Analysis of Aerobic Digestion Process of Domestic Solid Waste

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ABSTRACT

Composting is generally achieved by converting solid waste into stable humus like materials via biodegradation of putrescible organic materials generally in presence of oxygen. The microorganisms involved in solid waste composting include facultative and strict aerobic bacteria, fungi and actinomycetes. The end product, the compost, can be used as soil conditioner. It can divert a significant portion of organic waste from municipal collection services and from final disposal site, and therefore, enhances both economic and environmental sustainability of waste management system.

In this work, barrel type composting was carried out to identify the proper range of operating conditions for thermophilic composting of domestic solid waste consisting of moisture content, temperature and time. A perforated pipe is inserted in the barrels to make the digestion process aerobic. Then the various environmental parameters of composting are observed during the aerobic digestion processes to assess the parameters. Hence, the effects of operating conditions on thermophilic composting of domestic waste be determined and compared with the information from literature survey. Thereafter, an empirical model of thermophilic composting also be derived by fitting in experimental data. The regression values of different parametric studies are determined using a software SPSS for Windows 10.0.5 and analyzed statistically to fit the empirical model. Furthermore the derived model is confirmed by F-test. The empirical model developed, can be effectively used to predict and assess the operating conditions for thermophilic composting of domestic waste in a natural environment for designing a composting plant.

DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma (except for publication).

(Abdullah Al-Muyeed)

Name of the Candidate

DEDICATED TO MY PARENTS

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ABBREVIATIONS

BARC	:	Bangladesh Agricultural Research Center.
BBS	:	Bangladesh Bureau of Statistics.
BCSIR	:	Bangladesh Council of Scientific and Industrial Research.
CBO	:	Community Based Organization.
DMDP	:	Dhaka Metropolitan Development Program.
DSW	:	Domestic Solid Waste
HHW	:	Household Hazardous Waste
IRR	:	Internal Rate of Return
LGED	:	Local Government Engineering Department
MC	:	Moisture Content.
MSW	:	Municipal Solid Waste.
NGO	:	Non-Government Organization.
RDF	:	Refuse Derived Fuel
SW	:	Solid Waste.

SWM	:	Solid Waste Management.
UNCED	:	United Nations Conference of Environment and Development
W C	:	Waste Concern

CHAPTER ONE

INTRODUCTION

1.1 GENERAL

A major issue facing modern society is waste management what is produced. A growing emphasis has been placed on the three R's: Reduce, Reuse, and Recycle. Composting provides a means of accomplishing all three of the R's. Through composting the amount of garbage sent to the landfill is reduced, the organic matter is reused rather than dumped, and it is recycled into a useful soil amendment.

Natural ecosystems have a proven method of breaking down organic materials into a useful end-product: the decomposers found within the food chain break down nature's organic waste and turn it into humus, the organic component of soil.

Composting is a way of harnessing the natural process of decomposition to speed up the decay of waste. The history of composting dates back to the history of early agriculture. Many researchers find that composting is as much of an art as a science. Recent concern about managing wastes and producing food in an environmentally sound manner has led to a renewed interest in small-scale, backyard composting as well as an interest in developing large-scale, commercial and municipal composting systems.

A solid waste management system is an interrelated system of appropriate technologies and mechanisms involved in the generation, collection, storage, processing, transfer or transport and disposal of solid waste designed to reduce waste at the lowest possible cost. This should also minimize risk to the health of the people and the environment as a whole.

Studies conducted by Rahman and Sutradhar (2002) reveal that major portion (80-90%) of domestic solid waste in Dhaka city and its surrounding place is organic. Presence of high organic matter in the waste suggests that composting could be a viable option for disposal of solid waste in Bangladesh. The main objectives of composting are to decompose organic fraction of waste to: reduce its volume, weight and moisture content, minimize odor; decrease pathogens and increase potential nutrients for agricultural application. This process may minimize spread of diseases because of the destruction of some pathogens and parasites at elevated (composting) temperature. Therefore, presently composting is emerging to be a popular solid waste management alternative both in developed and developing countries. This research project proposes to look into these aspects of solid waste management with respect to solid waste generation in Dhaka city in general and Gazipur area in particular.

