygen availability is a prime environmental factor in composting, inasmuch as composting is an aerobic process. Oxygen is a key element in the respiratory and metabolic activities of microbes. Interruption in the availability leads to a shunt metabolism, the products of which are reduced intermediates, which characteristically are malodorous. The microbes involved in the composting process obtain their oxygen from the air with which they come in contact (i.e., the air that impinges upon them). Consequently, the oxygen content of this air must be continually replenished or the air itself must be continually replaced. The interstitial oxygen content in a windrow can be estimated by use of an oxygen probe inserted into the windrow. The oxygen content of the airstreams into and out of a static windrow (forced aeration) and in vessel systems can be directly measured. For convenience, the amount of oxygen required by the microbes is termed "oxygen demand".

Attempts to establish a universally applicable numerical rate of oxygen uptake for use as a design parameter have been unsuccessful. The underlying reason for the lack of success is the variability of key factors that influence oxygen demand; Among such factors are temperature, moisture, size of bacterial population and availability of nutrients. Therefore determination of the amount of aeration that would meet a specific demand adds another level of complexity, because the capacity and performance of the aeration equipment and the physical nature of the composting mass must be taken into account. The straightforward methods (procedures) used for determining oxygen demand in waste water treatment (e.g., COD,BOD) are poorly or not at all applicable to composting.

The variability of oxygen demand is demonstrated by the diversity of results reported in the literature. One of the earlier reports described a study in which air was passed at a known rate through composting material enclosed in a drum and the oxygen content of the influent and effluent airstream were measured (Schulz, 1960, 1964). Oxygen uptake rose from 1 mg/g of volatile matter at 30^0C to 5 mg/g at 63^0C. in a later study, Chrometska (1968) observed oxygen requirements that ranged from 9 mm^3/g.h for ripe compost to 284 mm^3/g.h forraw substrate. "Freash" compost (seven days old) required 176 mm^3/g.h. Lossin (1971) reports average chemical oxygen demands that range from almost 900 mg/g on the first day of composting to about 325 mg/g on the 24^{th} day. In a review of the decomposition of cellulose and refuse, Regan and Jeris (1970) observed that oxygen uptake was lowest (1.0 mg oxygen/g volatile matter per hour) when the temperature of the mass was 30^0C and the moisture content was 45 percent. The highest uptake (13.6 mg/g volatile matter per hour) occurred when the temperature was 45^0C and the moisture content was 56 percent.

With the respect to the design of air flow through an in air-vessel reactor and to a lesser extent through a static pile, the indicated procedure would be to estimate the carbon content and to determine the oxygen consumed in oxidizing the carbon. The flaw in such an approach is that it would result in an overdesign, because normally only a fraction of the carbon is available to the microbial population. Nevertheless, some overdesign is advisable because of the impossibility of aerating a mass such that all microorganisms simultaneously have access to sufficient oxygen. Perhaps the airflow requirement estimated by Schulze (562 to 623.4 m^3/tone volatile matter per day) could be of some use. However, his estimates are based upon the use of his particular equipment and on a laboratory-scale experiment.

Oxygen uptake is very useful parameter, because it is a direct manifestation of oxygen consumption by the microbial population and, hence, of microbial activity. Micros use oxygen to obtain the energy to carry on their activities. It is, however, very difficult to determine the exact oxygen requirement because of its dependence on many variables such as temperature, moisture content and availability of nutrients. An approximate method of monitoring sufficient oxygen supply is to check the compost for foul odors. Presence of foul odors indicates insufficient supply of oxygen.

Temperature

Temperature is a very useful parameter because it is a direct indicator of microbial activity. The biologically produced heat generated within a composting mass is important for two main reasons:

1. To maximize decomposition rate; and
2. To produce a material, which is microbiologically 'safe' for use. (Polprasert 1989)

Composts should be free from weed seeds and pathogens. Weed seeds and most microbs of pathogen significance cannot survive exposure to thermophylic temperature. Thermophylic is the temperature range from about 45 to 75^0C (Tchobanoglous and Kreith, 2002). Pathogens and such bacteria will be rapidly destroyed when all parts of a compost pile are subjected to temperatures of about 60^0C (Skitt, 1972). These higher temperatures, e.g., 60-70^0C for about 24 hours, should be maintained for pathogen destruction (Ahmed & Rahman, 2000). There are other temperature-time frames for pathogen destruction like 65^0C for at least three days (Enayetullah, et. al., 2006) and 55^0C for at least 72 hours or three days (Cooperband, 2002); also the German regulation mention, a temperature of at least 55^0C over a period of two weeks, with no or minimum interruption, or alternatively to a temperature of 65^0C (or, in the case of closed plants, 60^0C) over a period of one week. So, it is preferable for the temperature of the composting pile to stay at 55-65^0C for at least three days.

Moisture Content

Moisture content should be in the range of 50-60% during the composting process, the optimum being about 55%. At moisture levels above 65%, water begins to fill the interstices between the particles of the wastes, reducing the interstitial oxygen and causing anaerobic conditions. This results in a rapid fall in temperature and at the same time production of offensive odors. When the moisture contents drops much below 50%, the composting process become slow.

pH

Unless the substrate is unusually acidic, which rarely is the case with MSW, pH level has little value as an operational parameter. If the pH level is lower than 4.5, some buffering may be indicated (e,g., adding lime). Liming may also be indicated for certain cannery wastes.

Odor

Odor as an operational parameter received some attention in the discussion of aeration. Attempts to develop a quantitative standard for odor, based on hydrogen sulfide concentration, have met with little if any success, because the olfactory nerve senses H_2S concentrations lower than the detection level of H_2S analytical tests. In waste treatment practice, all odors are regarded as being objectionable to the public.

Color

Although the color of the composting mass progressively darkens, it is a crude parameter and at best is roughly qualitative and highly subjective.

2.9 Stability of Compost

"Stability" is a broad term that may refer to chemical and physical stability and/or to biological stability. As applied in composting, the composting mass is judged "stable" when it has reached a state of decomposition at which it can be stored without giving rise to health or nuisance problems. Immature compost should not mixed with the soil and cover this layer with soil because the natural decomposition process is not finished. With a lack of oxygen (by covering the compost- soil mixer with soil) anaerobic processes start and this is harmful for the plants (Bachert, et. al., 2008). Also immature compost has some environmental effects for further degradation reaction. This excludes the temporary stability due to dehydration or other condition that inhibits microbial activity. Despite many claims to the contrary, a satisfactory quantitative method for determining degree of stability has yet to be developed, at least one that can be used as a "universally" applicable standard.

The search for a method of determining stability that can be sufficiently standardized is almost as old as the compost practice; the list of proposed methods is correspondingly lengthy. It includes final drop in temperature (Golucke, et. al., 1955), degree of self heating capacity (Niese, 1963), amount of decomposable and resistant organic matter in the material (Rolle, et. al., 1964), rise in the redox potential (Moller, 1968), oxygen uptake (Schulze, 1960), growth response of the fungus *Chaetolnium gracillis* (Obrist, 1965), and the starch test (Lossin, 1970). Of this array of tests, the final drop in temperature is the most reliable, because it is a direct consequence of the entire microbial activity, as well as of the intensity of the activity. The weakness of temperature decline as a parameter is its time element. Because the decline represents a trend, it involves a succession of readings taken over a period of days. The other tests lack the necessary universality. For, example, a redox potential that characterizes stability under one set of compost conditions does not necessarily do so under another set. With certain tests, lack of universality is aggravated by the difficulty of conducting them (e,g., the *Chaetomium* test).

Phytoxicity frequently is regarded as being an indication of stability, although it is true that in the early stages of maturation, composting material often contains a substance that is inhibitory to plants (phytoxic), and which almost invariably disappears as maturation progresses. However, the disappearance does not always coincide with the attainment of the required degree of stability.

The self-heating test is widely adopted at solid waste composting plants as a simple and inexpensive test to determine the biological stability of the produced compost (Koenig, et. al., 2001). Procedure of self-heating test was developed in Germany. It is a sample test and an excellent indicator of biological maturity, if properly conducted and does not require sophisticated equipment (Bari and Koenig, 2002).

Self-heating Test

The self-heating test integrates a number of factors present in normal composts such as temperature, aeration etc. and therefore may be provide data that correlate well with field observations about compost behavior (Brinton, et. al., 1995). The maturity of compost can be assessed by comparing the temperature parameters obtain from a particular self-heating test (similar to Figure 2.4) with data as presented the following table 2.2 proposed by LAGA, 1985 (Bari & Koenig, 2002).

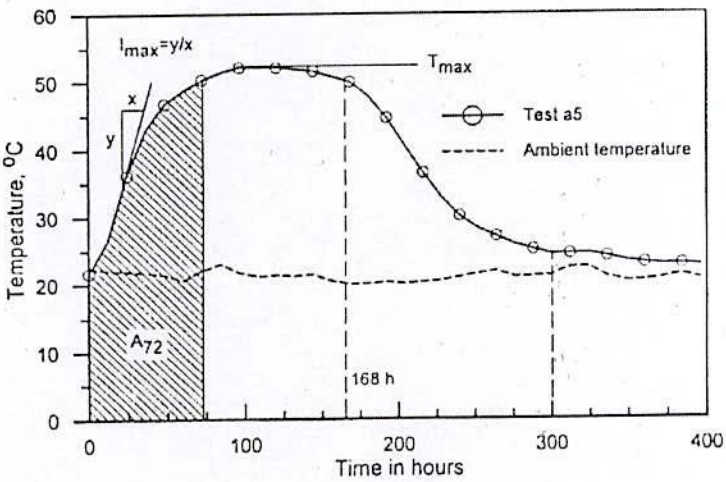


Figure 2.4 The Temperature curve of a typical self-heating test for fresh compost, matured compost, T_{max}, I_{max} and A_{72} are shown.

Table 2.2 Classification of waste or compost according to degree of biological maturity (LAGA 1985)

Degree of Biological Stability (Stability Index SI)	V	IV	III	II	I	I
	Stable ⟵				⟶	Unstable
T_{max}, in ^{0}C	20-30	30-40	40-50	50-60	60-70	>70
I_{max}, in ^{0}C/h	<0.3	0.3-0.45	0.45-0.8	0.8-1.4	1.4-2.0	>2.0
A_{72}, in ^{0}C-h	<1700	1700-2000	2000-3000	2500-3000	3000-3500	>3500

Maximum temperature, T_{max} (^{0}C), Maximum temperature Increaseing rate I_{max} (^{0}C/h) and three days area, A_{72} (^{0}C-h); Based on Iannotti, et. al. (1994) as cited by Epstein (1997)

2.10 Practiced Technique In Bangladesh

The composting techniques which are frequently practiced in Bangladesh are followed:

- Windrow composting

- Box composting
- Bin-composting

Windrow Composting

In contrast to the typical windrow method the waste is piled onto a triangular wooden or plastic rack allowing a passive aeration of the compost pile (figure 2.5). The additional aeration from the bottom of the pile allows micro-organisms to decompose the organic waste efficiently through a better oxygen supply and improved temperature control. Within 24 hours the micro-organisms within the waste start to multiply and generate heat. Pile temperature increases to 55-65^{0}C which is optimum for aerobic composting. To enable the micro-organisms to obtain sufficient oxygen, the pile is additionally aerated by turning the waste from time to time (approximately once a week). High temperature leads to water losses through evaporation, so additional water must usually be added with each turning. After 40 days of composting the temperature has decreased, indicating a slowing down of the process. As less oxygen is demanded, the raw compost can be removed from the aeration and piled again for the maturation phase with out a central aerator. For another 15 days mesophilic micro-organisms further stabilize the compost leading to the final mature compost product.

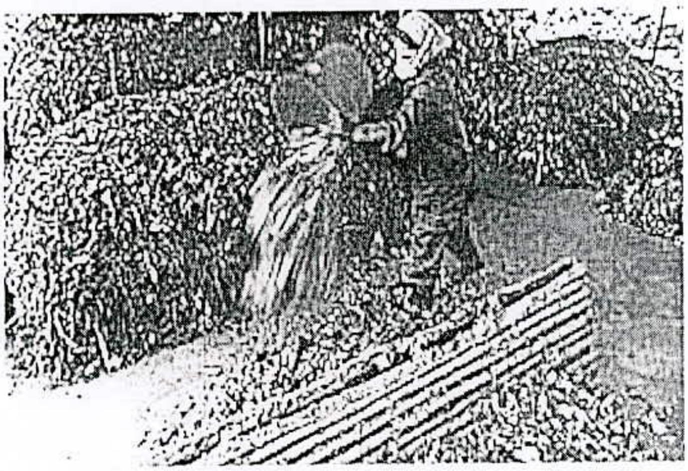


Figure 2.5 A photograph of Windrow Composting system

Box composting

The box Composting is constructed with perforated walls, a perforated bottom grid and vent-pipes allowing air circulation through the waste (figure 2.6). In contrast to the aerator method, the sorted organic waste is daily spread into the boxes in layers of 20 cm. The construction ob the box in combination with the layer technique ensures sufficient aeration and additional turning is not necessary. Air is supplied to the organic material through holes in the walls and through the perforated vertical pipes embedded in the pile. The perforated bottom of the box additionally acts as drainage for excessive water. As in the windrow system, the temperature within the mass increases within a few days up to 60^0C, ensuring that the final compost product is free of viable pathogens or weed seeds. Typically, a box is filled within 5-7 days and the waste in the box decomposes aerobically for 40 days before it is removed from the box. As with the windrow technique, the compost needs another 15 days of maturing.

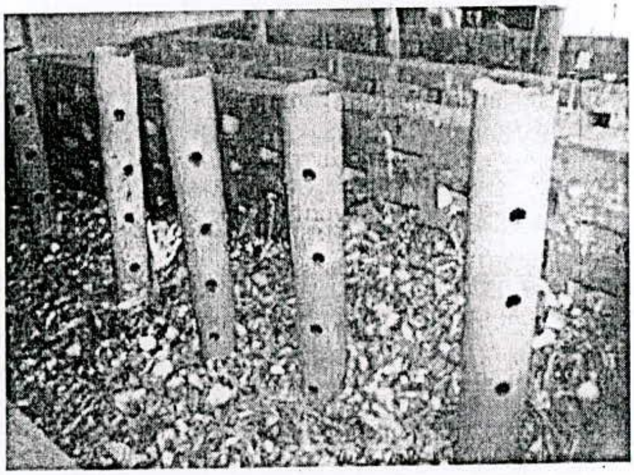
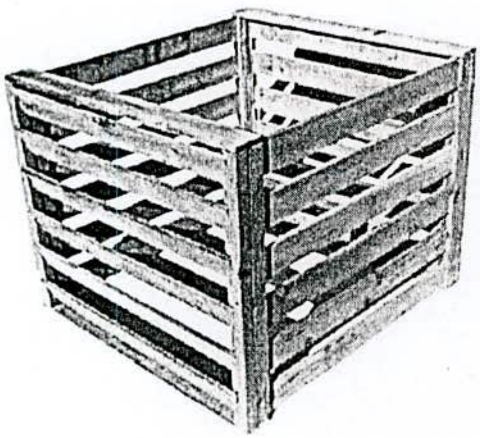


Figure 2.6 A photograph of Box Composting system

Bin composting

Bin composting is the most popular and advance version of home composting system that over comes problem experienced in other composting systems. There are different types of bins available for home composting and generally it varies from 200-300 L in size. These are from different materials such as cement/concrete, plastic, metal etc. as shown in Figure 2.7. 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 emerging solid waste disposal problems have bin the main constraints in popularizing the composting bin among citizens.



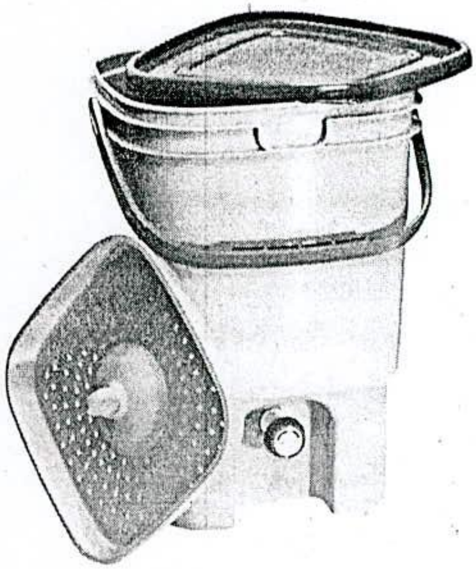


Figure 2.7 Photographs of Bin Composting system

2.11 Additives

Additives are the organic materials which can speed up the composting process. Additional microbes and bacteria are able to speed up the process (ourhouse.ninemsn.com.au). Organic matter is decomposed by the process of oxidation, reduction and hydrolytic enzymes. The process produces nutrients used by the microorganisms for further breakdown, enabling bacteria to carry on their life processes of growth and reproduction. The rate of oxidation and biological degradation of organic matter varies within the compost heap. Some compost heaps heat up very rapidly. The heat in the composting materials is produced by bacterial activity (biological burning). Additives can leave carbon and nitrogen easily, which can be used as food by micro-organisms for reproduction. Micro-organisms have to use the wastes as food to sustain and as well as increase the composting process. By using additives, this critical buildup of heat can be sustained, significantly reducing the time of composting (edie.net).

Wood chips or saw dust is an ideal carbon source for its high carbon and manure is an ideal nitrogen source for its high nitrogen. Wood chips can also increase the pile porosity, thereby improving aeration. Residue is also able to increase the pile porosity which produced after screening of degraded waste. The size of residue which used at compost pile is less than 1 cm. So, wood chips, sawdust, manure and residue are act as additives at composting.

2.12 Characteristics of Compost

Compost is a stable humus-like product and is a very good soil conditioner. It also supplements nutrients to soils. The important chemical characteristics of compost are shown in table 2.3.

Table 2.3 Chemical characteristics of compost

Chemical Constituents	Percent by Weight
Organic matter	25-50
Carbon	8-50
Nitrogen (as N)	0.4-3.5
Phosphorous (as P_2O_5)	0.3-3.5
Potassium (as K_2O)	0.5-1.8
Ash	20-60
Calcium (as CaO)	1.5-7.0

2.13 Standards of Compost

There is no standard for compost quality for Bangladesh. However, comparison can be performed with the standards for compost used in agriculture from Switzerland, India and Great Britain (2006), which is given at a users' manual on composting published by Waste Concern (Enayetullah, et. al., 2006). Since the presence of heavy metals at compost keeps an important role to negative impact on plant and also on environment, only for heavy metal another standard is present below, which given at the bio-waste ordinance of Germany. These standards are shown at the following tables 2.4 and 2.5.

Table 2.4 Compost quality standards from Switzerland, India and Great Britain

Criteria	Switzerland Association of SwissCompost Plants (ASCP)	India Indian Institute of Soil Science (04 Task Force)	Great Britain Pas 100 (BSI) and Apex-Standard*
Indicators for Maturity			
pH	< 8.2	6.5-7.5	7.5 – 8.5*
Organic Matter	< 50%	> 16% C_{org}	30-40%*
NO_3-N/NH_4-N ratio	> 2	-	
C/N ratio	> 21:1	20:1	15:1-20:1
Dry Weight	> 50%	75-85%	65-55%
Decomposition	Feedstock unrecognizable, except for wood	Dark brown no color	-
Plant Compatibility	Planting tests (cress, salad, beans, ...)		20% below control
Respiratory Test	-	< 15 mg CO2-C per 100g TOC/day	< 16 mg CO_2/g organic matter/day
Indicators for Nutrients			
Phosphorous (P_2O_5)	> 0.7%	0.5-0.8%	25-40 mg/l*
Potassium (K_2O)	-	1-2%	0.5-0.7%
Total Nitrogen	> 1% DS**	> 0.8%	0.7-1.0%
NO_3-N	> 40 mg/kg WS	-	15-120 mg/l*
NH_4-N	> 300 mg/kg WS	-	1-5 mg/l*
Indicators for Pollution			
Impurities	< 1%, no visible plastic, glass or metal	< 1% inert material and foreign matter	< 0.5% of total air dried sample by mass
Cadmium (mg/kg DS)	1	5	1.5
Chromium (mg/kg DS)	100	50	100
Copper (mg/kg DS)	100	300	200
Lead (mg/kg DS)	120	300	200
Nickel (mg/kg DS)	30	50	50
Mercury (mg/kg DS)	1	2.5	1
Zinc (mg/kg DS)	400	500	400

**Apex is a voluntary standard, launched by three of the UK's biggest waste management firms.*

*** DS= dry solids*

Table 2.5 Standards for heavy metal of compost at Germany

Heavy Metals	Quantity (mg/kg)
Lead	150
Copper	100
Zinc	400
Cadmium	1.5
Mercury	1
Chrome	100
Nickel	50

2.14 Situation of Composting in Bangladesh

Small scale composting of night soils and other organic wastes is common in some parts of Bangladesh (Ahmed and Rahman, 2000). The composting activities have been initiated by different organizations like City Corporation, NGOs and CBOs. The field survey from May 2004 to October 2004 on compost plant is shown in table 2.6. There is no compost plant in BCC (Barisal City Corporation) until the survey period. Windrow system for composting is mostly adopted in compost plant. The barrel or small container composting methods is also getting popularity.

Table 2.6 Different compost plant in six major cities of Bangladesh (Alamgir, et. al., 2005)

City	Name of Organization	Plant nos.	Plant Type	Capacity per pant (tons/day)	Compost Production (tons/day)	Retail price (Tk./kg)	Status
DCC	Waste Concern	5	Windrow & Box	1.00	0.18-0.20	2.5-5.0	R
	Prodipan	1	Windrow	1.00			R
CCC	NOUJUYAN	1	-	-	-	5.0	R
KCC	Prodipan	1	Windrow	1.00	0.2-0.3	-	R
	PRISM	4	Windrow	1.00			R
	RUSTIC	1	Windrow	1.00			R
RCC	LOFS	1	Windrow	0.40	0.13	4.0-5.0	R
BCC	-	-	-	-	-	-	-
SCC	SP	1	Box	2.50	0.60	-	S
	EPCT	1	Box	0.03	0.01		R

Note: SP- Sylhet Partnership; R-Running; S-Shutdown

In windrow system, about 3 ton presorted waste mixture are manually mounted on a bamboo frame. The bamboo frame is used to increase the passive aeration. Usually the compost piles are dismantled in every week for remixing and moisture adjustment. Degraded wastes are piled on another place after about six weeks to produce matured compost.

As mention in table 2.6, the PRISM Bangladesh had four plants, which found running during survey but in June 2008 it was found closed. PRISM Bangladesh was not directly collect waste from houses. PRISM Bangladesh had partner NGOs. The solid wastes, which are used for composting, are collected by partner NGOs through house-to-house collection system and deliver the collected waste to composting plant of PRISM Bangladesh. Prodipan has one plant, which also found well running in July 2005 but in July 2007 it was found poorly running. And RUSTIC has one plant. The situation of RUSTIC is same as Prodipan. Prodipan composting plant is situated near the UDS of KCC at Rajbandh. They collect waste from that dumping site also for composting. The average consumption of waste was one ton per day per plant. Now a day the capacity of those plants is reduced.

2.15 Concluding Remarks

Composting is a widely accepted environmental friendly technology to recover organic material in the form of compost from highly concentrated biodegradable organic solid waste. Among the techniques of disposal characterized by a low environmental impact, composting of the organic fraction of municipal solid waste is an environmentally and economically interesting solution. Composting is controlled decomposition process of organic residues. Composting transforms organic waste mixture into biologically stable, humus substances that make excellent soil amendments. This final product is a valuable soil resource. Compost can replace materials like peat and top soil as seed starters, container mixes, soil amendments, mulches and natural fertilizers in commercial greenhouse production, farms, landscaping, and land remediation.

CHAPTER THREE

STUDY ON A COMPOST PLANT

3.1 General

It is revealed that despite the huge prospects to convert the MSW of Bangladesh into compost, no significant development has been seen. Moreover, some plants already shut-down and others are just fairly running. It is realized that there is a strong need to establish an acceptable and sustainable composting technology considering the socio-economic aspects and technological capabilities of Bangladesh. To this endeavor a demo compost plant has been designed to investigate the various aspects of composting such as different ways of passive aeration, possibility of introducing forced aeration system and suitable options to enrich the quality of compost for the satisfaction of potential buyers/consumers.

This activity has been conducting with the collaboration of SAMADAN's compost plant located as Alam Nagar, Khalishpur, Khulna (an own funding Khulna based NGO). The demo plant was set-up in its land just besides the existing compost plant of SAMADAN.

3.2 Location of Plant

Khulna, the third largest city and one of six divisional cities of Bangladesh is located in south-west region, lies between $22^{0}49'$ North Latitude and $89^{o}34'$ East Longitudes and its elevation is 2.13 meters above mean sea level (BBS, 2004). The city extends from the south-east to north-west along the Rupsha-Bhairab River. Total area of Khulna City is about 45.65 sq. km and total population is about 1.5 million as roughly estimated by KCC. Gross population density of Khulna city is 18,000 persons per sq. km. The Khulna City Corporation (KCC) consists in total 31 wards. Alam Nagar is in the ward no. 15. 1.6 km is the short distance of SAMADHAN's compost plant from the main city road and the distance of it from KUET is 8 km. The location of the SAMADHAN's compost plant is shown in following map (Figure 3.1).

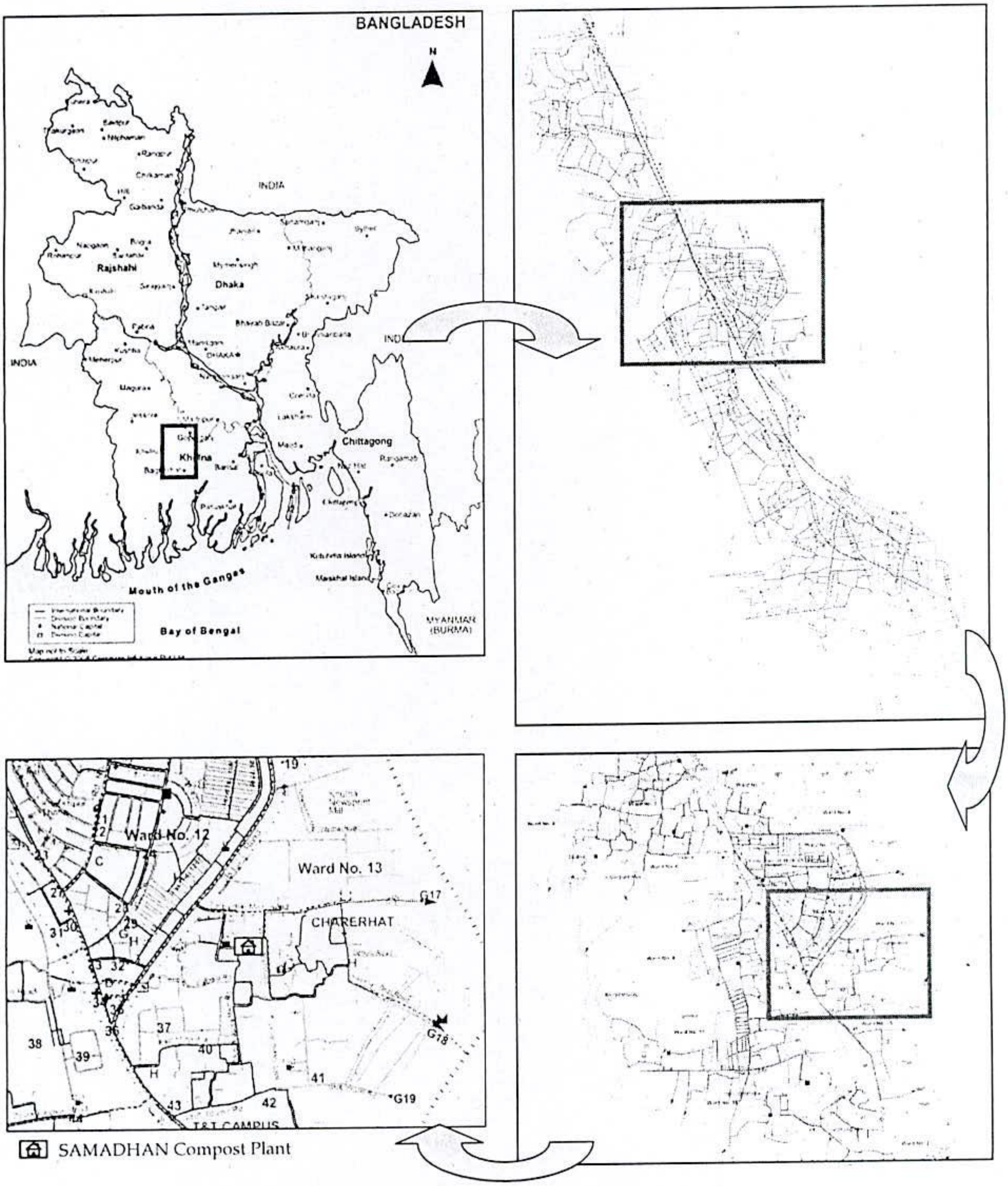
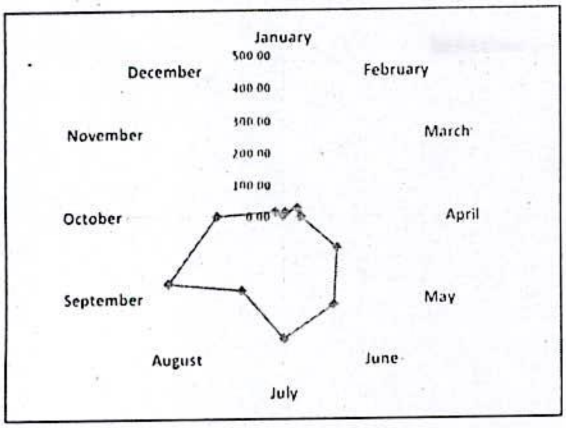
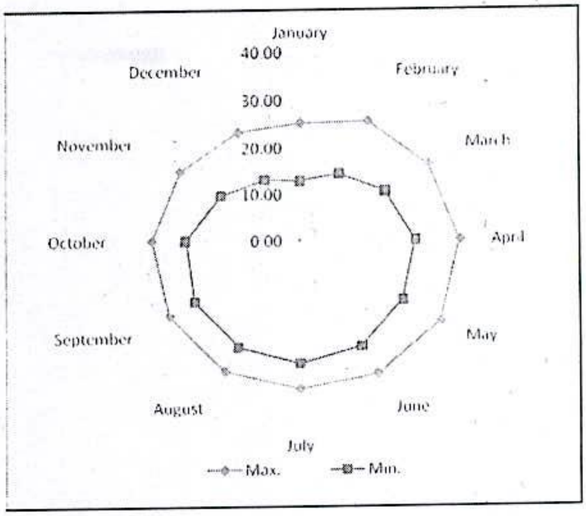


Figure 3.1 Location of SAMADHAN Compost Plant

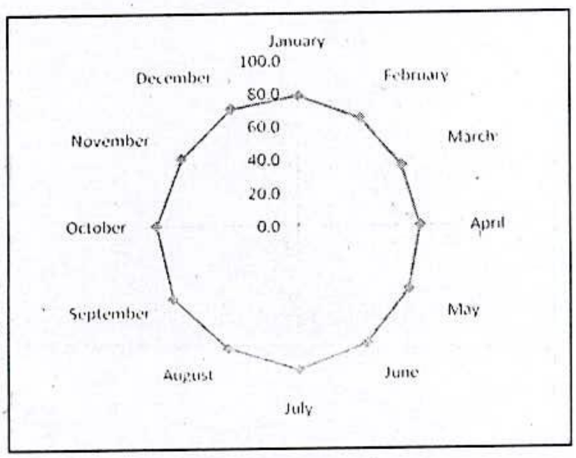
3.3 Climatic Condition

Along a year, precipitation, maximum and minimum temperature and humidity are shown in the following Figure (Figure 3.2).





Precepitation round the year (mm) Max. & Min. temperature round the year (^{0}C)



Average humidity round the year (mm)

Figure 3.2 Precipitation, temperature and humidity curve round the year.

3.4 Brief Description of the Studied Compost Plant

The name of the studied compost plant is Samadhan compost plant. This compost plant builds up from the mixed realization of doing some thing for environment and economic beneficial aspect, because there is a demand of compost. Owner of the compost plant is local person of Alam Nagar and he builds the compost plant in his own property. In figure 3.3, showed pictorial view of the compost plant which the layout is given in figure 3.4.

Figure 3.3 Photograph of the compost plant

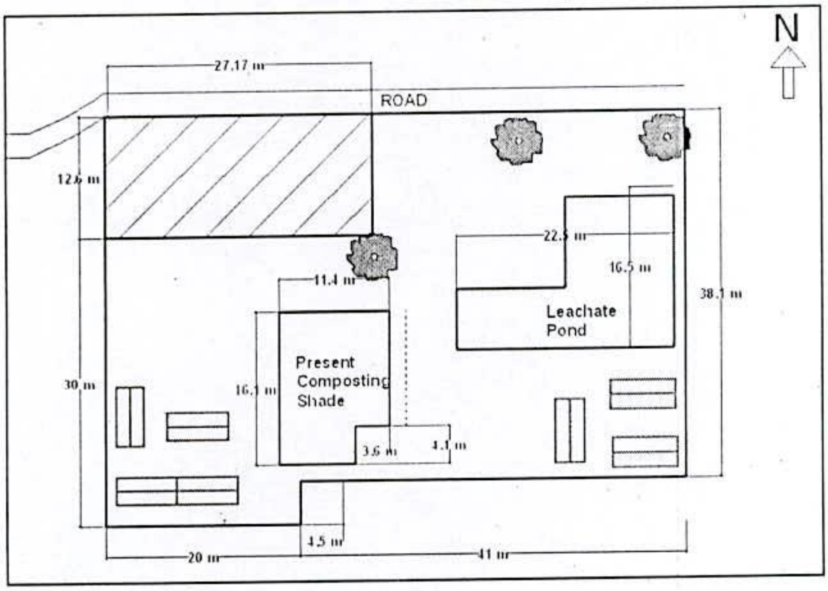
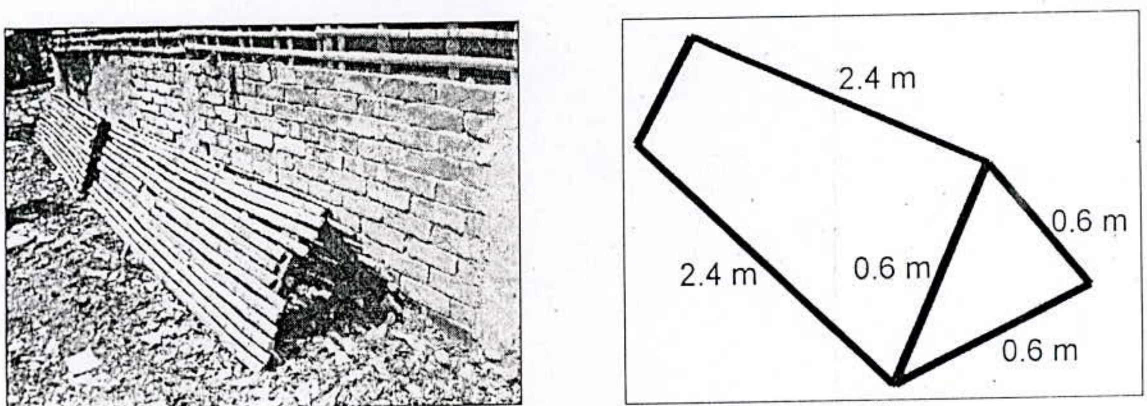


Figure 3.4 Layout of the Compost plant

Based on the compost plant 10 people works and lead their live. For collection of waste, presently three rickshaw vans provide the door-to-door waste collection service from the source. For compost pile, spaces for 32 aerators are available, however, at present 18 aerators are active. In table 3.1, an overview about the aerator is given. These aerators are made by bamboo. Sizes of aerator and a photograph are shown in figure 3.5.

Table 3.1 An overview of the compost plant

Items	Description
Materials of the aerator	Bamboo
Available land for the plant	1000 sq. meter
Sorting and composting area	856 sq. meter
Area for office and utility	31 sq. meter
No. of Rickshaw van	2 nos.
Size of Rickshaw van	1.36 m×1.00 m×0.86 m
Capacity of Rickshaw van	410 kg/van
Nos. of trip per day per van	2 trip
Size of aerator	244 cm×61 cm triangular.
Capacity	3 ton per aerator
Number of aerator available	32
Worker: waste collection	4 man+2 woman
And full time worker in plant	3-4 woman
Number of Turning during maturation	As per required



(a) *(b)*

Figure 3.5 (a) Pictorial view of aerator and (b) Dimension of aerator

3.5 Site Selection Strategy

Selection of right site for establishing a decentralized compost plant is the first step and also one of the principal factors. In the selection of present site for the plant, the following factors were kept in mind. These factors have also been required to consider while establishing a community based small scale compost plant.

- A suitable location for the plant in terms of accessibility, waste availability and the availability of required utility services such as electricity, suitable water supply, etc. is required. Here the selected sites at Alam Nagar, Khalishpur meet these requirements.

- For sustainability, long term ownership of the land of the plant must be ensured. Here, the owner of the land is the owner of the plant.

- Sufficient numbers of households should be available to ensure uninterrupted supply of MSW. There are about 800-1200 families in the selected areas which generate together around 3 tons of solid wastes daily.

- The local area should not more than one square kilometer so that rickshaw van can be used to collect waste from house to house.

3.6 Social Aspect of the Plant

A socio-economic surveying is required to conduct at selected locality for the compost plant. For surveying the subject of question should be selected by structured dialogue session with the representative of the local community. The objectives of surveying are to find out the opinion of local people, where a compost plant can be established. After establishing a compost plant, surveying needs to continue after every six months to know the opinion of the people regarding the plant. The questions are consisting:

- What is the present situation of waste management in your area?
- What are the constraints to establish a proper waste management system?
- How the local people want to solve their own problem?
- Whether they know about composting? Whether local people have any objection to establish a compost plant? If so what is the way of solution?
- Whether a social welfare team can be found to supervise the whole work?
- Whether the local people will do any financial help to collect waste from house to house?

The survey was conducted on the local people to set up the studied compost plant, where the above questionnaires were used. Based on the outcome of survey results, the people of the locality were made conscious about solid waste management. The meeting and communication with local social leader also conducted to encourage the people. As the separation of waste is an important issue, assistance was sought from every family member to collect the waste. Steps were taken to concern all the city dwellers to know the difference of organic and inorganic waste, hazardous and non hazardous waste, and their benefit and adverse aspects, a non political committee was formed with student and females, who have been working for better environment. In the committee, the retired personnel worked as advisor. Members of the committee were trained to know about separation of waste, collection of waste, composting process and to preserve the environment.

3.7 Solid Waste Collection Method

Collection of commingled and separated solid waste is a critical part of any solid waste management program. Samadhan compost plant collects their required amount of solid waste from selected source by door to door collection method. There are two vans for collection. Every family pays for collecting their waste (biowaste).

For the plant, the selected collection area is 1 sq. kilometer. To collect the waste from 200 houses, it is need 4 to 5 hours by one collector and one driver. Collector and driver use to wear designated dress, hand gloves and ID card during collection. They ring the bell when reach to the house, it can reduce the collection time. If the house holder kept organic and inorganic waste separately, then the collector keep them in separate container. If the house holder does not keep them separately, then the collector separates them accordingly to his instant capacity. A register book is maintained to record the collection process such as number of Vans and trip, amount of collected wastes, Staff's daily working hours and overall quality of works.

It is found that about 375 kg wastes are compostable into the collected wastes. The wastes which have value, drivers sell those wastes and the other wastes, which can not be composted, are sorted out by the workers at plant after receiving.

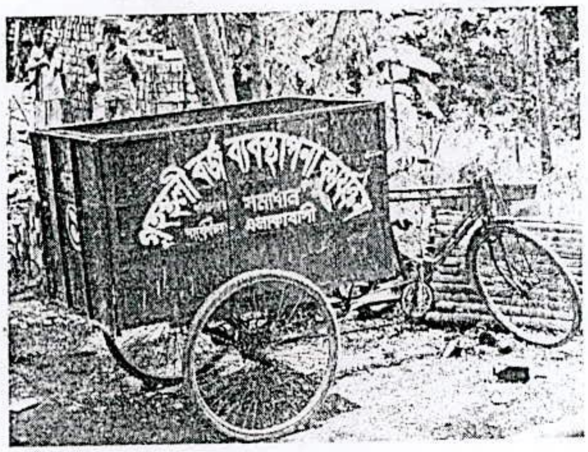


Figure 3.6 A van of SAMADHAN Compost Plant

3.8 Adopted Composting Process

Sorting of Waste

Organic Waste are the waste part of vegetable, fruits, fish, grasses, leaves, waste foods etc. which are sorted for few time composition and un-compostable waste are Coconut shell, mango seeds, jack fruit seeds, bone, dead animal and birds, cloths, napkins, branches of trees, earthen pots etc which are thrown in dustbin although those are organic.

Sorting are started upon receiving the van from collection, otherwise odor smell will spread. The workers wear gloves, boot shoes, long handle reik, full slive shirt so that no waste can come in contact to the body. In figure 3.7, it is shown that the worker sorts the mixed solid waste. Organic, inorganic and non compostable materials (e.g. $TC=TIC+TOC_{deg.}+TOC_{non\text{-}deg.}$) are separated immediately. Composting material and Re-cycling materials keep separate. In-organic and un-compostable waste are thrown in dustbin within the same day, which are collected by city authority to dispose at landfill.

Figure 3.7 Photograph of sorting of waste

Mixing

Ratio of carbon and nitrogen is called C/N ratio, which is one important factor for producing desirable compost. If carbon remains 25% and nitrogen remain 1% then the ratio will be 25:1 that is 25. Composting process will be affected for C/N was not remaining standard. The ratio of C/N present in the collected waste should ensure by laboratory test. Depending on that C/N balancing is needed by adding extra. Before mixing for C/N balancing the weight of waste should know. For faster and effective composting extra carbon and nitrogen should mix to get the ratio 25-40. For proper balancing of C/N, wood powder, cow dung, chicken liter or euria fertilizer can be mixed with waste.

From the laboratory test, it is known that the wastes which are collected by Samadhan compost plant having C/N value below 20 that is why more carbon enriched materials is mixed with waste. Also compost residues are mixed with waste; due to that bigger grain can decompose again as well as it will accelerate the composting work. Following table presents the mixing materials with the waste and their quantity.

Table 3.2 Name of the mixing materials with waste and quantity

Component	Quantity
Wood powder	10-20%
Cow dung	1-2%
Chicken liter	1-2%
Euria	1 kg/ton
Compost residue	5%
Dust of tobacco leaf	Little quantity
Powder of margosa leaf	Little quantity
Powder of Mahogani leaf	Little quantity

In the table 3.2, it is shown that dust of Tobacco leaf, powder of Margosa leaf, powder of Mahogani leaf are mixed with MSW to a very small quantity as stated. But these ingredients are not mixed in a time; these are mixed alternatively to keep away the insects from the waste.

Preparation of Compost Pile

In order to pilling the mixed waste are carried with pore less bucket having capacity of 30 to 32 liter. Then unload the waste without giving any pressure so that leachate can drain out. Old compost/wooden powder/residue are spread out on the pilling waste so that insects or fly can not seat or lay eggs. Plate numbers are kept for every pile and details are kept in resister. Worker wear leachate proof gloves, boot etc. Figure 3.8 presents a photograph of compost pile.