It is apparent from the field survey that most of the implementing authorities in Bangladesh are promoting this technology, without proper attention to research and development to renovate and optimize the design to make them more suitable to the local conditions. This study is aimed to assess the aerobic digestion process of domestic waste, by which an empirical model can be established to optimize composting design plants in Bangladesh.

1.2 OBJECTIVES OF THE STUDY

This study is aimed at identifying the management problems of solid waste and brings into discussion the recycle process of huge quantities of organic waste to composting.

The following are the major objectives of this thesis:

a) To evaluate the characteristics of Aerobic digestion of solid waste.
b) To evaluate the impacts of different environmental factors on composting.
c) To determine the rate of volume reduction in composting process.
d) Empirical modeling of environmental parameters of composting process to optimize its design.

1.3 OUTLINE OF METHODOLOGY

The methodology to be applied in this study is literature review of the past studies, sample collection of solid waste, quantitative and qualitative analysis of solid waste of Gazipur area, assessment of the various physical controlling parameters for composting process in the context of our country, which are stated below :

i. Assessment of the characteristics of solid waste used for composting experiments.
ii. Assessment of different environmental parameters (e,g, moisture content, temperature)

those affect composting process.

iii. Design of home composting plants on the basis of available information from literatures

And field survey.

iv. Observation of different Parameters during Aerobic digestion of solid waste.

1.4 ORGANIZATION OF THE THESIS

The thesis presents literature review, data analysis and findings of the study in six chapters and five annexure, as shown below. In addition, a bibliography of related publications has also been presented.

Chapter 1: includes general introduction, objectives and methodology of the study.

Chapter 2: includes literature review covering details of composting, their various control parameters and microbiology of composting. Brief reviews of relevant literature are discussed.

Chapter 3: experimental works which are done in the thesis are described in this chapter.

Chapter 4: presents the analysis of various physical parameters from the experiment and hence an empirical model has been developed from the experimental data and confirmed by statistical analysis.

Chapter 5: presents a general discussion on the findings of the study identifies precise conclusions and provides a number of recommendations for future study.

References: at the end of the main chapters provides a list of relevant publications and reports, which may be useful for any future study in this context.

Abbreviations: provides a list of abbreviations used in this thesis.

Annexure : provides Tables showing Experimental data of thermophilic composting..

CHAPTER TWO

LITERATURE REVIEW

2.1 PHYSICAL PROCESSING OF SOLID WASTE COMPOSTING

The recent upsurge of interest in composting the organic fractions of municipal solid waste (MSW) builds on largely successful efforts with composting yard trimmings, agricultural wastes, and sewage sludge. While experience with these other materials is helpful in considering and MSW composting program, there are a number of challenges unique to MSW which need to be addressed. MSW contains materials which vary widely in size, moisture, and nutrient content, and the organic fractions can be mixed with varying degrees of non-compostable wastes and possibly hazardous constituents. Manufacturing a marketable compost product from this material requires a range of physical processing technologies in addition to the biological process management common to other types of composting.

Four tasks are central to the design of a modern MSW composting system: collection, contaminant separation, sizing and mixing, and biological decomposition. The first of the preprocessing tasks, collection, largely determines the processing requirements of the remaining tasks because they must be tailored to the characteristics of the incoming waste. Separation processes at the composting facility generate recyclable and reject streams, usually at several places in the process. Size reduction increases the surface area of the organic wastes, enhancing opportunities for biological activity, while mixing ensures that nutrients, moisture and oxygen are adequate throughout the material. Options for accomplishing these first three tasks are described below.