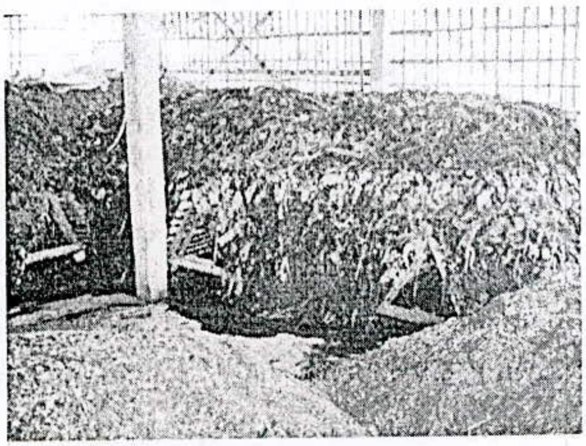


Figure 3.8 Photograph of compost pile

Turning

In composting more air is needed for oxygen. In bamboo aerator (Figure 3.5) process turning is necessary. When temperature reaches to more than 70^0C then it reduces by turning. Turning makes inner materials to come out and outer materials to go in. Due to turning the composting process accelerate and uniformity can be achieved.

Wastes are brought down from the pile then spread over the floor for certain period and after that these are brought back on aerator. During first few weeks 2 to 3 times turning will be good for composting. If pile temperature reach to 70^0C, then turning becomes necessary. Turning of compost pile is performed in the studied compost pile, which shown in figure 3.9.

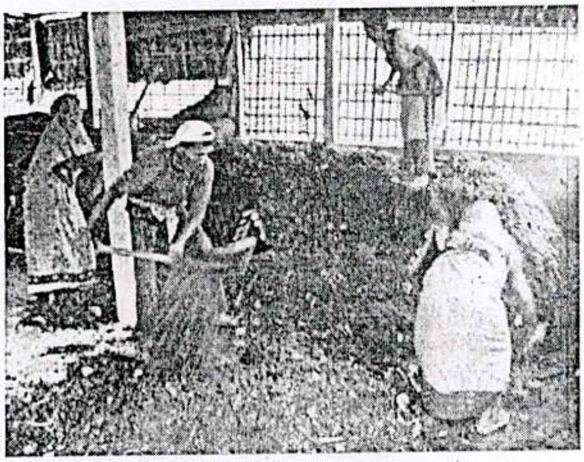


Figure 3.9 Turning of Compost Pile

3.9 Monitoring and Quality

Monitoring of Temperature

Temperature increases due to composting in presence of microscopic bacteria. Not only that the humidity, presence of oxygen, nature of waste and season affect the rise of temperature. 49 type of disease generating virus destroyed in aerobic composting.

If the temperature of a composting heap remain above 62^{0}C during one hour, above 50^{0}C during one day, 46^{0}C during 1 week then the waste carriage diseases virus die own self. But for compost pile, the temperature at 55^{0}C during 3 days is necessary; also the German regulation mention, a temperature of at least 55^{0}C over a period of two weeks, with no or minimum interruption, or alternatively to a temperature of 65^{0}C (or, in the case of closed plants, 60^{0}C) over a period of one week. Due to increase of temperature, the larvae of flies and seeds of insects get destroyed.

Thermometer is used for temperature measurement. This one foot long thermometer is inserted about 10 inches into the pile, after 30 second of insertion the temperature is recorded. Temperature is recorded twice in a day at top of heap and side of heap. It is plotted in a graph for record. A typical temperature curve of compost pile is shown in the following figure.

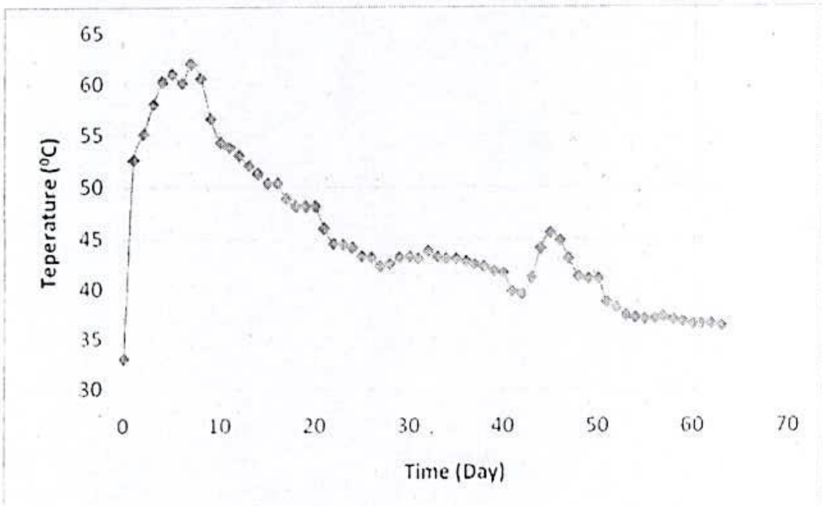


Figure 3.10 Temperature curve of compost pile at SAMADHAN Compost Plant

Optimization of Moisture Content

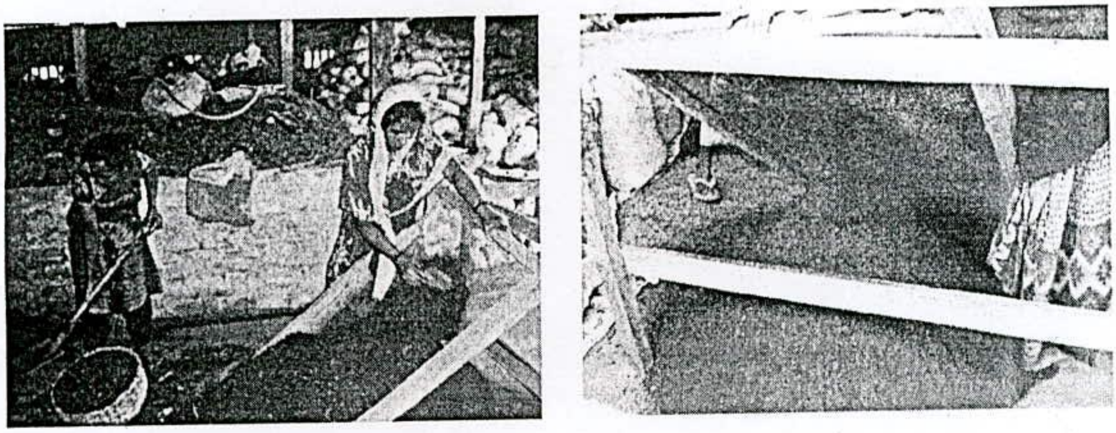
Physical inspection is used to check the level of moisture content in the pile. A hand full of waste from 2-3 inch deep is taken and pressure is applied with finger, if no water comes out then it means water is needed, if 3-5 drops of water comes out then it means moisture content is satisfactory, if more water than that comes out then it means moisture content is higher than the standard. If water is needed, then water is applied using a sprinkler (Enayetullah, et al., 2006). Water is not applied using pipe because water intensity will not be able to control. Depending on weather condition water is generally needed during winter season but during rainy season water is not necessary. If the water content remains higher, it will oppose to composting, then some old compost residue are spread over the pile.

Maturation of the Compost

The solid waste piled bamboo aerator becomes compost within 6 weeks and the temperature reaches below 40^0C. Some of the wastes remain un-composted with more moisture content, which can not be sieved. Compost shifted to another place for maturing after 6 weeks, then after next 2 to 4 weeks the compost become matured and become suitable for screening. The compost downloads from piles and spreads on floor having thickness of 4-6 inch. During rainy season, covered place is used for the maturation of composting. Temperature monitoring is continued. Screenings are not started when temperature do not comes less than 45^0C during summer or less than 30^0C during winter. Turning is done once in a day during the stage of maturing. Compost become black-brown color, granular, soil odors or odor less at end of maturing stage. Compost is mixed with water, if no any odor comes out then it confirm that the compost is matured. Compost is weighted before and after maturation for records.

Screening

Based on the general grain size of compost, 4 mm to 8 mm square hollow sieve fitted on wooden frame is used for screening. The screening fitted inclined at 45 degree angle for operation (Figure3.11a). Degraded wastes after maturation are used to fall from upper side of screen and one worker bring the lower retained waste back to upper side of the screen using a peace of plank or hardboard, it helps the smaller grain to go through the sieve. The compost is collected from lower side of net (Figure 3.11b) and weigh for storage. It is taken care about glass, polythene; iron nails, battery, bones, blade etc. may not mix with the compost. If any of all those material is found then it is sorted out. During first step of screening some of the bigger grain which does not go through the net is collected and step of screening is repeated. By this way after 2-3 times of screening if the compost do not pass through the net then certain quantity of it keep to mix with new waste at a certain rate and rest part are sorted out and go for ultimate disposal. All compost and residue was weighted before and after maturation and at different stages. About 30% compost of total sorted waste (by weight) is got at this studied plant. 150 kg degraded wastes can be screening in a hour, if two person are involved with this function.



(a) *(b)*

Figure 3.11 Screening is going on at SAMADHAN Compost Plant

Constraints of the Screening system

Production of compost from degraded waste is less in this screening system. Since production rate is low, more time is required to find out designated amount of compost. Operation cost is high, because more labors are required (about 4 people). This system is not sufficient when amount of material is more. Since wastes are screened using hand pressure, screen is spoiled quickly. Since waste have to screen through two different opening sizes, screening is done in two steps separately. Compost should be wet to use. When waste is wet, it is hard to screen for clog the opening. Workers don't want to wear gloves and boots. So, this system is unhealthy for workers.

Stability of Compost

The self-heating test is widely adopted at composting plants as a simple and inexpensive test to determine the biological stability of the produced compost (Koenig, et al., 2001). Procedure of self-heating test was developed in Germany. It is a sample test and an excellent indicator of biological maturity, if properly conducted and does not require sophisticated equipment (Bari and Koenig, 2002). To determine the stability of compost, which produced from SAMADHAN compost plant, self heating test was conducted.

Temperature vs. time in day, which is found by self heating test of final composts, is shown in Figures 3.12. From Figures 3.12, value of T_{max}, I_{max} and A_{72} are found, which are shown at the Table 3.3. Based on Iannotti, et al. (1994) as cited by Epstein (1997), degree of biological stability or Stability Index (SI) of final compost is also found from the table 3.3.

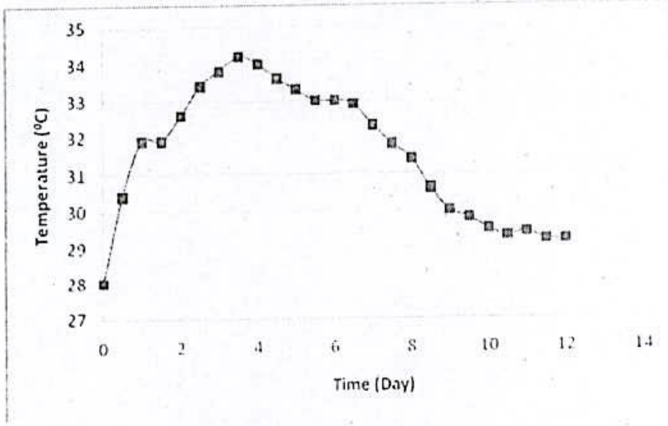


Figure 3.12 Temperature Curve of Self Heating Test of final composts from SAMADHAN Compost Plant

Table 3.3 Degree of biological stability or Stability Index of final compost

Parameter		Value
Maximum Temperature	T_{max} (°C)	34.2
Max. Temperature Increase	I_{max} (°C/h)	0.17
Area under temperature curve after 72 hours	A_{72} (°C-h)	2300
Stability Index	SI	IV

Quality of Final Compost

The quality of compost from SAMADHAN Compost Plant are shown into the following table (Table 3.4). To evaluate the quality of final composts of SAMADHAN, composts were sent to Bauhaus University Weimar, Germany. In the laboratory, all the relevant properties of the composts were performed using the required equipments and methods such as "EDEV H

55", "DIN EN 10694", "BGK e.V. (Federal assurance association compost)- Method book" methods.

Table 3.4 Quality of final composts from SAMADHAN Compost Plant

Parameters	Quantity	Unit
Dry matter (DM)	56,5	Weight %
Loss on ignition/ volatile solids burn loss of DM	18	Weight % (DM)
Total C (TC) of DM	9	Weight % (DM)
Respiratory activity (AT_4)	2	g O/ kg
pH-Value	8,38	-
Salt content/ salinity	1,52	g/ 100 g
Total nitrogen	0,95	Weight %
Nitrate nitrogen	594	mg/ kg
Ammonia nitrogen	72	mg/ kg
Potassium	1,24	Weight % as K_2O
Magnesium	1,48	Weight % as MgO
Phosphorus	1,84	Weight % as P_2O_5
Lead	92	mg/ kg
Copper	59	mg/ kg
Zinc	271	mg/ kg
Cadmium	0,5	mg/ kg
Mercury	< 0,1	mg/ kg
Chrome	20	mg/ kg
Nickel	11	mg/ kg

Concentration of Heavy Metal

Concentrations of heavy metals are found from the table 3.4. There is no standard for compost quality for Bangladesh. However, comparison can be performed with the standards for compost used in agriculture from Switzerland and India, which is given at a users' manual on composting published by Waste Concern (Enayetullah, et al., 2006). There is another standard which given by German Bio-waste Ordinance, is also used to compare. Through

Figures 3.13, comparison of heavy metal concentration of final compost with Switzer and Indian standard are shown by bar chart.

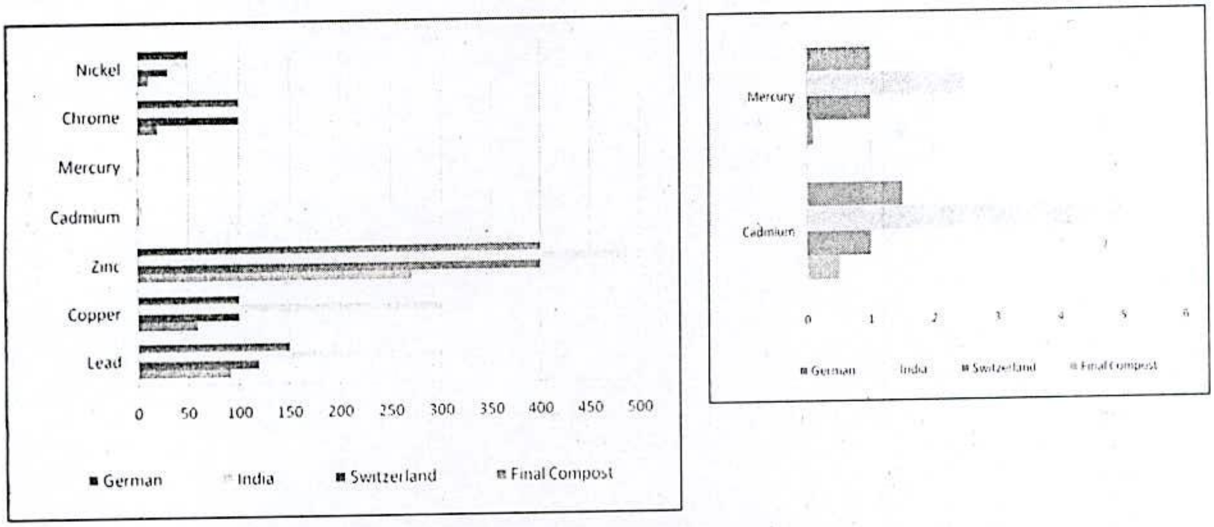


Figure 3.13 Comparison of Heavy Metal Concentration with Standards

3.10 Enrichment of the Product

Table 3.5 shows a list of various organic ingredients used to mix with the matured compost to increase the various nutrients components in the compost. These organic ingredients have been mixed based on the demand from the farmer trial and error methods used in the plant to increase the quality of compost.

Table 3.5 Component and their quantity for the enrichment of the product

Organic ingredients	Increased Component	Quantity
Mastered Cake	Nitrogen	200 kg/metric ton
Teel Khaile (local name)	Nitrogen	200 kg/metric ton
Soyabean Cake	Nitrogen	200 kg/metric ton
Blood (Cow)	Nitrogen	0.005% (depending on Weight, kg)
Fish powder	Nitrogen	Little quantity
Ash	Potassium	Little quantity
Seashell powder	Calcium	0.001% (depending on Weight, kg)
Bone crash	Calcium	0.001% (depending on Weight, kg)

The ingredients as shown in the table are not mixed with compost at a time. Such as, Master Cake and Teel Khaile are mixed alternatively with the compost. From laboratory test, it is seen that animal blood is good to increase the quantity of nitrogen. At first, when start to mix the enriched materials with compost, blood is not mixed with compost and Table 3.6 presents the laboratory test result of compost at that time. After that, blood is mixed with compost to increase nitrogen, test results of such compost is presented in Table 3.7.

Table 3.6 Laboratory test results of Compost (Without animal blood)

Chemical components	Quantity (%)
Nitrogen	3.41
Phosphorus	2.91
Potassium	1.98

**Institute of Soil Resource Development and Department of Chemistry, KUET, Khulna*

Table 3.7 Laboratory test results of Compost (after mixing of animal blood)

Chemical components	Quantity (%)
Nitrogen	6.51
Phosphorus	2.91
Potassium	1.98
Organic matter	41.83

**Department of Soil, Water and Environment, DU, Dhaka*

From Tables 3.6 and 3.7, it is shown that for using animal blood, nitrogen has increased about 3.1%. But there is a problem of using blood. It produce enormous odor if it is not use within 3-5 days and Nitrogen component is also not found satisfactorily. Compost without mixing blood, nitrogen components has reduced with time. After about 30 days nitrogen is not found in the compost. Now, it is trying to keep nitrogen in the compost for long time and also trying to remove odor problem.

3.11 Marketing of Product

Compost is kept under the shade and at a dry place. It is also kept in a safe place from rat or other animals. Temperature have check at different places of compost stock, if the temperature reaches to higher by 20^{0}C than the surroundings, it proves that the compost is not fully matured. It will not be suitable for plantation. Compost is packaged in water proof bags. Bag sizes are 1 kg to 40 kg depending on market demand. Before packaging and marketing, the compost was sent the laboratory for test to check the standard of nutrition. Standard of nutrition was written on the bags. Compost is kept in store during not more than 1 year in order to remain with standard nutrition.

Since compost is enriched by various organic materials, extra steps are taken for marketing. Such as, to sell the product within 30 days otherwise there is a loss of nitrogen. From test it is found that Nitrogen lost after 30 days various enriched materials of table 3.5 without blood mixed with compost. For this, if 30 days expired, enriched materials are mixed with compost again. Blood mixed compost are used especially for plough of betel leaf. So, blood is mixed with compost after order. In the following table (Table 3.8), it is shown that the quantity of compost which use in the land according to the crops.

Table 3.8 Use of Compost in land

Name of Crops	Volume	Uses in kg	Application Procedure
Paddy, Wheat and Vutta	One Sq. meter	0.25-0.50	During Preparation of Land
Potato, Onion etc.	One Sq. meter	0.50-0.70	During Preparation of Land
Vegetables	One Sq. meter	0.40-0.60	During Preparation of Land
Fruit trees	One tree	0.60-0.75	Twice in a year
Seasonal flower	One Sq. meter	1.00	During Preparation of Land
Gardening	One Sq. meter	1.00	During Preparation of Land
Vessel plants	One tree	0.30-0.50	Twice in a year
Rose	One tree	0.40-0.50	After cutting the branches

3.12 Sustainability of the Plant

Study on various compost plant, some factors are found which are the cause of shut down the activities of a compost plant. Factors are as follows:

- Funding
- Compost quality
- Odor at plant
- Regularity of workers
- Sufficient waste flow
- Marketing of compost

To sustain a plant, funding is the main problem. Some plants, which are built up depending on donation, are shut down after finishing its fund. This plant is not built on any kind of donation. This plant is built on owner's land and the required money to run the plant, is collect from a part of the service charge of waste collection and sell of compost.

To sell the compost, compost quality keeps an important role. To meet this requirement, SAMDHAN enriched its compost by various organic materials.

Directly collection of wastes from kitchen and no storage of collected waste at plant are the main cause of less odor of this compost plant.

SAMADHAN fulfill the minimum requirement of workers and give lunch at every working day.

Uninterrupted flow wastes are required to run a plant well. SAMADHAN has its own collection system.

Marketing is another major factor to sell compost. Though there are some govt. embargoes, SAMADHAN keep running the awareness program to the farmers about compost.

3.13 Remarks on Samadan's Plant

- This compost plant should have lab facility to find out the properties of compost.
- There is no well pavement at the yard of plant for the movement of vehicles.
- Because of lagging of drainage system, at the rainy season, water is logged on the surrounding of the plant.
- According the collected waste, plant area is not sufficient.
- Awareness and motivation is required to keep people their kitchen waste separately.
- The vans which are used to collect waste should have cover and build using good steel materials to minimize the maintenance cost.

CHAPTER FOUR

DEVELOPMENT OF DEMO COMPOST PLANT

4.1 General

Generally the steps of composting process, which are followed to produce compost by three set-ups in Demo Compost Plant, are shown by the following flow diagram.

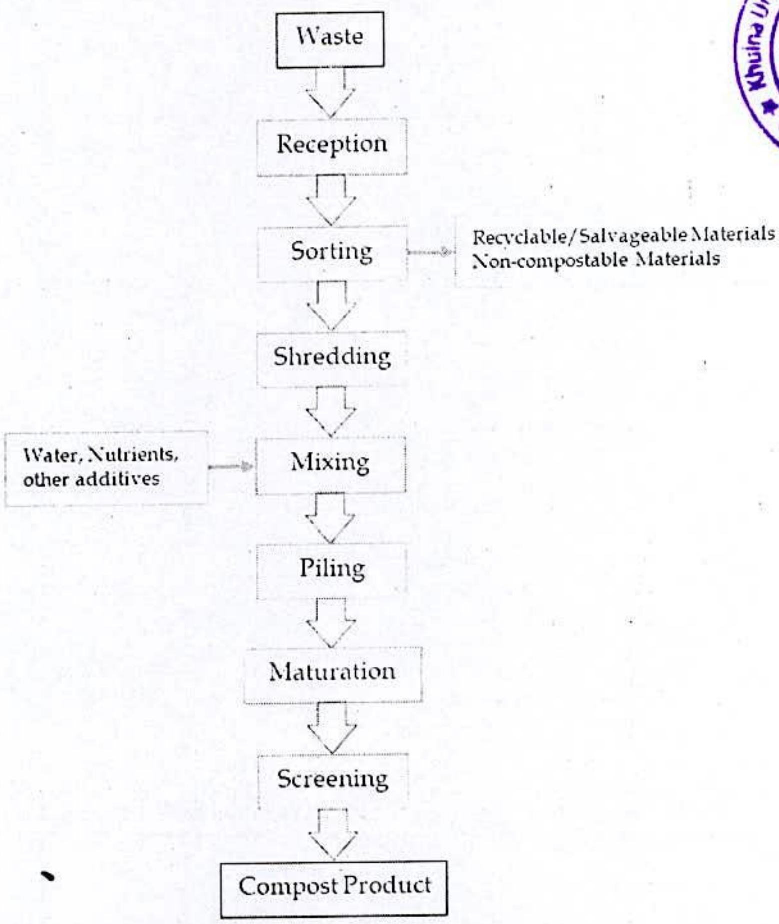
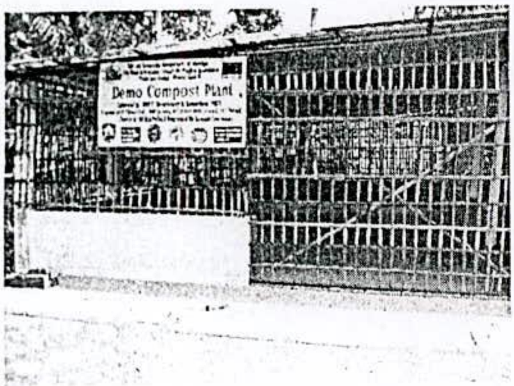


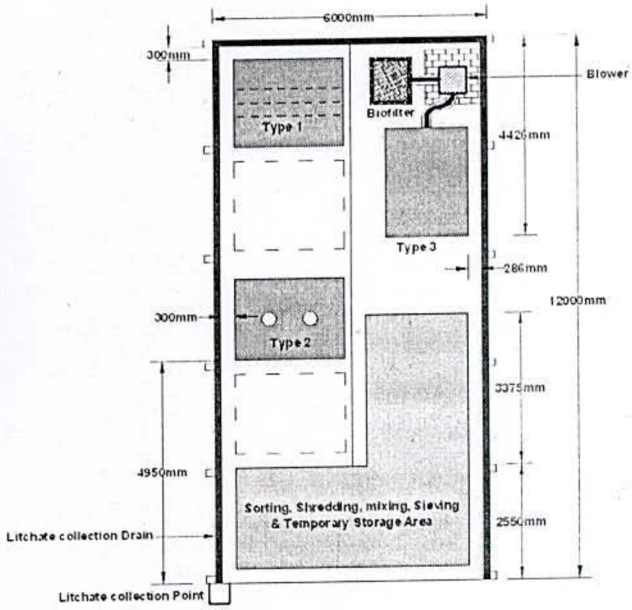
Figure 4.1 Flow diagram of Composting Process conducting at Demo Plant

4.2 Preparation of Demo Compost Plant

Demo Compost Plant, around 77.5 m^2 areas, is built on the land of Samadhan, just adjacent to its present compost plant. From the study on SAMADHAN Compost Plant, some facilities and infrastructures were not found like well entry road, proper drainage system, leachate collection system etc. Required facilities for demo compost plant were developed to complete research work smoothly. A photograph of this compost plant and its layout are shown in figure 4.2.



(a) Front view of Compost Plant



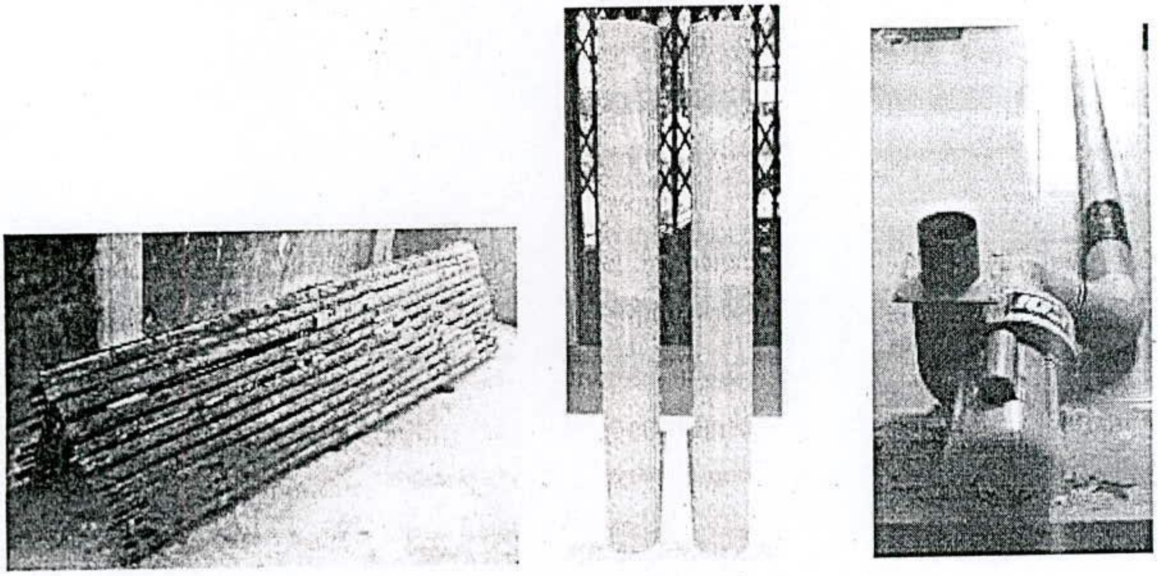
(b) Layout of various working space

Figure 4.2 A photograph of Plant and layout of various work space

4.3 Aeration System

Newly designed Aerators (as shown in the following figure) are fabricated for used in the compost pile. Cause of introduction of newly designed aerator is to find out a suitable aeration system for aerobic composting for Bangladesh. First one is bamboo made horizontal frame which is used at SAMADHAN Compost Plant. This frame lied into the compost pile horizontally. Length, width and height of this frame are 2.4 m, 60 cm and 60 cm, respectively (Figure 4.3a). Second one is vertical perforated PVC pipe which was designed to increase aeration into compost pile by chimney effect. Length and diameter of vertical frame are 1.5 m and 15 cm. There are pores on the surface of vertical frame with 6 mm dia @ 50 mm c/c

(Figure 4.3b). These two aerators are in the category of passive aeration system. Last aerator was horizontal perforated PVC pipe with air blower which is in the category of forced aeration system. The forced aeration arrangement is made by the PVC pipe of 10 cm dia and 2.4 m long. For forced aeration composting, a locally made air blower is bought and fabricated which is functioning well so far (Figure 4.3c).



(a)Horizontal Bamboo Frame *(b)Vertical perforated PVC pipe* *(c)Horizontal perforated PVC pipe with air blower*

Figure 4.3 Various types of aeration arrangement

4.4 Collection of Solid Wastes

For marketing reasons, only separately collected (and treated) green waste has a future because of better quality, because of less unwanted substances (or in such sense). Over the last decades, some countries have shifted to separately collected green waste, so as to ensure a marketable quality of the product. This tendency was particularly marked in Germany, Holland, Austria and Switzerland, where the agricultural use of compost from MSW is forbidden since 1986. In many countries, mechanical-biological pre-treatment (using aerobic process) is still considered a treatment process for MSW prior to landfilling (Ludwig, et al., 2003).

The wastes which are used for composting in demo compost plant are mainly kitchen wastes collected by door to door collection system. There are three rickshaw vans engaged daily to collect the waste at the Samadhan Compost Plant from different householders of ward no. 14 and 15 of Khulna City Corporation.

4.5 Sorting of Wastes

Separation means removal of non-biodegradable or non-compostable material from highly compostable materials. It is a necessary operation for any compost plant. It can be seen that about 6% materials are non-biodegradable and unsuitable for composting are present in collected waste. In demo compost plant separation is done by manually. Organic Waste are the remaining/unused part of vegetables, fruits, fishes, grasses, leaves, waste foods etc. which are sorted in the next step and un-compostable waste are Coconut shell, mango seeds, jack fruit seeds, bone, dead animal and birds, cloths, napkins, branches of trees, earthen pots etc which are thrown in dustbin although those are organic. In Figure 4.4, it is shown that the worker sorts the mixed solid waste. Sorting is started manually upon receiving the van from collection. Organic, inorganic and non compostable materials are separated immediately. Composting material and Re-cycling materials keep separate. In-organic and un-compostable waste are thrown in dustbin for final disposal within the same day.

Figure 4.4 Pictorial view of the process of sorting

4.6 Shredding Of Wastes

Material will compost best if it is between 12 to 25-12 mm in size (Raabe, Website). From the study, it is found that about 40% material is greater than the mentioned size. After sorting of the waste, the larger particles are shredded in to smaller particles to increase the degradation rate and facilitates better aeration through the compost pile. In demo compost plant cutter is used to shred the wastes and shredding is done manually. A photograph of shredding process at demo compost plant is shown in Figure 4.5.

Figure 4.5 Pictorial view of the process of shredding

4.7 Mixing of Different Components

In demo compost plant, no additives were used with the waste in the experimental compost piles of 1st set-up except Samadhan's compost pile. The composting process of Samadhan's compost piles is reported at chapter three. The shredded wastes are mixed with proper proportionate of water to obtain desired moisture content in the waste mixture. In composting system, suitable moisture content, pore volume, particle size to keep the pore volume etc. is necessary to avoid anaerobic condition and also for rapid degradation of organic waste.

To improve the temperature curves as per theory and the degradation rate of waste, two additives charts are introduced at the 2nd set-up according to the C: N ratio, which taken 16.08 for Khulna city (Alamgir, et al., 2005), and the experience of the Samadhan Compost Plant. These two additives charts are applied to three types of compost piles at 2nd set-up. Additives Charts are presented in Table 4.1.

Table 4.1 Name of the mixing materials with waste and quantity

Components	Quantity		
	Compost pile #1	Compost pile #2	Compost pile #3
MSW	3000 Kg	3000 Kg	3000 Kg
Cow dung	55 kg	55 kg	45 kg
Chicken liter	45 kg	45 kg	60 kg
Saw Dust	75 kg	75 kg	-
Compost residue	150 kg	150 kg	150 kg

At the 3rd set-up additives were mixed with waste using the ratio which elaborated at Table 4.2. This ratio is designed by analyzing the result of 2nd set-up.

Table 4.2 Name of the mixing materials with waste and their percentage

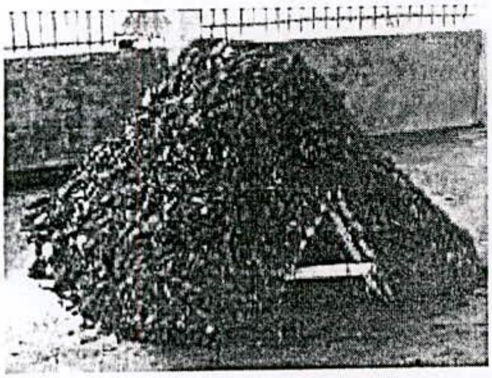
Components	Quantity (% of waste by weight)
Cow dung	1.8
Chicken liter	1.5
Saw Dust	2
Compost residue	5

4.8 Mounting of Waste or Piling

1st Set-up Composting

Set up of three types of compost piles at the demo compost plant are shown in the figure 4.4. The size of both passively aerated compost piles using horizontal bamboo frame and vertical frame is 2.4 m long, 2 m wide and 1.1 m high (Figure 4.6a and 4.6b). Two vertical pipes spaced 80 cm and inserted into the waste as shown in Figure 4.4b are used. Dimension of the force aerated compost pile is same as the passively aerated compost pile. The position of the perforated pipe for forced aeration is at the lower-middle portion of the pile (Figure 4.6c). Around the perforated pipe about 200 mm thick 18 mm sized gravel layer used to prevent any possible clogging of the pores. These three types of compost pile are named as Pile #1, Pile

#2 and Pile #3 respectively. Pile #4 is same as Samadhan's compost pile, which shown in Figure 4.6d.



(a) Compost Pile using horizontal bamboo frame - Pile #1

(b) Compost Pile using vertical perforated PVC pipe – Pile #2

(c) Forced aerated Compost Pile – Pile #3

(c) Compost Pile same as SAMADHAN's compost pile _Pile #4

Figure 4.6 Different types of compost piles

2nd Set-up Composting

After proper mixing of wastes at 2nd set-up, mixed wastes were mounted on aerator manually in two types of aerators. In this set-up three types of aerators were used to examine their performance as describe below and shown in Figure 4.5.

Compost Pile #1

In this compost pile a bamboo frame was used as aerator, which laid horizontally into the compost pile. Total weight of mounted waste after mixing the additives was 3325 kg and the dimension of this compost pile was 205 cm width, 245 cm length and 138 cm height and formed about trapezoidal shaped cross section at the both direction e.g. along the length and along the width (Figure 4.7a). At the top of this shape were 87 cm and 138 cm along the width and length of the compost pile respectively.

Compost Pile #2

Here as an aerator perforated PVC pipe was used, which is placed vertically in the compost pile. In this compost pile, also 3325 kg wastes are mounted. Size of this compost pile is 256 cm length, 163 cm width and 115 cm height and formed about trapezoidal shaped cross section at the both direction (Figure 4.7b). At the top of this shape were 62 cm and 132 cm along the width and length of the compost pile respectively.

Compost Pile #3

This compost pile was same as compost pile #1, only difference from that is additives mixing. From the Table 4.1, it is shown that in compost pile #1 & #2, ratios of the additives are same but in compost pile #3, one type additives is absent and ratio is different. Sometimes sawdust is not available. To evaluate the difference, sawdust was cut off from compost pile #3. Here total weight of mounted waste after mixing the additives was 3255 kg and the dimension of this compost pile was 210 cm width, 245 cm length and 95 cm height. At the top of this pile were 75 cm and 132 cm along the width and length respectively. Compost Pile #3 is shown in the Figure 4.7c.

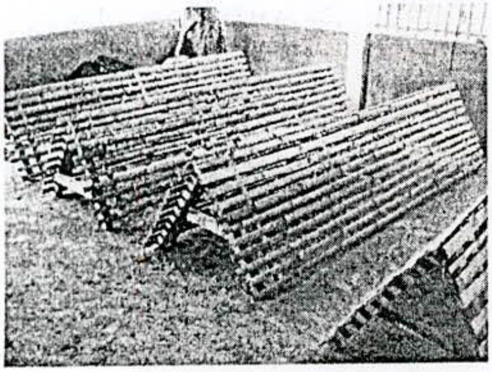
(a) Compost Pile #1 *(b) Compost Pile #2* *(c) Compost Pile #3*

Figure 4.7 Different types of compost piles of 2nd set-up at Demo Compost Plant

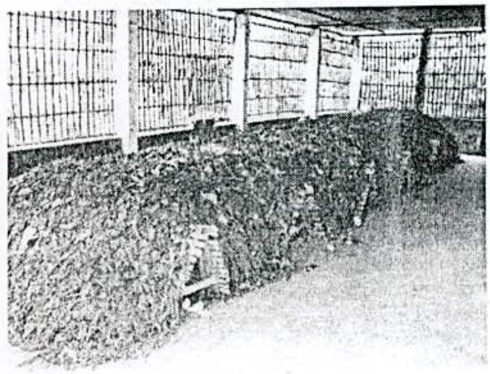
3rd Set-up Composting

In this set-up only one pile is studied which can be said continuous pile. The procedure of this pile is similar to the procedure of the SAMADHAN's compost pile. This system can be reduced the requirement of the space at the plant and increase the capacity. As an aerator, horizontal bamboo frame was used here. Six aerators were laid horizontally into this compost pile. As the experience of SAMADHAN compost plant, it was found that to reduce the odor, the wastes should use for composting every day which collected. Wastes should not store more than one day.

The aerators were arranged on the floor one after another transversely as figure 4.8a. It was started the mounting of wastes from the end of the aerator line. The collected wastes were mounted every day after sorting, shredding and mixing. To rise the temperature in the compost pile as required, about three tone wastes are needed for a single aerator. So, in this pile about fifteen tone wastes were required. But to avoid the anaerobic condition in the compost pile, the amount of wastes were reduced and it was about 11.2 tones, since the aerators were close. The space between the two aerators was 80 cm. Twenty seven working days were used to complete this compost pile. Day wise wastes position in continuous compost pile is shown in figure 4.9. The length of this compost pile was about 735 cm, width was about 245 cm and height was 120 cm. At the end of the wastes mounting on aerators, the height became about 90 cm. the complete continuous pile is shown in Figure 8b.



(a) The arrangement of aerators for continuous compost pile



(b) Complete continuous pile

Figure 4.8 Pictorial view of aerators arrangement and continuous pile

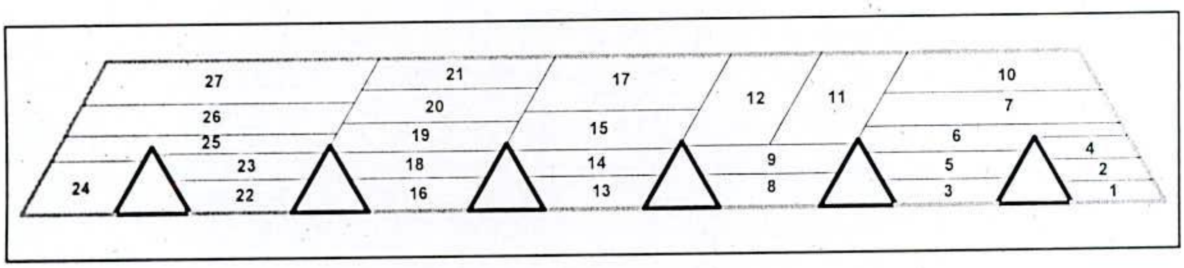


Figure 4.9 Day wise wastes' position at Continuous pile

4.9 Turning of Compost Pile

Oxygen uptake is a very useful parameter, because it is a direct manifestation of oxygen consumption by the microbial population and hence, of microbial activity. Microbes use oxygen to obtain the energy to carry on their activities. A very effective means of monitoring for adequacy of oxygen supply is by way of the olfactory sense, namely, detection of odors (Tchobanoglous and Kreith, 2002). A lack of oxygen likely favors the growth of anaerobic organisms which cause unpleasant odors. Turning is an important factor during the composting process to ensure sufficient air (Enayetullah, et al., 2006). In aerobic composting more air is needed for more oxygen. When temperature reaches to more than 70^0C then it is reduced by turning. Turning makes inner materials to come out and outer materials to go in. Due to turning the composting process accelerate and uniformity can be achieved. Wastes are brought down from the pile then spread over the floor for certain period and after that these are brought back on aerator.

At 1st set-up, wastes were mounted on aerator for 80 days, because after 80 days the temperature of compost piles became more close to ambient temperature. Compost piles were turned in every week along this period. There was no development of odor problem during composting at this set-up.

Based on the experience of Samadhan compost plant, 2nd set-up was designed for 9 weeks, where wastes were mounted into compost pile for 6 weeks and degraded wastes were kept for maturation for remaining time. Since no odor problem at 1st set-up, turning was done only one time along first 6 weeks at 2nd set-up. Though turning is very useful for accelerate the composting process, practically it is painful for workers, causes health hazards, and also time consuming because the whole process of turning are done manually as shown in Figure 4.10.

3rd set-up was also designed for 9 weeks, where wastes were mounted into compost pile for 6 weeks and degraded wastes were kept for maturation for remaining time. Since turning is painful for workers, causes health hazards and time consuming, it was obsolete at this set-up except two occurrences though it is important. It was designed that turning could be done when the temperature rose above 70^0C and the odor problem created.

Continuous compost pile was divided into five segments as figure 4.11. Temperature was taken at every segment in every day. The temperature of three segments of this compost pile raised above 70^0C, where two segments were turned and one was kept as unturned to view the temperature variation. The numbers of these three segments were 1, 4 and 5, where segment 1 was kept unturned.

Figure 4.10 Pictorial view of turning process

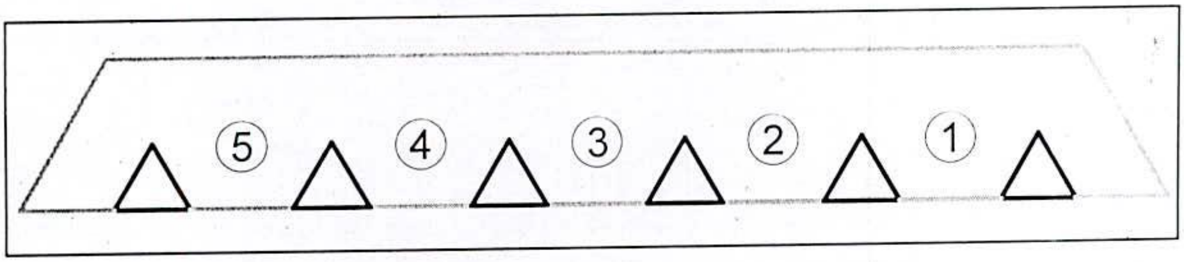


Figure 4.11 Segments of continuous compost pile

4.10 Maturation of Degraded Wastes

Since maturation phase is over within 80 days, degraded wastes, which were degraded at 1st set-up, were kept for one week at a designated place of the plant for drying and becoming suitable for screening.