2.1.1 COLLECTION

If we take the perspective that composting is a manufacturing process, the ideal input material for a compost product is a consistent and clean organic waste. This ideal is rarely reached, and even leaf composting facilities receive tennis balls, plastic bags, and street sweepings which can contain a variety of contaminants such as motor oil and asbestos. Moving across the collection spectrum from leaves and grass to "biowaste" (such as food scraps, yard trimmings, and selected other organics like soiled paper) to totally mixed MSW, the types and volumes of non compostable contaminants increase. These include visible materials such as plastic and glass, and chemical contaminants, such as Household Hazardous Wastes (HHW). Both physical and chemical contaminants can have a negative impact on the marketability of the finished product, and their removal forms a large part of the expense of modern MSW composting facilities. Some composting programs require source separation of organic compostables by participating residents and businesses, while others accept a mixed stream and separate non-compostables at a centralized facility. Separate collection of compostable materials programs can include everything from yard and food waste to soiled paper products, and in some cases have recovered 45 to 50 percent of the entire solid waste stream for composting. However, even when organic compostables are separately collected, a small fraction of non-compostable wastes will need to be removed at the composting facility. Educational programs are a critical aspect of source separated composting systems, since such programs depend on residents to accomplish much of the separation. Composting programs which accept a mixed waste stream accept material more or less as it is currently collected, relying on the facility separation techniques described below. One important modification to traditional collection techniques is the establishment of a HHW collection program. To be effective at reducing the contaminants of concern in MSW compost, such programs must emphasize heavy metal sources such as batteries and consumer electronics. The remaining mixed waste (less any separately collected recyclables and HHW) then serves as feedstock for the composting facility, where centralized separation of non compostable materials will occur. With this approach, 60 to 70 percent of the solid waste stream is typically processed into compost. The remaining 30 to 40 percent includes recyclables as well as rejects destined for the landfill or an incinerator and landfill. There are several trade-offs between source separation and centralized separation of compostables. It is clear that source separation can produce a higher quality, less contaminated compost, as well as maximize the recycling of glass and paper. And while source separation is generally less convenient for the waste generator, pilot programs are finding that many generators like to do it. However, two other important factors, the overall system cost and the quantities of materials recovered for recycling and composting, have not yet been adequately researched or evaluated.

2.1.2 SEPARATION

In composting systems there are three objectives for materials separation:

1) recover recyclable or combustible materials as marketable by-products,

2) reduce the levels of visible inert materials (e.g., plastics and glass), and

3) reduce the levels of chemical contaminants (e.g., heavy metals and HHW).

Table 2.1 : MSW Composting Centralized Separation Technologies

TECHNOLOGY	MATERIALS TARGETED
Screening	Large: film plastics, large paper, cardboard misc. Mid-sized: recyclables, organics, misc. Fines: organics metal fragments, misc
Hand Picking	Recyclables, inerts and chemical contaminants
Magnetic Separation	Ferrous plus contaminants associated with ferrous metal
Eddy Current Separation	Non-ferrous metals
Air Classification	Lights: paper, plastic Heavies: metals, glass, organics
Wet Separation	Floats: organics, misc Sinks: metals, glass, gravel, misc.
Ballistic Separation	Light: plastic, undecomposed paper Medium: compost Heavy: metals, glass, gravel, misc.

Many of the separation technologies now applied to MSW composting were originally developed to recover recyclable or combustible materials from solid waste. While some of these technologies have been adapted for reduction of inerts, they have rarely been optimized for reducing chemical contaminant levels. Reduction of inerts and chemical contamination will be highlighted in the discussion below. A wide range of technologies are available (Table 1), and many facilities use a sequence of steps employing different processes. While this discussion attempts to cover these technologies in a logical sequence of processing steps, individual facilities may omit some options or may choose to arrange them in a different order. Facility designers can select among them based on expected feedstock characteristics, finished product quality specifications, and the options for marketing separated by-products. For recovered recyclables, as with the compost product itself, a knowledge of local market conditions and specifications should be central to facility design. Many of these technologies are mechanically sophisticated, but for the reduction of chemical contaminants the most effective systems use human beings. While machines can do a reasonably good job of separating by size, density, or electromagnetic characteristics, we have yet to invent a pattern recognition device as good as the human brain. Manual separation can occur at several points in the process, starting at the tipping floor where large bulky items such as mat-tresses, carpets, appliances and hazardous materials such as pro-pane cannisters are removed.

Screening: Most MSW composting facilities first convey the waste in to a bag opener and screen or trommel to separate different sizes of waste (Figure 2.1). Fine