The wastes at 2nd set-up became compost within 6 weeks and the temperature came down to below 40^{0}C. Some of the wastes remain un-composted with higher moisture content, which can not be sieved. Compost shifted to another place for maturing after 6 weeks then after next 3 weeks the compost became matured and became suitable for screening.

The wastes at 3rd set-up became compost within 6 weeks and the temperature came down to around 40^{0}C. Compost shifted to another place for maturing after 6 weeks then after next 3 weeks the compost became matured and became suitable for screening.

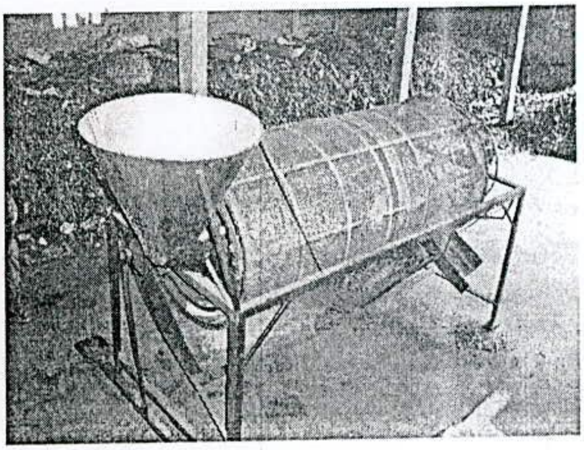
Before screening, the degraded wastes were downloaded from piles and spread on the floor having thickness of 100-150 mm for one day. Degraded wastes became black-brown color, granular, soil odors or odor less at end of maturing stage.

4.11 Screening of Degraded Wastes

Based on the general grain size of compost, 2 mm square hollow sieve fitted on wooden frame (Figure 4.12a) was used to find out the compost at 1st set-up. Before screening into the 2 mm hollow sieve, degraded wastes were screened into 12 mm square hollow sieve. A rotating screening system (Figure 4.12b), where two types of sieve (2 mm and 12 mm sq.

hollow) are fitted, was used to screen degraded waste of 2nd set-up and 3rd set-up. Which pass through into the 12 mm hollow screen and retain on the 2 mm hollow screen are known as residue. Residue can be used back to the compost pile with the fresh waste to help the degradation process and reduce the odor and remaining portion is thrown away.

(a) Wooden frame screening system



(b) Rotating Screening System

Figure 4.12 Pictorial view of screening systems

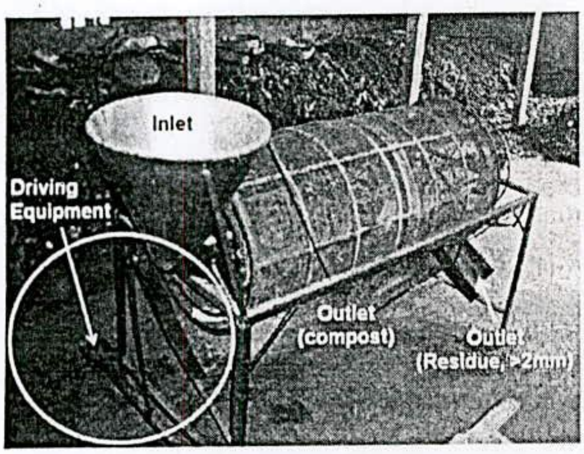
4.12 Development of Screening System

To remove the disadvantage of wooden frame screening system, a rotary type screening system is developed (Figure 4.12b). This screening system is derived manually, where two people are involved. The features, from where a view can be found about the rotary screening system, are described at the following table 4.3. Details of this new screening system are found from the figure 4.13. The driving arrangement is shown in figure 4.13a.

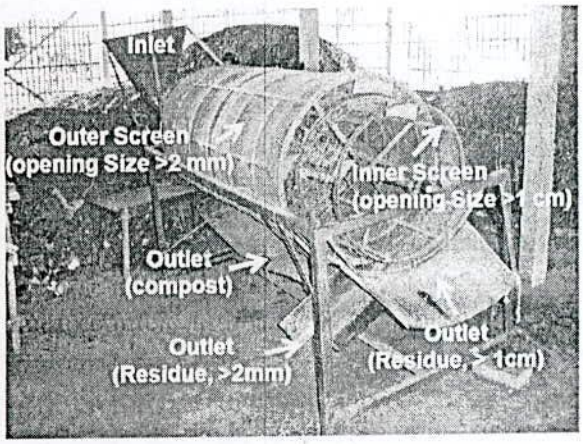
Table 4.3 Feature of rotary screening system

Items	Description
Length	200 cm
Width	90 cm
Height	130 cm
Used Materials	Mild Steel (MS) Angle
	MS Bar

	MS Sheet
	Two types Net
Opening size of Inner Screen	1 cm
Opening size of Outer Screen	2 mm
Diameter of Inner Screen	60 cm
Diameter of Outer Screen	80 cm
Inlet	A Hooper
Outlet	Three outlet to come out three types Materials
Driving system	Manually
Capacity	360 kg/h



(a) Showing driving arrangement



(b) Showing different parts of new screening system

Figure 4.13 Feature of Rotary screening system

4.13 Monitoring of Temperature

Temperature is a very useful parameter because it is a direct indicator of microbial activity. The biologically produced heat generated within a composting mass is important for two main reasons:

1. To maximize decomposition rate; and
2. To produce a material, which is microbiologically 'safe' for use. (Polprasert, 1989)

The temperature was measured daily at the three different position of compost piles.

4.14 Optimization of Moisture Content

A hand full of waste was taken from 50-75 mm deep of all compost piles and pressure was applied by fingers. In most of the cases some drops of water came out which indicated the satisfactory quantity of moisture content presence in the compost.

4.15 Monitoring of pH

A parameter which is important in evaluating the microbial environment is the pH of wasts. The pH varies with time during the composting process and is a good indicator of the extent of decomposition within the compost mass (Ahmed & Rahman, 2000).

The optimum pH range for most bacteria is between 6.0 and 7.5, whereas the optimum for fungi is 5.5 to 8.0. Precipitation of essential nutrients out of solution rather than inhibition due to pH per se establishes the upper pH limit for many fungi.

In practice, little should be done to adjust the pH level of the composting mass. Owing to the activity of acid-forming bacteria, the pH level generally begins to drop during the initial stages of the compost process. These bacteria break down complex carbonaceous materials (polysaccharides and cellulose) to organic acid intermediates. Some acid formation may also occur in localized anaerobic zones. Some may be due to the accumulation of intermediates formed by shunt metabolisms. Shunt metabolism may be triggered by an abundance of carbonaceous substrate and/or perhaps by interfering environmental conditions. Whatever the cause, the early pH drop in composting MSW may be to 4.5 or 5.0. The drop could well be lower with other wastes.

Organic acid synthesis is paralleled by the development of a microbial population for which the acids serve as a substrate. The consequence is a rise in pH level to as high as 8.0 to 9.0. The mass becomes alkaline in reaction.

Buffer against the initial pH drop through the addition of lime is unnecessary. Moreover, it promotes a loss of nitrogen. The loss can be particularly serious during the active stage of the compost process. For, example, in research conducted at the university of California at Berkeley in the 1950s, nitrogen loss always greater from piles to which lime [$Ca(OH)_2$] had been added to raise the pH (Golueke, et al., 1955).

Despite the potential promotion of nitrogen loss, the addition of lime might be beneficial in cases in which the raw waste is rich in sugars or other readily decomposed carbohydrates (e.g., fruit and cannery waste). Acid formation in such wastes is more extensive than in MSW and yard waste. For example it was found in studies on the composting of fruit waste bulked with sawdust, rich hulls or composted refuse that the three to four days lag in temperature rise characteristic of unbuffered fruit waste could be eliminated by adding lime (NCA, 1964). However, nitrogen loss also was greater.

Occasionally, the addition of lime may lessen offensive odors because of the effect of pH. Lime addition also improves the handling characteristics of some wastes (Tchobanoglous & Freith, 2002).

For the 1st and 2nd set-up, pH was not measured but at the 3rd set-up pH was measured. Sample was collected from every segments of 3rd set-up during first six weeks of segments. The procedure to measure pH of a sample is described followed.

Procedure

Weighing 10 gm waste into a small beaker then add 25 ml water (i.e. waste: water = 1: 2.5) and stir frequently about 50 minutes (Peterson, 2002). Leave the mixture one night without stirring. Rinse the p^H meter (Model: HANNA HI 9210N ATC) electrode with waste suspension and immerse the electrode in the suspension. Read the p^H value from the display when the reading has become stable. For each 10 gm waste samples or less: checked the p^H meter by measuring p^H in the buffer solution. Sometimes the calibration procedures are repeated for accuracy, while required.

4.16 Density Change

During the composting process, the total volume and the total mass of the compost pile decreases. Because of the abrasion by other materials and of maceration, the size of particles decreases. Hence, the total volume becomes smaller and the bulk density increases (Bachert, et. al., 2008).

Densities were measured in every week for all the different type compost piles of both set-ups. The bulk densities of waste were determined in two conditions that are designated as loose and dense by using a mold (container) and used in Standard Proctor Test of soils for compaction (Aminul, 2005). The bulk densities in loose condition were measured by normally filling the mold without any compaction or input energy. But the mold is constantly shaken during filling until lightly filled up to the mold brim and these in compact condition were measured by compacting the waste in 3 layers providing 25 blows per layer using a hammer of 5.5 pounds in 12" free fall (Das, 1983) until lightly filled up to the mold brim. The result is expressed as kg/m^3. The specifications of mold are given below:

1. Total length of mold = 218 mm
2. Effective length of mold = 176 mm
3. Thickness of collar = 42 mm
4. Diameter of mold = 152 mm
5. Volume of mold = $\pi/4 \times 0.152^2 \times 0.176 = 3.192 \times 10^{-3}$ m^3

Weight of mold = 8349 gm

4.17 Mass Reduction

Bio-oxidation through the living activity of micro-organism to carbon dioxide is the reason for the mass reduction (Bachert, et. al., 2008).

Weight of wastes were measured at the three phase of composting of all compost piles. At first weights were measured after completing the sorting of collected waste. At second phase, those were measured after completing the composting process including maturation. At third phase weight of first residue (>1 cm and which are gone to landfill), second residue (>2 mm and which are used again with fresh waste at compost pile) and compost were measured after screening.

4.18 Self Heating Test

To determine the stability of compost, which produced from the 2nd set-up composting of demo compost plant, self heating test was conducted. Different type composts, which produced from 1st set-up, were also tested for stability Index (SI). After completing of composting process, compost from five segments of 3rd set-up were tested for SI.
The procedure is described below.

Procedure

- After collecting the sample, required water is added to adjust the water content require for test.
- A vacuum flask was filled with the sample and a thermometer is inserted into the sample to record the temperature.
- After inserting the thermometer, some pieces insulating materials kept on the mouth of flask, because, heat can not pass out but produced gases.
- Interval of taking temperature reading is depends on the increase or decrease rate of temperature reading. However, the interval is about 6 hours.
- The period of this test depends on two factors, one, it have to pass three days and two, the temperature have to reach its peek point.
- A temperature versus time curve in term of ^{0}C and days was plotted in the graph paper and following terms are evaluated.
    1. Maximum temperature, T_{max} (^{0}C)
    2. Maximum temperature Increaseing rate I_{max} (^{0}C/h) and
    3. three days area, A_{72} (^{0}C-h)

4.19 Quality of Final Compost

Not all the composts have the same quality. What goes in as feedstock partly determines what comes out. Compost quality depends on the composting process used, the state of biological activity, and, most importantly, the intended use of the compost. Just as beauty is in the eye of the beholder, the end use defines compost quality (Cooperband, 2002).

There are some specific chemical, physical and biological parameters that can be used to evaluate compost quality. To evaluate the quality of final composts from 1st and 2nd set-up, composts were sent to Bauhaus University Weimar, Germany. In the laboratory, all the relevant properties of the composts were performed using the required equipments and methods such as "EDEV H 55", "DIN EN 10694", "BGK e.V. (Federal assurance association compost)- Method book" methods.

4.20 Competency of Workers

The steps of whole composting process at compost plant are mentioned earlier as receiving, sorting, shredding, mixing, mounting, Turning and finally screening. To established a sustainable compost plant, there is required a proper plan with other requirements. To optimum use of fund it is required to known how many workers are needed to run a compost plant properly. In Bangladesh context, about all of works are done manually. So, to design the numbers of workers, the capacity of worker at different steps of composting process are required to know. Since female workers are available in Bangladesh easy than male, in this study the capacity of female workers is tried to find out through this Demo Compost Plant at Khulna.

If the workers number is n then from the following equation it will be calculated.

$$n = \frac{1}{t_{w/day}} \times \left(\frac{Q_{total}}{C_{w/re}} + \frac{Q_{total}}{C_{w/sort}} + \frac{W_{p/shredding}}{C_{w/shredding}} + \frac{W_p}{C_{w/mix}} + \frac{W_p}{C_{w/piling}} + \frac{W_p}{C_{w/turning}} + \frac{W_p}{C_{w/mat}} + \frac{W_p}{C_{w/screen}} + \frac{W_{compost}}{C_{w/bag}} \right)$$

Where,

$t_{w/day}$ = Working time in a day

Q_{total} = Quantity of coming waste in kg

$W_p = \frac{Q_{total}}{100}(100 - \%R_j - \%R_e) + W_{additives}$ [Percent of rejects is $\%R_j$ and Percent of recyclables is $\%R_e$]

$W_{additives}$ = Total weight of additives in kg

$W_{p/shredding}$ = Weight of waste which are shredded in kg

$W_{compost}$ = Weight of Produced Compost in Kg

$C_{w/re}$ = Capacity of worker at the step of Receiving in Kg/hour

$C_{w/sort}$ = Capacity of worker at the step of Sorting in Kg/hour

$C_{w/shredding}$ = Capacity of worker at the step of Shredding in Kg/hour

$C_{w/mix}$ = Capacity of worker at the step of Mixing in Kg/hour

$C_{w/piling}$ = Capacity of worker at the step of Piling in Kg/hour

$C_{w/turning}$ = Capacity of worker at the step of Turning in Kg/hour

$C_{w/mat}$ = Capacity of worker at the step of Maturation in Kg/hour

$C_{w/screen}$ = Capacity of worker at the step of Screening in Kg/hour

$C_{w/bag}$ = Capacity of worker at the step of Packaging in Kg/hour

Capacities are calculated by measuring the required time to complete different steps by the workers at three set-ups of composting. Measuring of this time was not taken every time of these set-ups. It was taken randomly but several time and then average.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 General

The relevant parameters were measured at different stages of composting process and the out put i.e., compost samples were also tested to determine its properties. The results and the relevant discussion on these natures of results are illustrated in the following sections:

5.2 Characteristics of Waste

Some important physical characteristics of the input wastes like composition, moisture content, density and particle size were determined. The characteristics of 1st set-up compost piles also are shown in following tables. Since the characteristic of wastes at different piles of this set-up varies a little, only the characteristics of one pile are shown in the table 5.1 to 5.5. The physical characteristics of 2nd set-up compost piles are shown in the Tables 5.6 to 5.10. Also the physical characteristics of wastes of 3rd set-up are given in the Table 5.11 to 5.15.

Table 5.1 Composition of waste for the compost piles of 1st Set-up composting

Type	Quantity (%)
	1st Set-up Composting
Food	92.67
Paper	1.31
Plastic	0.4
Robber	0.01
Cloth	1.27
Yard waste	3.23
Glass	0.01

Stone	0.01
Metal	0.02
Eggshell	0.63
Bone	0.44

Table 5.2 The percent of biodegradable waste and non-biodegradable wastes (1st set-up)

Waste Type	1st Set-up Composting
Biodegradable	98.28%
Non-biodegradable	1.72%

Table 5.3 Bulk density & Moisture Content of waste for the compost piles of 1st set-up

Property	1st Set-up Composting
Bulk Density (kg/m^3)	910
Loose Density (kg/m^3)	598
Moisture Content (%)	70.58

Table 5.4 Particle Size distribution of waste for the compost piles of 1st set-up composting

Sieve Opening (mm)	Percent retained
	1st Set-up Composting
100	1.68%
75	3.20%
38.2	12.55%
19.1	35.12%
9.52	29.68%
4.76	14.11%

Table 5.5 The percent of large size (>25 mm) and small size (<25 mm) materials (1st set-up)

Material size	1st Set-up Composting
> 25 mm	17.43%
< 25 mm	82.75%

Table 5.6 Composition of waste for the compost piles of 2nd set-up composting

Type	Quantity (%)		
	Compost Pile #1	Compost Pile #2	Compost Pile #3
Food	88.81	84.12	82.54
Paper	2.41	1.95	1.49
Plastic	0.6	0.76	0.85
Robber	0	0.01	0
Cloth	2.54	1.66	1.71
Yard waste	4.32	6.35	7.02
Glass	0	0	0
Stone	0	4.02	5.1
Metal	0.03	0.02	0.01
Eggshell	0.72	0.55	0.64
Bone	0.57	0.56	0.64

Table 5.7 The percent of biodegradable waste and non-biodegradable wastes

Waste Type	Compost Pile #1	Compost Pile #2	Compost Pile #3	Average
Biodegradable	96.83%	93.53%	92.33%	94.23%
Non-biodegradable	3.17%	6.47%	7.67%	5.77%

Table 5.8 Bulk density & Moisture Content of waste for the compost piles of 2nd set-up

Property	Compost Pile #1	Compost Pile #2	Compost Pile #3
Bulk Density (kg/m^3)	1181	1110	1150
Moisture Content (%)	47	48	56

Table 5.9 Particle Size distribution of waste for the compost piles of 2nd set-up composting

Sieve Opening (mm)	Percent retained		
	Compost Pile #1	Compost Pile #2	Compost Pile #3
100	0%	9.89%	7.69%
75	8.51%	13.19%	10.00%
38.2	21.28%	23.08%	23.08%
19.1	28.37%	24.18%	26.92%
9.52	14.89%	13.19%	12.31%
4.76	12.06%	5.49%	8.46%

Table 5.10 The percent of large size (>25 mm) and small size (<25 mm) materials

Material size	Compost Pile #1	Compost Pile #2	Compost Pile #3	Average
> 25 mm	29.79%	46.16%	40.77%	39%
< 25 mm	70.12%	53.84%	59.23%	61%

Table 5.11 Composition of waste for the compost piles of 3rd set-up composting

Type	Quantity (%)				
	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5
Food	80.42	87.64	81.85	88.02	84.48
Paper	2.41	1.59	1.2	2.71	3.35
Plastic	0.36	0.85	1.93	0.41	0.99
Robber	0.01	0.03	0.05	0.2	0.08
Cloth	1.42	0.74	2.89	0.41	1.37
Yard waste	5.69	5.84	2.41	4.74	4.57
Glass	0.43	0.32	0.1	0.54	0.35
Stone	3.56	1.27	7.94	2.71	3.87
Metal	0.14	0	0.19	0	0.08
Ash	0	0.21	0.19	0	0.1
Eggshell	0.28	0.96	0.96	0.14	0.46
Bone	0.57	0.53	0.29	0.14	0.38

Table 5.12 The percent of biodegradable and non-biodegradable wastes of 3rd set-up

Waste Type	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Average
Biodegradable	89.37	96.56	86.71	95.75	93.24	92.33
Non-biodegradable	10.63	3.44	13.29	4.25	6.76	7.67

Table 5.13 Bulk density & Moisture Content of waste for the compost piles of 3rd set-up

Property	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5
Bulk Density (kg/m^3)	1190	1128	1065	1033	1013
Moisture Content (%)	62	72	64	61	61
pH	8.22	6.05	6.89	7.98	8.44

Table 5.14 Particle Size distribution of waste for 3rd set-up compost piles

Sieve Opening	Percent retained (%)				
(mm)	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5
100	2.28	10.9	10.3	1.42	6.32
75	15.23	9.35	3.41	7.14	8.87
38.2	21.57	34.27	19.66	24.3	24.69
19.1	38.07	24.92	27.36	34.3	31.51
9.52	15.23	12.46	17.1	18.57	15.74
4.76	5.07	4.98	10.26	8.57	7.22

Table 5.15 The percent of large (>25 mm) and small (<25 mm) size materials of 3rd set-up

Material size	Seg. 1	Seg. 2	Seg. 3	Seg. 4	Seg. 5	Average
> 25 mm	39.08	54.52	33.37	32.86	39.88	39.94
< 25 mm	60.92	45.48	66.63	67.14	60.12	60.06

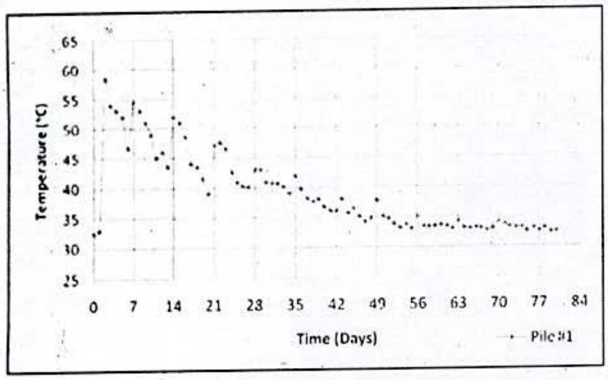
The compositions of collected wastes are shown in the Table 5.1, 5.6 & 5.11 and in the Table 5.2, 5.7 & 5.12, the percent of biodegradable wastes and non-biodegradable wastes are shown. From the Table 5.2, 5.7 & 5.12, it can be seen that about 1.8-7.7% materials are non-biodegradable and unsuitable for composting, where there is 7.5% and 20.5% unsuitable materials for composting at commingle waste for residential area and mixed MSW respectively (Alamgir, et. al., 2005). By sorting these wastes, plastic, robber, cloth, glass, stone and other non degradable materials were removed as possible. Bulk density and moisture content of the wastes are shown in the Table 5.3, 5.8 & 5.13. pH of wastes of 3rd set-up are shown in table 5.13.

Particle size distributions of wastes are given in the Table 5.5, 5.9 & 5.14. It was performed after completion of sorting. From this distribution Table 5.6, 5.10 & 5.15 can be composed, where the percent of large size (>25 mm) and small size (<25 mm) materials are shown. From Table 5.5, 5.9 & 5.14, it is found that about 40% material is greater than the designated size, which should be shredded.

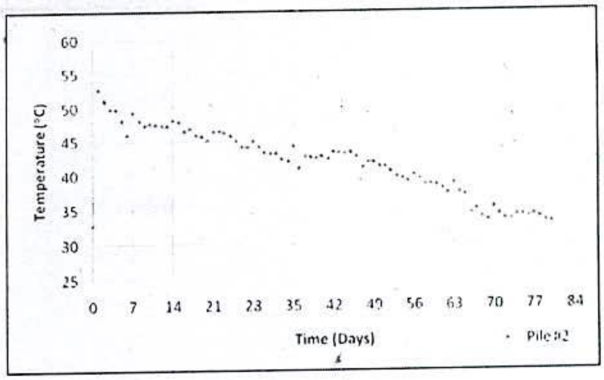
5.3 Temperature

Composts should be free from weed seeds and pathogens. Weed seeds and most microbs of pathogen significance cannot survive exposure to thermophylic temperature. Thermophylic is the temperature range from about 45 to 75^0C (Tchobanoglous and Kreith, 2002). Pathogens and such bacteria will be rapidly destroyed when all parts of a compost pile are subjected to temperatures of about 60^0C (Skitt, 1972). These higher temperatures, e.g., $60\text{-}70^0$C for about 24 hours, should be maintained for pathogen destruction (Ahmed and Rahman, 2000). There are other temperature-time frames for pathogen destruction like 65^0C for at least three days (Enayetullah, et. al., 2006) and 55^0C for at least 72 hours or three days (Cooperband, 2002); also the German regulation mention, a temperature of at least 55^0C over a period of two weeks, with no or minimum interruption, or alternatively to a temperature of 65^0C (or, in the case of closed plants, 60^0C) over a period of one week. So, it is preferable for the temperature of the composting pile to stay at $55\text{-}65^0$C for at least three days.

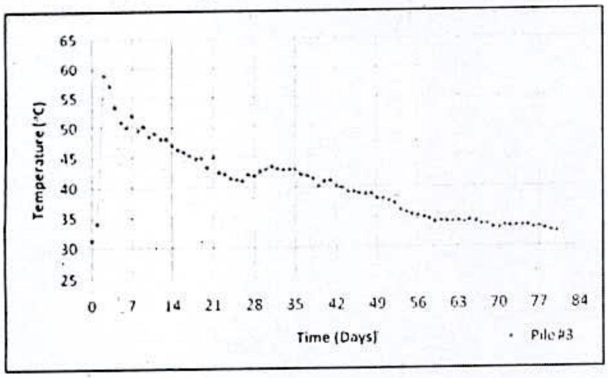
Temperature curve of different compost piles of 1st, 2nd and 3rd set-up are shown at the figures 5.1, 5.2 and 5.3, respectively.



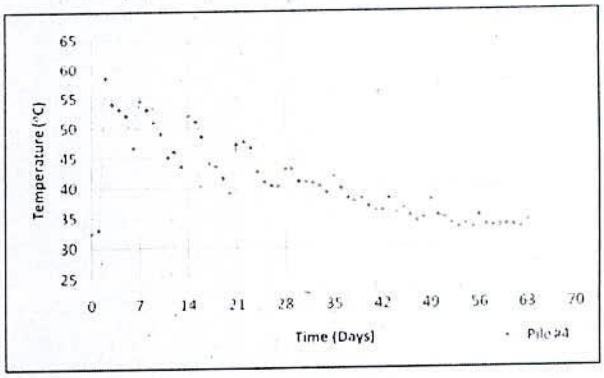
(a) Temperature Curve of Pile #1



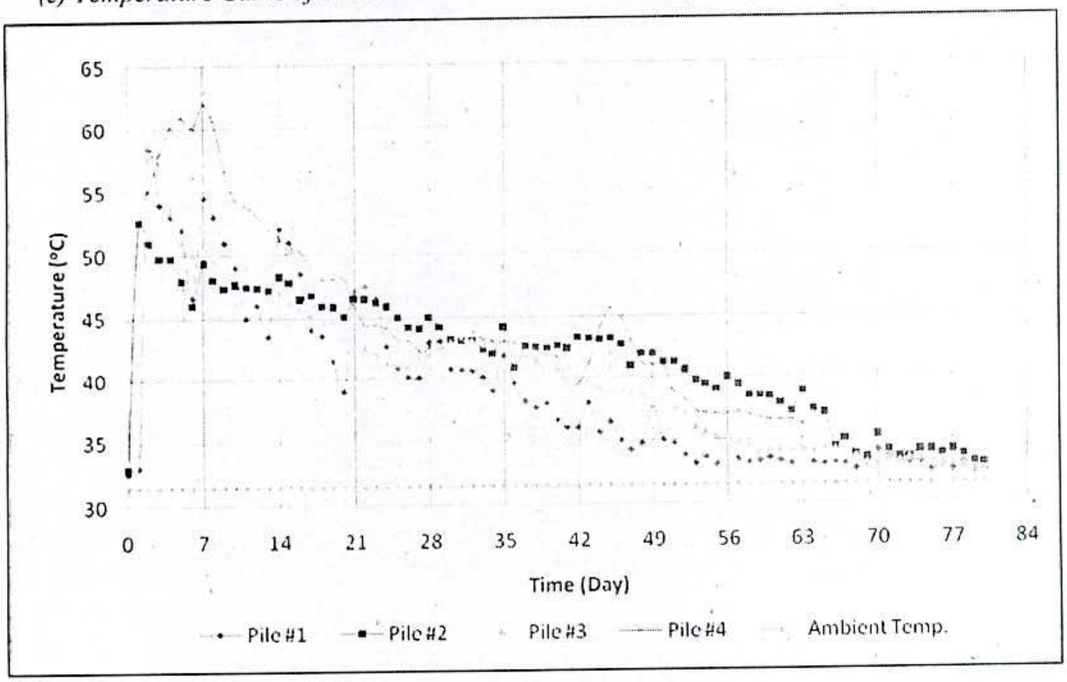
(b) Temperature Curve of Pile #2



(c) Temperature Curve of Pile #3



(d) Temperature Curve of Pile #4

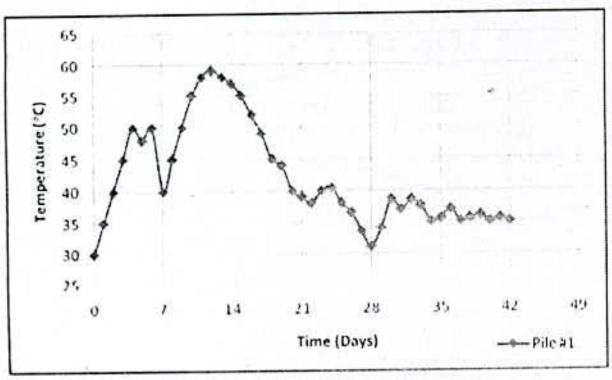


(e) Temperature Curves of all Piles

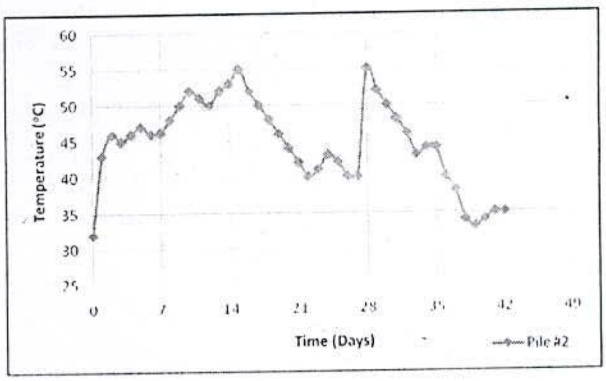
Figure 5.1 Temperature curves of compost piles of 1st set-up composting

The temperatures in four piles of 1st set-up are sharply raised to 50 to 60^{0}C. Cause of frequent turning (every week), many peaks along the composting period are made at the curve of first two compost pile that means pile #1 and pile #2. Since the pile #3 is forced aerated, it doesn't turned. So, there are no such peaks at curve of pile #3. After peak the temperature were decreased to around 40^0C in most of the piles until 6 weeks as shown in Figure 5.1. Since the temperature, which is higher than 60^0C, stayed for five days, Compost from pile #4 can be said pathogen free. Sometimes slightly lower temperatures would also ensure pathogen destruction, provided that all pathogen bearing material was brought into the composting reaction by adequate turning of windrows, mechanical agitation in drums or by the periodic air sucking technique (Skitt, 1972). So, composts from pile #1 and #2 have a good probability to be pathogen free. Due to much power fluctuation, aeration was not sufficient for pile #3. So, this compost has a chance to be infected by disease-causing organisms. Most of the temperature followed the general pattern indication the smooth operation as temperature is usually used as a feed back parameter of the process.

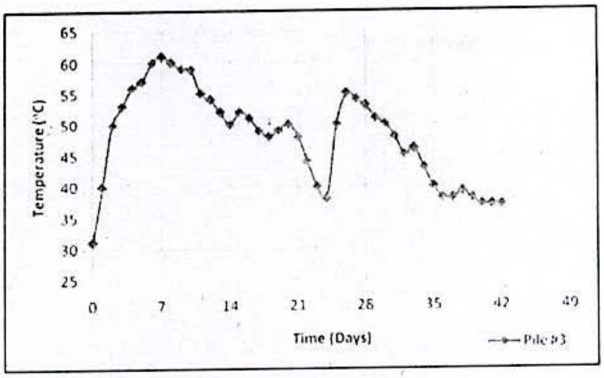
From the Figure 5.2, it is found that there are two remarkable peek at the temperature curves of compost piles of 2nd set-up. First one is just after placement of compost pile and second one is after turning. Since the temperature, which is higher than or equal to 58^0C, is stay for three days, Compost from pile #1 can be said pathogen free. But there is risk to infect by pathogen. The temperature of Compost pile #3 is higher than or equal to 60^0C for three days. So, the compost of this pile is pathogen free. Most of the temperature followed the general pattern indicating the smooth operation of pile #1 and #3. The temperature of pile #2 does not follow the general pattern and not sufficiently higher. After 6 weeks the temperature of all compost piles decreases to less than 40^0C.



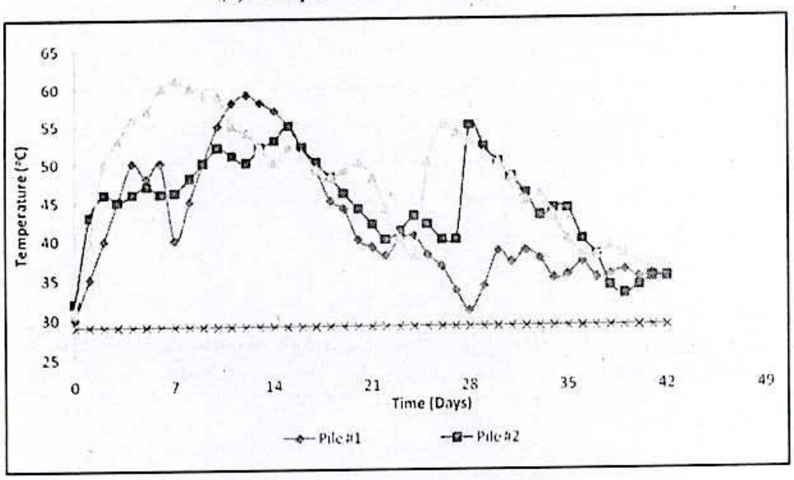
(a) Temperature Curve of Pile #1



(b) Temperature Curve of Pile #2

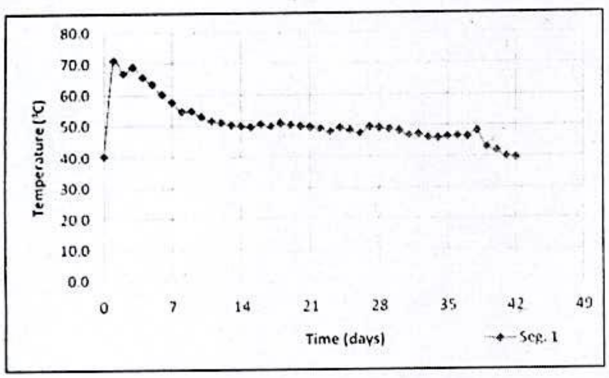


(c) Temperature Curve of Pile #3

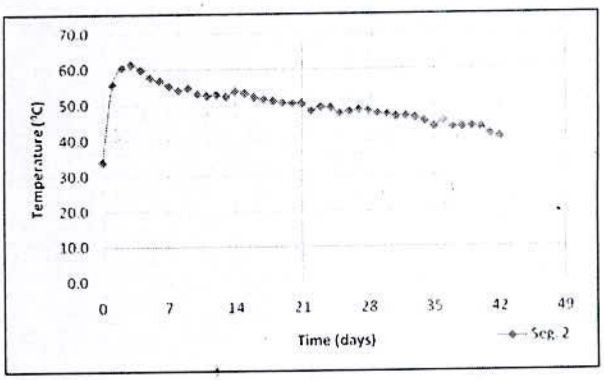


(d) Temperature Curves of all Piles

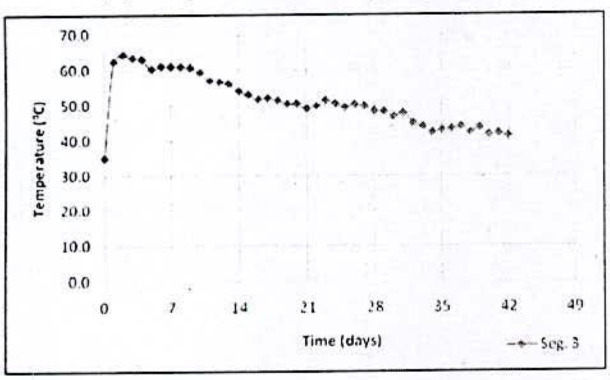
Figure 5.2 Temperature curves of compost piles of 2nd set-up composting



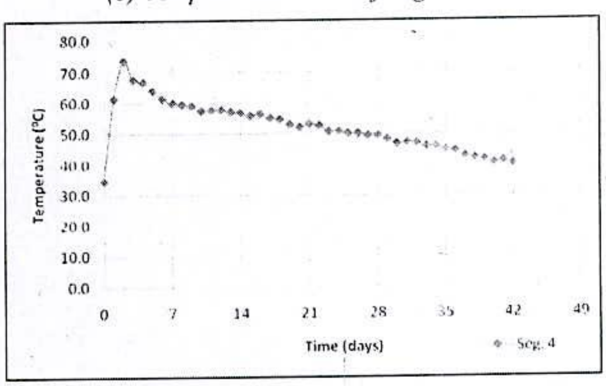
(a) Temperature Curve of Segment 1



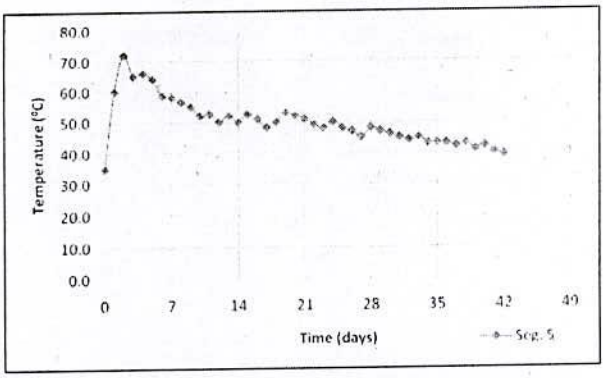
(b) Temperature Curve of Segment 2



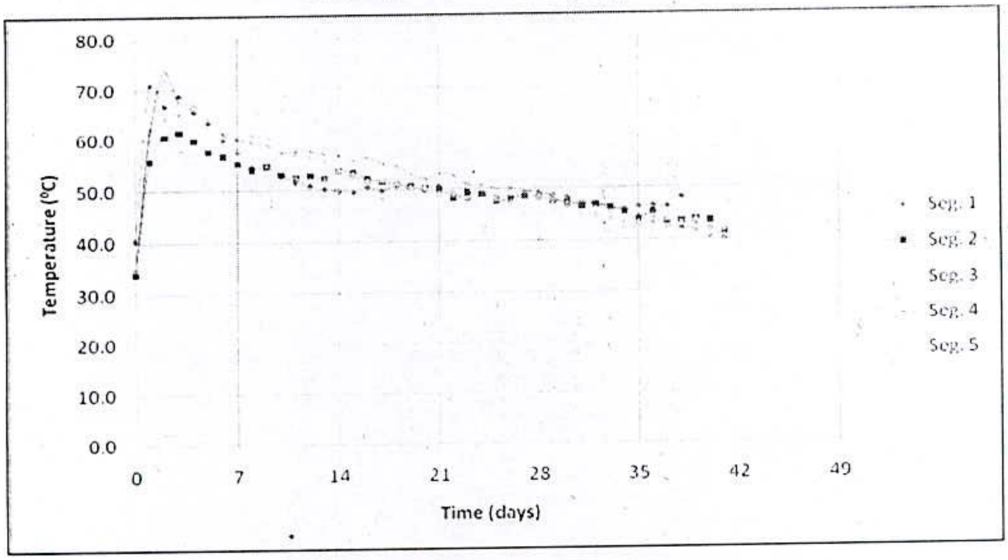
(c) Temperature Curve of Segment 3



(d) Temperature Curve of Segment 4



(e) Temperature Curve of Segment 5



(f) Temperature Curves of all Segments

Figure 5.3 Temperature curves of compost pile of 3rd set-up composting

From the Figure 5.3, it is found that there is only one peek at the temperature curves of compost piles of 3rd set-up. Because turning was cutoff at this set-up but it was done only when the temperature rose above 70^0C. The temperature of three segments of this compost pile raised above 70^0C, where two segments were turned and one was kept as unturned to view the temperature variation. The numbers of these three segments were 1, 4 and 5, where segment 1 was kept unturned.

From the temperature curves (Figure 5.3), it is found that the temperature kept above 60^0C for about one week of all segments except segment 2. Since the segment 1 was kept unturned though the temperature reached above 70^0C, micro-organisms was dead. So, the temperature of segment 1 reached below 55^0C with in one week and the temperature could not rise sufficiently at the segment 2. The compost from segment 2 can be said infected by pathogen. Since the segments were attached, pathogen can migrate to all remaining segments. Most of the temperature followed the general pattern indicating the smooth operation of this compost pile.

5.4 pH

pH at the segment 1 of 3rd set-up are shown in the figure 5.4. The pH was not follow the general pattern. These may occur for the mounting waste every day and at this segment, the wastes of six different days are mounted.

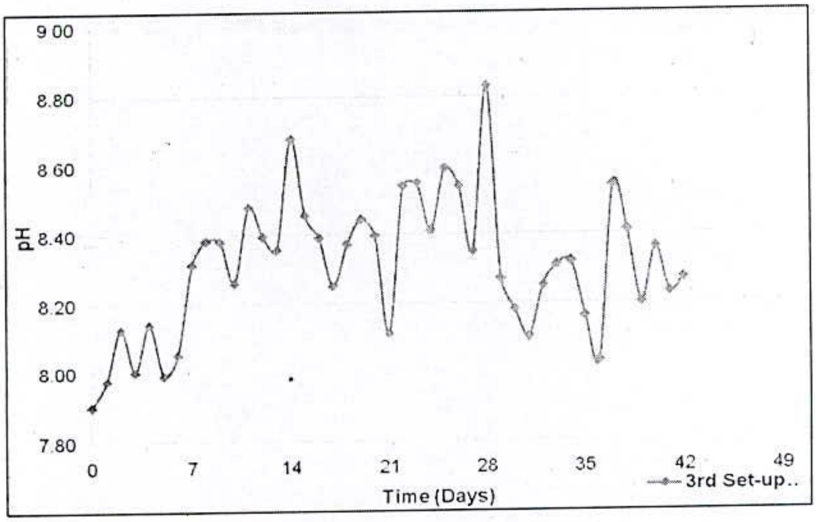
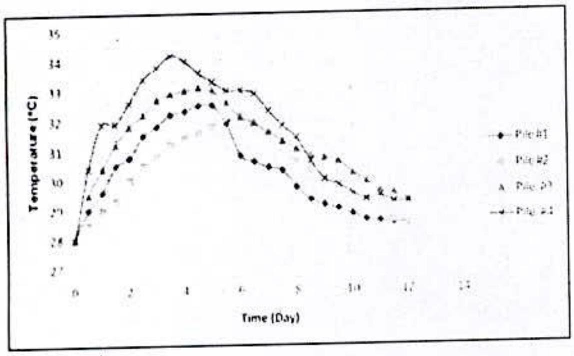


Figure 5.4 pH at the segment 1 of 3rd set-up composting

5.5 Self Heating Test

By plotting temperature, which are found by self heating test of different final composts of 1st, 2nd and 3rd set-up composting, vs. time in day, following two figures, Figures 5.5, 5.6 and 5.7, are found. From figures 5.5 and 5.6, value of T_{max}, I_{max} and A_{72} are found, which are shown at the Table 5.16 and from Figure 5.7, such value are found, which shown in Table 5.17. Based on Iannotti et. al. (1994) as cited by Epstein (1997), degree of biological stability or Stability Index (SI) of final compost, which produced from different type of compost piles of 1st, 2nd and 3rd set-up composting at Demo compost plant, are also found from the Table 5.16 and 5.17. Although the stability indexes of all composts are same, the composting period at 2nd set-up is less than 1st set-up, which may occur as the additives have an important role to accelerate the composting process. Also the stability indexes are same for every segment of 3rd set-up and similar to 2nd set-up.