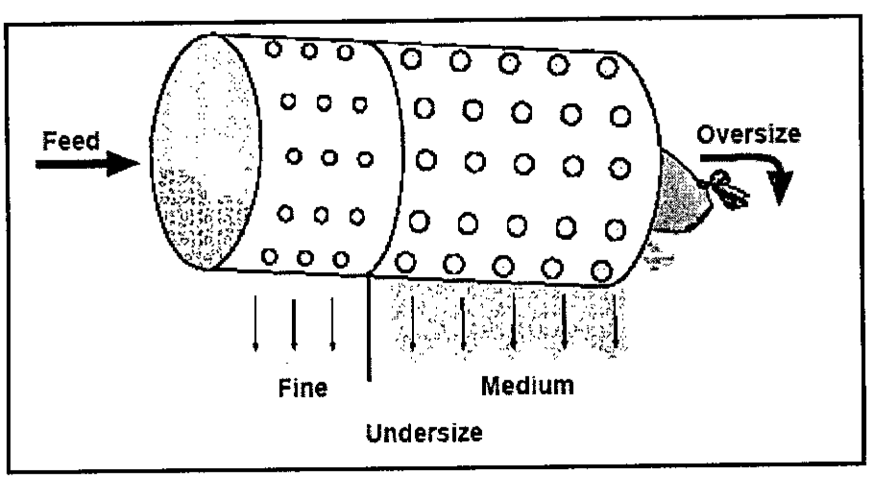


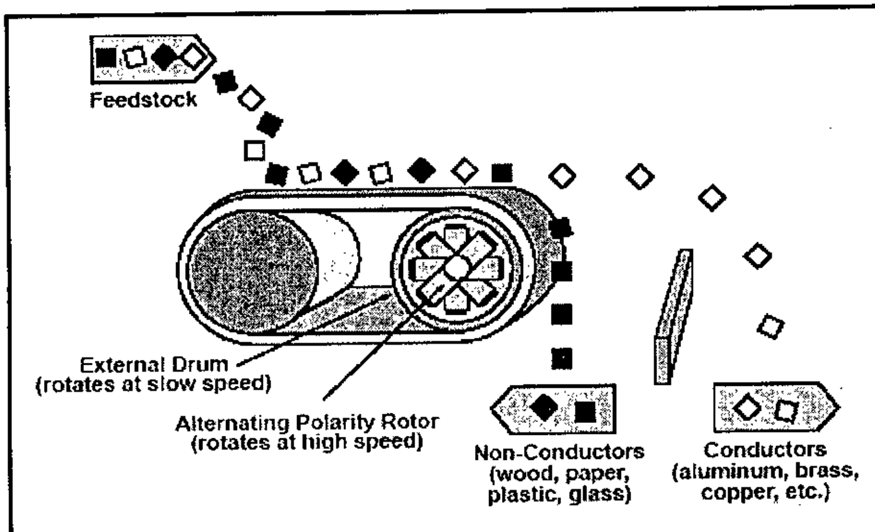
Figure 2.1: Trommel

materials, including soil, grit, and much of the organic wastes, fall through the screen as "unders". Plastic films and large paper products are retained on the screen as "overs" and may possibly be recycled or marketed as a refuse derived fuel (RDF), which is burned for energy recovery. But the main purpose of size segregation in a composting plant is to facilitate further separation. It is much easier for either people or machines to further separate materials of a similar size, as small items are not buried under large ones. Size fractionation also takes advantage of the size distribution properties of different waste components, generating streams in which certain recyclables or contaminants are concentrated.

Manual Separation: With materials segregated to a relatively uniform size, it becomes much more practical to hand separate recyclables and contaminants as they move along conveyor lines. As manual separation of MSW can be an unpleasant task, worker comfort and safety are very important. Ergonomic design can help workers function at their best, and issues such as conveyor speed, reach, placement of containers, flooring material, lighting, ventilation and dust control should all be considered. Here, as throughout the plant, it is recommended that workers wear safety glasses, gloves and adequate clothing to protect against injury from sharp objects, and hearing and respiratory protection wherever appropriate.

Conveyors and other materials handling machinery are critical to the operation of a plant. While this equipment may seem mundane, proper materials handling can minimize downtime and cleanup, and contribute to the overall efficiency of the facility. Steady materials flow will improve the efficiency of all the separation devices described below.