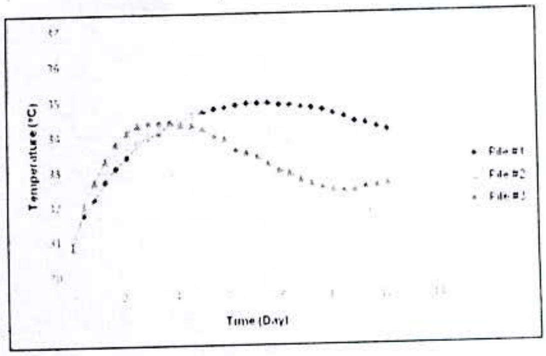


Figure 5.5 Temperature Curve during Self Heating Test of 1[st] Set-up

Figure 5.6 Temperature Curve during Self Heating Test of 2[nd] Set-up

Table 5.16 Degree of biological stability or Stability Index of final composts

	1[st] Set-up Composting				2[nd] Set-up Composting		
	Pile #1	**Pile #2**	**Pile #3**	**Pile #4**	**Pile #1**	**Pile #2**	**Pile #3**
T_{max} (°C)	32.6	32.2	33.1	34.2	34.9	34.5	34.4
I_{max} (°C/h)	0.07	0.06	0.12	0.17	0.12	0.11	0.14
A_{72} (°C-h)	2189	2120	2225	2300	2362	2378	2412
SI	IV	IV	IV	IV	IV	IV	IV

T_{max} = Maximum Temperature, I_{max} = Max. Temperature Increase, A_{72} = Area under temperature curve after 72 hours.

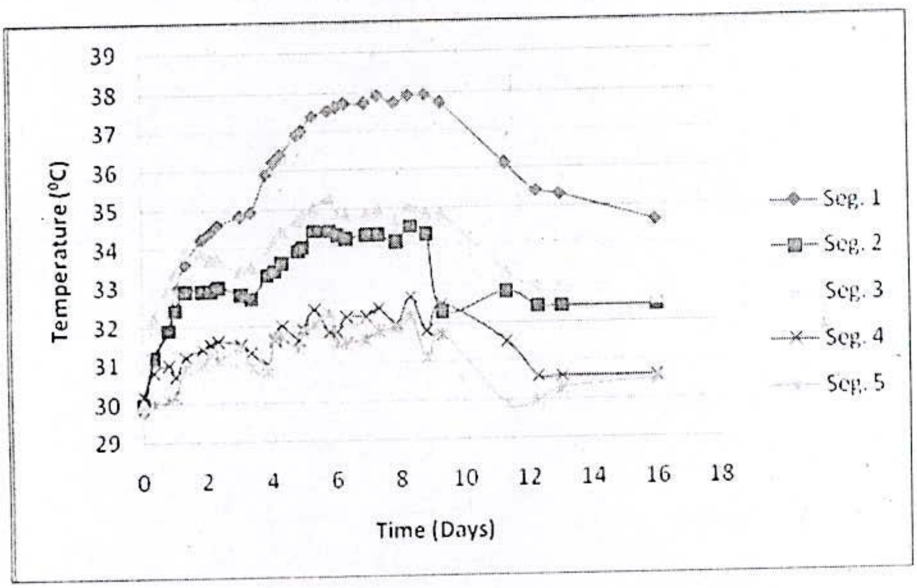


Figure 5.7 Temperature Curve during Self Heating Test of 3[rd] Set-up

Table 5.17 Degree of biological stability or Stability Index of final composts

	3rd Set-up Composting				
	Seg. 1	**Seg. 2**	**Seg. 3**	**Seg. 4**	**Seg. 5**
T_{max} (°C)	37.9	34.5	35.3	32.7	32.3
I_{max} (°C/h)	0.17	0.07	0.14	0.07	0.1
A_{72} (°C-h)	2328	2294	2388	2241	2205
SI	IV	IV	IV	IV	IV

T_{max} = Maximum Temperature, I_{max} = Max. Temperature Increase, A_{72} = Area under temperature curve after 72 hours.

5.6 Density Changes

Density at two state (one, loose and two, dense) was taken at every week of composting for 1st and 2nd set-up, which shown in the Table 5.18 and 5.19 respectively. Density change of wastes in term of percent of initial density at loose and dense state during composting process at 1st and 2nd set-up are shown in Figure 5.8 and 5.9, which composed from Table 5.18 and 5.19. From these Figures, it is found that density has changed up to about 77% at loose state and about 50% at dense state.

Table 5.18 Density at different stage of conversion of wastes of 1st set-up composting

	Density (kg/m^3)							
	Pile #1		Pile#2		Pile #3		Pile #4	
Days	Loose	Dense	Loose	Dense	Loose	Dense	Loose	Dense
0	350.88	895.99	330.51	858.40	336.78	881.89	347.74	889.72
7	418.23	1112.16	407.27	1082.39	386.90	1058.90	386.90	1015.04
14	466.79	1182.64	449.56	1141.92	432.33	1146.62	422.93	1085.53
21	509.09	1237.47	485.59	1193.61	471.49	1182.64	457.39	1152.88
28	531.02	1245.30	505.95	1212.41	494.99	1217.11	488.72	1192.04
35	551.38	1254.70	520.05	1235.90	518.48	1235.90	516.92	1218.67
42	571.74	1276.63	535.71	1245.30	535.71	1256.27	532.58	1237.47
49	588.97	1284.46	548.25	1251.57	552.94	1270.36	546.68	1254.70
56	599.94	1290.73	559.21	1253.13	562.34	1278.20	559.21	1259.40
63	607.77	1295.43	565.48	1256.27	573.31	1287.59	568.61	1264.10
70	614.04	1300.13	576.44	1262.53	582.71	1296.99		

77	618.73	1304.82	578.01	1267.23	584.27	1296.99
80	618.73	1307.96	579.57	1270.36	584.27	1298.56

Table 5.19 Density at different stage of conversion of wastes of 2[nd] set-up composting

	Density (kg/m^3)					
	Pile #1		Pile#2		Pile #3	
Days	Loose	Dense	Loose	Dense	Loose	Dense
0	333.65	867.79	352.44	891.29	338.35	869.36
7	383.77	1015.04	419.80	1065.16	410.40	1069.86
14	419.80	1102.76	455.83	1145.05	451.13	1170.11
21	463.66	1210.84	490.29	1250.00	491.85	1270.36
28	494.99	1286.03	515.35	1292.29	518.48	1287.59
35	524.75	1284.46	545.11	1301.69	541.98	1290.73
42	546.68	1287.59	563.91	1303.26	562.34	1295.43
49	557.64	1289.16	582.71	1306.39	568.61	1304.82
56	578.01	1290.73	588.97	1306.39	582.71	1306.39
63	590.54	1293.86	606.20	1307.96	592.11	1304.82

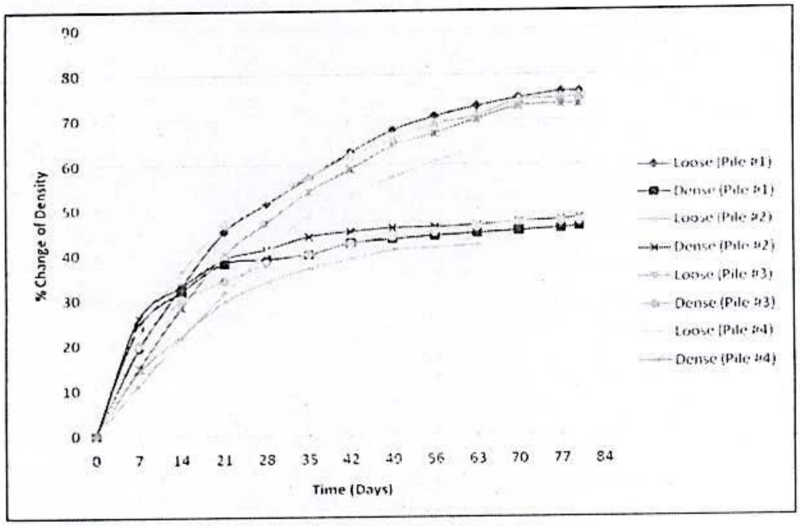


Figure 5.8 Density change of all compost pile at 1[st] set-up Composting

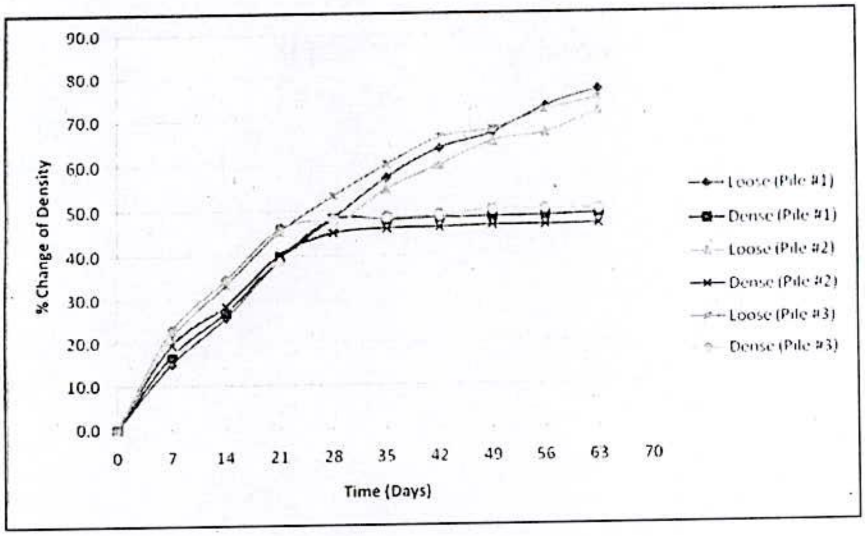


Figure 5.9 Density change of all compost pile at 2nd set-up Composting

5.7 Mass Reduction

Results of 1st set-up, 2nd set-up and 3rd set-up are shown in the following figure. From the figure 5.10, it is seen that the production of compost is varied from 25 to 39% of total input waste. In 2nd set-up the production of compost is much and that varies from 38 to 39%.

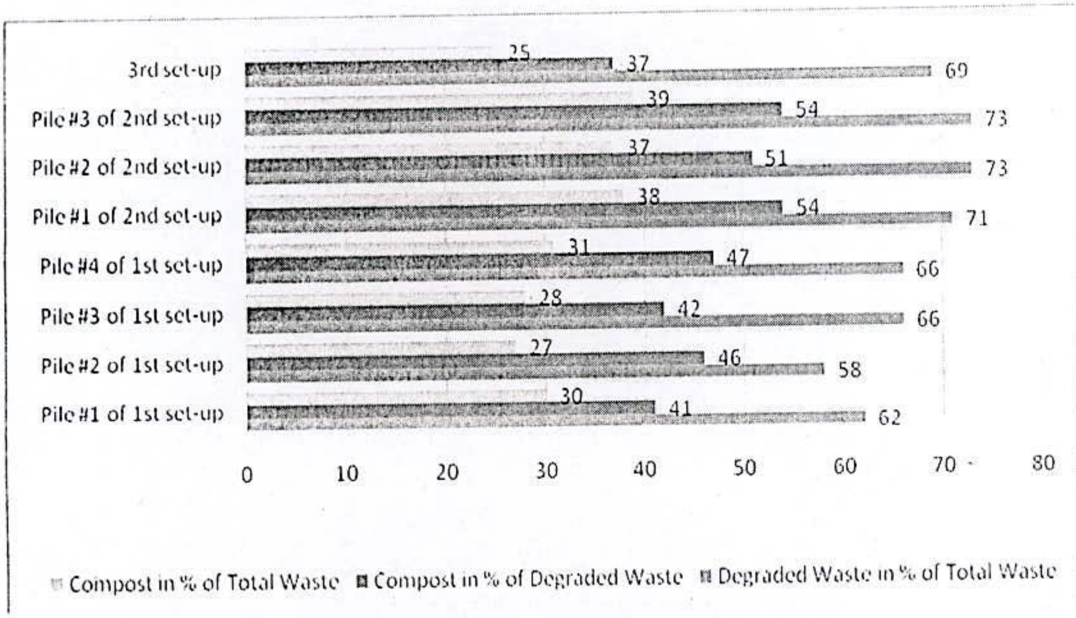


Figure 5.10 Mass reduction comparison of 1st and 2nd set-up

5.8 Properties of Final Compost

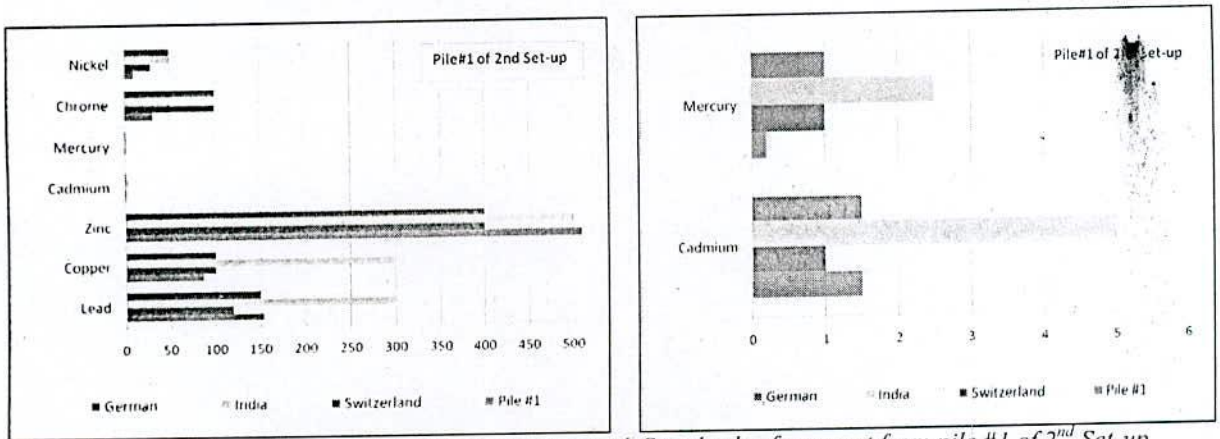
The measured values of various parameters of composts, sampled from 1st and 2nd set-up composting, are shown in Tables 5.20 and 5.21. From the Table 5.20 and 5.21, the Figure 5.11 and 5.12 can found where the heavy metals are compared with the various standards and each others.

Table 5.20 Quality of final composts of the 1st set-up composting

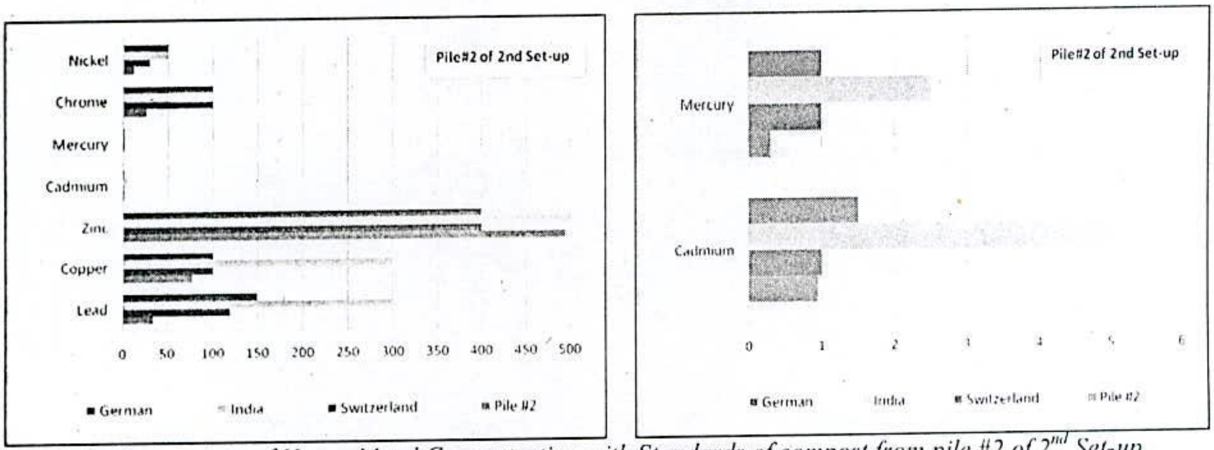
Parameters	Pile #1	Pile #2	Pile #3	Pile #4	Unit
Dry matter (DM)	55,35	61,85	79,45	56,5	Weight %
Loss on ignition/ volatile solids burn loss of DM	26,1	15,6	15,4	18	Weight % (DM)
Total C (TC) of DM	14	10	9	9	Weight % (DM)
Respiratory activity (AT_4)	3,5	2,5	1	2	g O/ kg
pH-Value	7,74	8,40	8,51	8,38	-
Salt content/ salinity	1,47	1,80	1,43	1,52	g/ 100 g
Total nitrogen	1,27	0,72	0,67	0,95	Weight %
Nitrate nitrogen	1165	547	535	594	mg/ kg
Ammonia nitrogen	73	64	59	72	mg/ kg
Potassium	1,15	1,06	1,02	1,24	Weight % as K_2O
Magnesium	1,51	1,47	1,46	1,48	Weight % as MgO
Phosphorus	2,25	1,55	1,54	1,84	Weight % as P_2O_5
Lead	22	17	30	92	mg/ kg
Copper	68	66	51	59	mg/ kg
Zinc	277	301	345	271	mg/ kg
Cadmium	0,35	0,3	< 0,2	0,5	mg/ kg
Mercury	< 0,1	< 0,1	< 0,1	< 0,1	mg/ kg
Chrome	20	18	20	20	mg/ kg
Nickel	9	9	11	11	mg/ kg

Table 5.21 Quality of final composts of the 2nd set-up composting

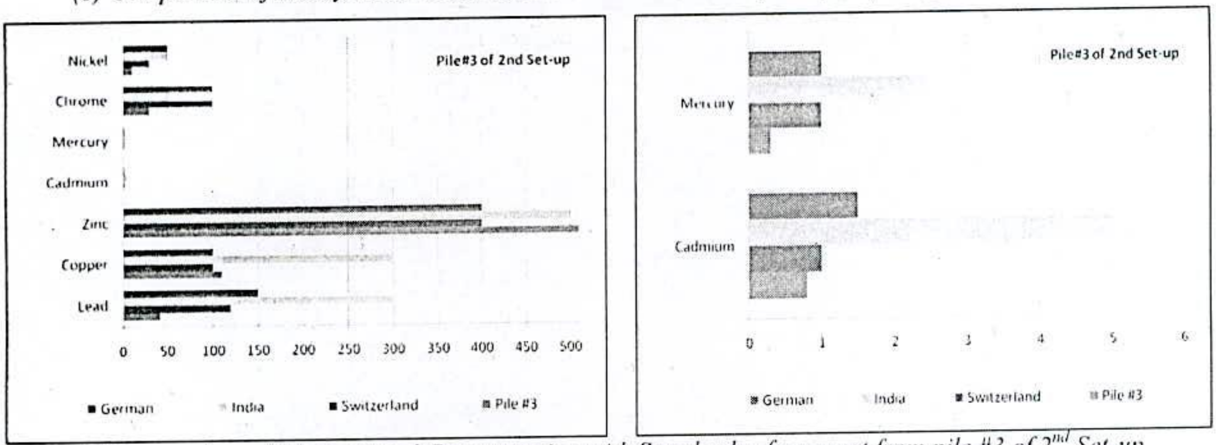
Parameters	Pile #1	Pile #2	Pile #3	Unit
Dry matter (DM)	61,4	70,8	74,7	Weight %
Loss on ignition/ volatile solids burn loss of DM	17,95	18,45	21,9	Weight % (DM)
Total C (TC) of DM	9,5	8,5	9,5	Weight % (DM)
Respiratory activity (AT_4)	4,5	7	3	g O/ kg
pH-Value	8,9	8,2	7,9	-
Salt content/ salinity	1,39	1,62	1,74	g/ 100 g
Total nitrogen	0,62	0,68	0,99	Weight %
Nitrate nitrogen	93	391	403	mg/ kg
Ammonia nitrogen	33,5	27,5	39,1	mg/ kg
Potassium	0,86	0,76	0,79	Weight % as K_2O
Magnesium	1,49	1,47	1,45	Weight % as MgO
Phosphorus	1,64	1,86	1,69	Weight % as P_2O_5
Lead	153	35	42	mg/ kg
Copper	87	78	110	mg/ kg
Zinc	516	495	564	mg/ kg
Cadmium	1,5	0,95	0,8	mg/ kg
Mercury	0,2	0,3	0,3	mg/ kg
Chrome	32	27	30	mg/ kg
Nickel	11	12	11	mg/ kg



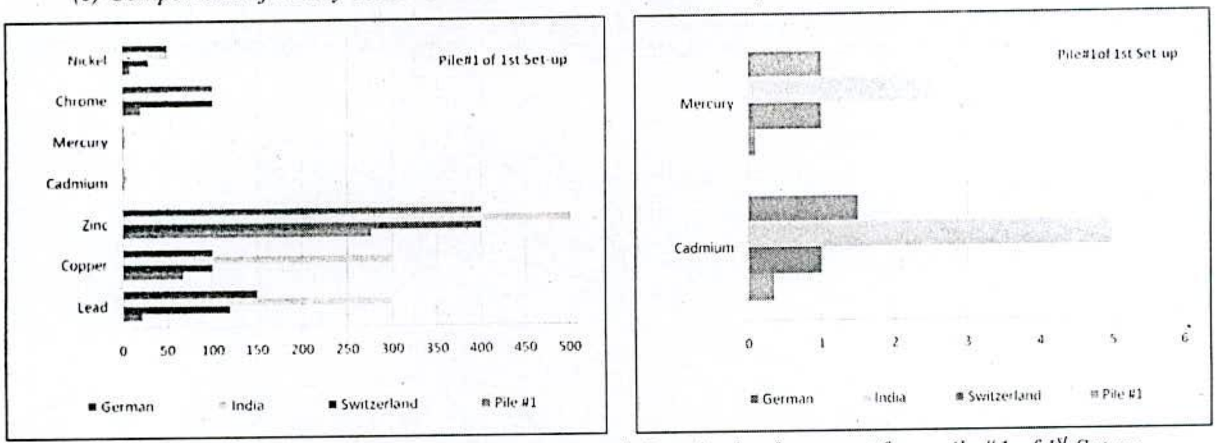
(a) Comparison of Heavy Metal Concentration with Standards of compost from pile #1 of 2nd Set-up



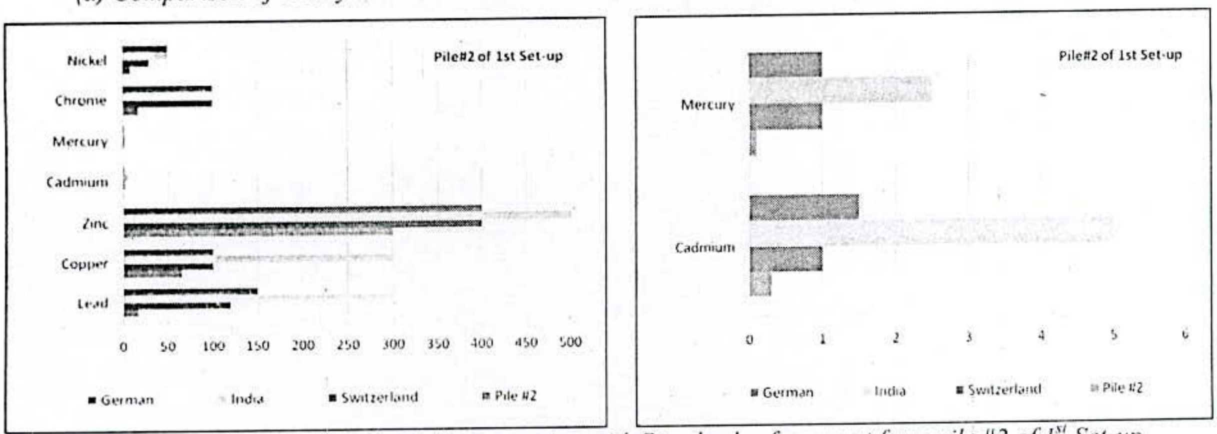
(b) Comparison of Heavy Metal Concentration with Standards of compost from pile #2 of 2nd Set-up



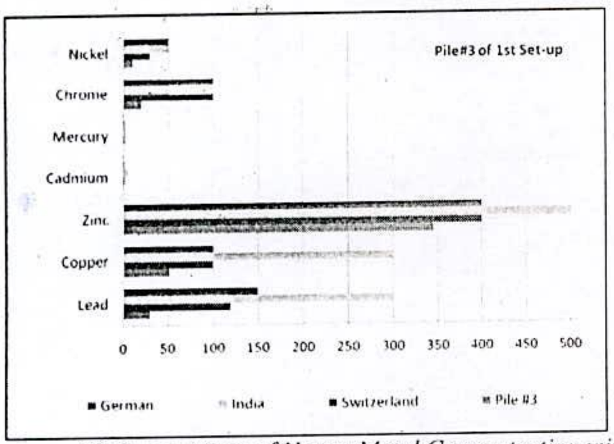
(c) Comparison of Heavy Metal Concentration with Standards of compost from pile #3 of 2nd Set-up

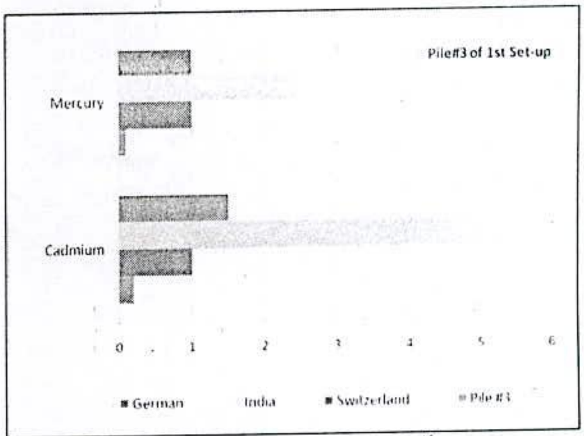


(d) Comparison of Heavy Metal Concentration with Standards of compost from pile #1 of 1st Set-up

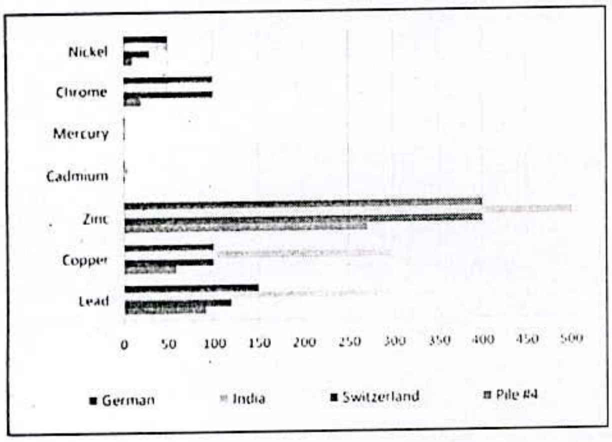


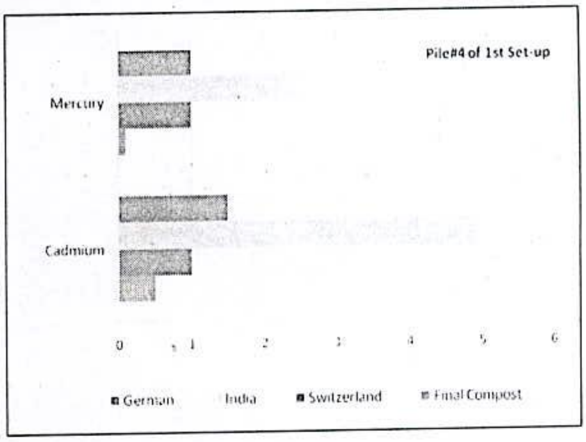
(e) Comparison of Heavy Metal Concentration with Standards of compost from pile #2 of 1st Set-up





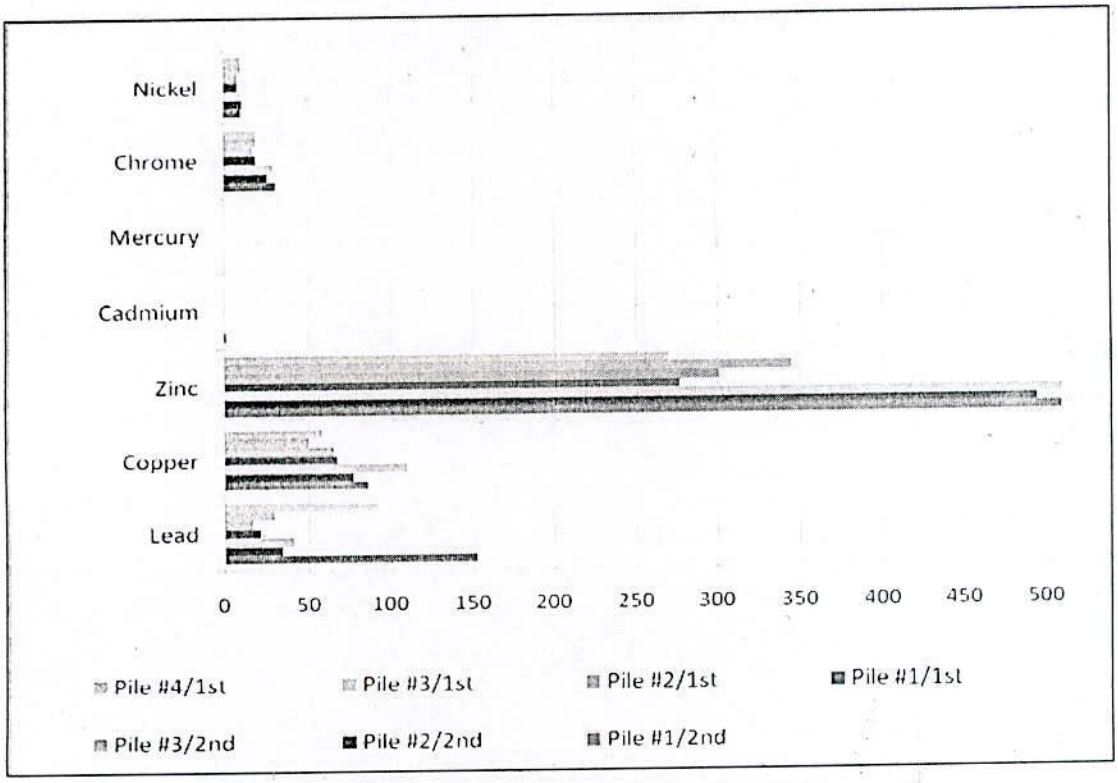
(f) Comparison of Heavy Metal Concentration with Standards of compost from pile #3 of 1st Set-up



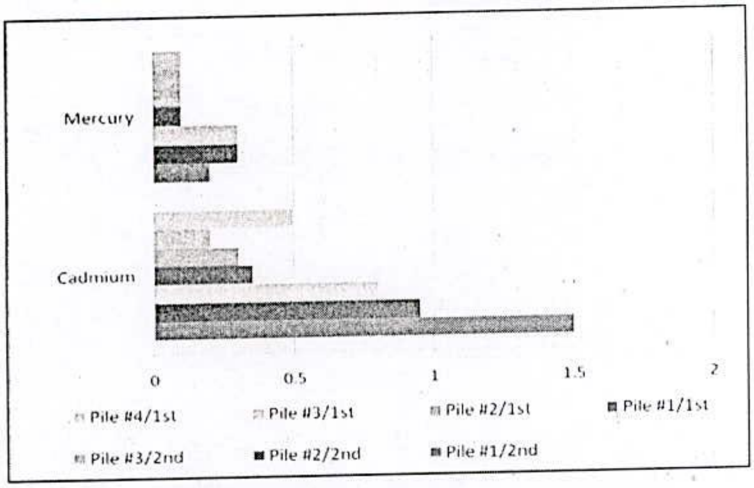


(a) Comparison of Heavy Metal Concentration with Standards of compost from pile #4 of 1st Set-up

Figure 5.11 Comparison of Heavy Metal Concentration with Standards



(a) Comparison of Nickel, Chrome, Zinc, Copper, Lead Concentration



(a) Comparison of Mercury and Cadmium Concentration

Figure 5.12 Comparison of Heavy Metal Concentration of all Composts from 1st set-up and 2nd set-up Composting

Presence of heavy metals at compost keeps an important role to negative impact on plant and also on environment. There is no standard for compost quality for Bangladesh. However, comparison can be performed with the standards for compost used in agriculture from Switzerland and India, which is given at a users' manual on composting published by Waste Concern (Enayetullah, et. al., 2006) and another standard of Germany, which given at the bio-waste ordinance of Germany.

The levels of heavy metals presence in the composts of 1st set-up satisfy the three standards but in case of 2nd set-up, only one standard (exclude Switzer and German standard) are satisfied. The increase of quantity of heavy metals may be due to less sorting and/or mixing of additives such as sawdust. Because sawdust is brought from the local wood industries where there is a possibility of contamination. However, it needs more investigation to make definite conclusions on the increase of heavy metals in 2nd set of composting.

5.9 Competency of Workers

The capacity of workers that means how much waste in an hour could handle by a worker of different steps of composting are given at the following table. Here the showing results are of female workers of Khulna region, whose are young to middle aged.

Table 5.22 Capacity of handle wastes at different steps of Composting

Step	Capacity (kg/h/person)
Receiving	2800
Sorting	200
Shredding	30
Mixing	280
Piling	1200
Turning	750
Maturation	750
Screening	280
Bagging	120

Note: capacity of workers for screening is also depends on the capacity of screener.

5.10 Capacity of Screening Systems

The capacity of two screening systems, which were used at demo compost plant, is given in the following figure 5.13. From the Figure 5.13, it is found that the Capacity of rotary screening system is about 2.4 times greater than the frame screening system.

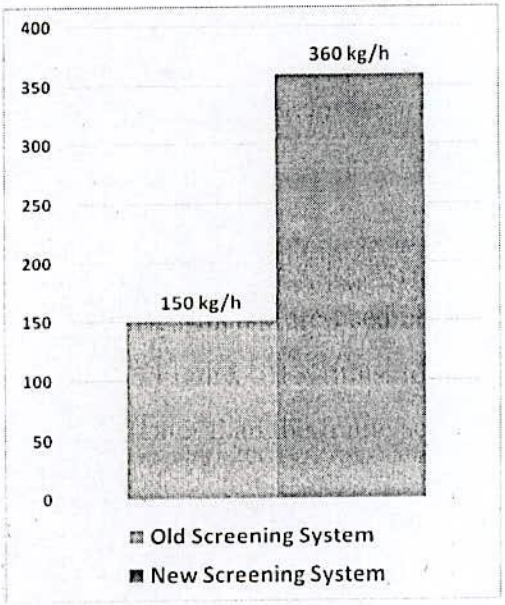


Figure 5.13 Comparison of the capacity of two screening system

5.11 Advantage of Rotary Screening System

- Production rate of compost from degraded waste is high in this screening system.
- Save the time in this system.
- Operation cost is low, because less labors are required than old system (2 people).
- This system is able to handle more material.
- Screen in this rotary screening system can sustain more time than old system, since wastes are screened by centrifugal force.
- In this system, two steps of screening are done at a time.
- By this system, health hazards of workers can be reduced.

5.12 Constraints of Rotary Screening System

- Construction cost of rotary screening system is high.
- Inlet of this system is higher than affordable by workers.
- Since wastes are wet, they clogged the inlet.
- After screening wastes, screen gets clogged. It is not so easy for workers to clean screen by hand as wooden frame screening system. After drying the clogged wastes, it is clean using fire.
- Since it is fixed and heavy, it can not be easy to move.

- Optimum rotation speed is required for better performance, which can not be controlled.

- Sometimes workers can remove small materials from compost during the screening using wooden frame screening system, which can not be perform in this new system.

- It takes a space at plant when it is not working.

5.13 Field Investigation

In this field investigation, the perforated PVC pipe was used as an aerator at compost piles to increase aeration for its chimney effect. From Figures 5.1, 5.2 and 5.3, it is found that, there is no significant benefits at temperature curve. Stability Index (SI) of the composts from this pile are same with SI of other composts (Table 5.16 and 5.17) and the quality are not different significantly from others (Tables 5.20 and 5.21). Moreover, it is more difficult to place properly into the compost pile than horizontal frame and there is also a possibility of damage of aerator during turning.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The present study can be concluded as the followings:

- Additives with required types and quality should be mixed properly with the solid wastes to shortening the composting period as well as to achieve the necessary quality of the compost to satisfy the users' requirements.

- Since turning is an important factor to reduce the period of composting and to produce stable and harmless compost, it should perform at the designated interval. Because of hard working and time consuming nature, it is strongly recommended to introduce mechanical equipment for turning.

- Traditional screening system presently practiced in the compost plant of Bangladesh causes severe health hazards to the staffs working in the compost plant. This traditional system can easily be replaced by an improved locally fabricated mechanical means rotary screening system driven manually. The system evolved in this study is environment-friendly, cost effective and around 2.4 times efficient than the existing one.

- The laboratory test results revealed that the compost produced in Bangladesh from the MSW is very much safe for use as a soil conditioner since it contains very negligible amount of heavy metals components. Moreover, the compost contains necessary amount of chemical and physical components.

- Routine evaluation of the quality of compost is to be performed to meet the requirements of the buyers and to ensure the sustainability of the compost plant.

6.2 Recommendations

For further study and research to develop appropriate composting technology for Bangladesh, the following aspects can be the interested topics for future researchers

I. Modification of traditional Bamboo aerator is required for proper aeration to reduce the required number of turning and to guide the temperature as standard.

II. Further investigation on the mixing proportion of admixtures is needed to control the quality of compost and reduce the composting time, which is very much desirable.

III. Study on admixture types is also needed to guide composting process and to achieve the required quality of the compost. Organic and inorganic materials should be classified with respect to quality and quality to ensure efficient admixture and desired quality of the compost.

IV. Modification of the developed rotary screening system is necessary to overcome the existing drawbacks thus make system more efficient, environment-friendly and sustainable.

V. Study on various microbes which are not present in waste should be performed to accelerate composting process and introduce with new direction of composting.

REFERENCES

Alamgir, M., McDonald, C., Roehl, K. E. and Ahsan, A. 2005. *Integrated Management and Safe Disposal of Municipal Solid Waste in Least Developed Asian Countries-A Feasibility Study* WasteSafe, ISBN 984-32-3003-5, KUET, Bangladesh

Ahmed M. F. and Rahman M. M. 2000. *Water Supply & Sanitation: Rural and Low-income Urban Communities*, ITN-Bangladesh, ISBN 984-31-0936-8, Bangladesh

Ali M. 2004. *Sustainable Composting: Case studies and guidelines for developing countries*, WEDC, ISBN Paperback 1 84380 071 3, Loughborough University, UK

Bachert C., Bidlingmaier W. and Surapong W. 2008. *Open Windrow Composting Manual*, ORBIT e. V., Weimar, ISBN , Germany.

Bari, Q. H. and Koenig, A. 2002. *Measuring Solid waste Compost Maturity: A Review and Practice*. International Conference on Bangladesh Environment-2002, 19-21 December, 2002, Dhaka, Bangladesh

Bari, Q. H., Koenig, A. and Hassan, K. M. 2001. *Forced Aeration Composting for Urban Solid Waste*, 45th Annual General Meeting of the Institute of Engineers, Bangladesh

Brinton, W.F., Evans, E., Droffner, M.L. and Brinton, R.B. 1995. *Standardized Test for evaluation of Compost Self-Heating*. BioCycle, Vol. 36, No. 11, pp. 64-68.

Cooperband L. 2002. *The Art and Science of Composting: A resource for farmers and compost producers*, University of Wisconsin-Madison, Center for Integrated Agricultural Systems, March 29, 2002.

Diaz, L. F., Savage, G. M., Eggerth, L. L. and Golueke, C. G., 1993. *Composting and Recycling of Municipal Solid Waste*, Lewis Publishers, Inc., Ann Arbor, MI

Enayetullah, I., Sinha, A. H. M. M., Rothenberger, S. and Zurbrügg C. 2006. *Decentralised Composting for Cities of Low- and Middle- Income Countries,* Waste Concern, ISBN 978-3-906484-36-5

Epstein, E. (1997). The Science of Composting. Technomic Publishing, Lancaster.

Golueke, C. G. And McGauhey, P. H., 1955. *Reclamation of Municipal Refuse by Composting,* Technical Bulletin 9, Sanitary Engineering Research Laboratory, University of California, Berkeley.

Golueke, C. G., 1972. *Composting : A Study of the Porcess and Its Principles,* Rodale Press, Inc., Emmaus, PA.

Hasan K. M. M., Bari Q. H., Alamgir, M., Martens J. and Haedrich G. 2008. *Demo Compost Plant in Khulna of Bangladesh: Search for Acceptable Composting Technology,* 6th International Conference ORBIT 2008, 13-15 October 2008, Wageningen, The Netherlands, Paper ID 247.

http://edugreen.teri.res.in/explore/solwaste

http://ourhouse.ninemsn.com.au/ourhouse/factsheets/db/tips/02/210.asp

http://web.extension.uiuc.edu/homecompost/history.html

http://www.edie.net/products/view_entry.asp?id=1756

Iannotti, D.A., Grebus, M.E., Toth, B.L., Madden, L.V. and Hoitink, H.A.J. (1994). Oxygen Respirometry to Assess Stability and Maturity of Composted Municipal Solid Waste. J.Environ. Quality, 23: 1177-1183.

Koenig, A. and Bari, Q. H. 2000. *Application of Self-Heating Test for Indirect Estimation of Respirometric Activity of Compost: Theory and Practice.* Compost Science & Utilizaion, Vol. 8, No. 2, pp. 99-107

Ludwig C., Hellweg S., Stucki S. (ed). 2003. *Municipal Solid Waste Management: Strategies and Technologies for Sustainable Solutions*, Springer-Verlag Berlin Heidelberg, ISBN 3-540-44100-X, Germany

NCA (1964) *"Composting Fruit and Vegetable Refuse, Part II, Investigation of Composting as a means of disposing of Fruit Waste Solids,"* Progress Report, National Canners Association Research Foundation, Washington, DC.

Polprasert, C. 1989. *Organice Waste Recycling*, John Wiley & Sons, Chichester, UK

Raabe R. D. Website. *The Rapid Composting Method, Cooperative Extension University of California, Division of Agriculture and Natural Resources*, Leaflet 21251, http://vric.ucdavis.edu/pdf/compost_rapidcompost.pdf

Sarwar, S. G., Hasan, K. M. M., Alamgir, M., Bari, Q. H., 2008. *Performance of a Small Scale Compost Plant: A Case Study*, National Seminar on Solid Waste Management-WasteSafe 2008, Khulna, Bangladesh, pp. 279-287.

Seasay A. A.,Lasaridi, K. E., and Stentiford, E. I., 1998. *Aerated Static Pile Composting of Municipal Solid Waste (MSW): A Comparison of Positive Pressure Aeration with Hybrid Positive and Negative Aeration,* Waste Management and Research, Vol. 16, No. 3, pp. 264-272.

Skitt J. 1972. *Disposal of Refuse and Other Waste*, Charles Knight & Co. Ltd, London

Tchobanoglous, G. and Kreith, F. 2002. *Hand book of Solid Waste Management-2nd edition,* McGRAW-HILL, ISBN 0-07-135623-1, United State of America

WasteSafe 2005. *Integrated Management and Safe Disposal of Municipal Solid Waste in Least Developed Asian countries: A feasibility study.* Alamgir, M., McDonald; C., Roehl; K.E. and Ahsan; M., Edited, WasteSafe, Department of Civil Engineering, KUET, Bangladesh.