Magnetic Separation: As materials are conveyed from one separation system to another, the conveyors can utilize magnetic belts, rollers or overhead magnets to separate the ferrous metals from the rest of the stream. Magnetic separation efficiency is sensitive to the depth of waste, as small ferrous items will not stick to the magnet if they are buried in non-ferrous materials, while larger ferrous items can drag non-ferrous items like pa-per and plastic along. Air classification to remove the light paper and plastic fractions prior to magnetic separation minimizes the contaminants in the scrap ferrous. Pre-shredding and screening can also enhance ferrous recovery. Because magnetic separation is relatively inexpensive, it can sometimes be found at several locations in the composting facility. A minimum of two stages of magnetic separation are usually needed to achieve efficient ferrous recovery. Magnetic separation is effective with iron and most steel, but does not separate aluminum, copper, and other non-ferrous metals. Consumer electronics can be difficult to separate magnetically, depending on the ratio of ferrous to non-ferrous materials. Eddy current separation systems have been developed to separate non-ferrous metals. This technology works by exerting repulsive forces on electrically conductive materials. These systems should be located after magnetic separation to minimize contamination by ferrous materials. Aluminum is the primary metal recovered from MSW, although some copper and brass will also be separated. Cans literally jump off the conveyor into a waiting bin (Figure 2.2). Eddy separators, while they do not achieve perfect removal of aluminum, do produce a relatively marketable aluminum by-product.



Adapted with permission from *Eriez Magnetics*

Figure 2.2 : Eddy Current Separator

Air classification is an additional separation technology used in some MSW composting facilities, and is commonly used to generate a marketable RDF. This technology has been used in the combustion industry for many years. The heart of an air classification system is an air column or "throat", into which the waste stream is fed at a gradual rate. The air column is usually oriented vertically. A large blower sucks air up through the throat, carrying light materials such as paper and plastic, which then enter a cyclone separator where they loose velocity and drop out of the air stream. Heavier materials, such as metal, glass, and food waste, fall directly out of the throat (Figure 2.3). These two streams tend to be different sizes as well as densities, facilitating further separation. Glass and metal can be sorted out of the heavy fraction by systems such as the wet separator described below. The light fraction can be marketed directly as an RDF, or sorted for recyclable paper or plastic prior to composting.

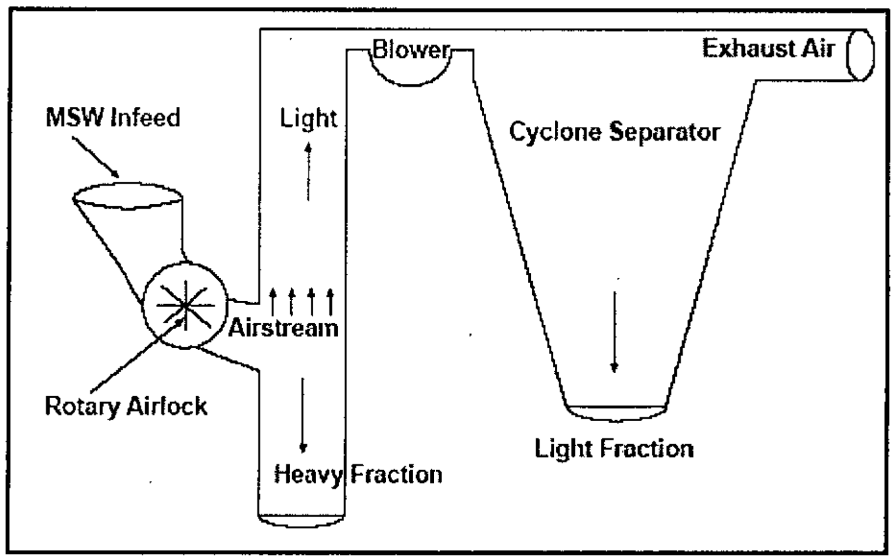


Figure 2.3 : Air Classification

2.2 COMPOSTING METHODS

Commonly used composting methods are:

a) Windrow composting
b) Aerated static pile composting.
c) In-vessel composting systems.
d) Vermi-Culture and Vermi composting
e) Barrel type Composting

2.2.1 Windrow Composting

Windrow composting is one of the oldest methods of composting. In its simplest form, a windrow compost system can be constructed by forming the organic material to be composted into windrows 8 to 10 ft high by 20 to 25 feet wide at base (Tchobanoglous 1993). A minimal system could use a front-end loader to turn the windrow once per year. While such a minimal system would work, it could take up to three to five years for complete degradation. Also such a system would probably emit objectionable odors, as parts of the windrow will likely be anaerobic. A high-rate windrow composting system employs windrows with a smaller cross section, typically 6 to 7 ft high by 14 to 16 ft wide. The actual dimensions of the windrows depend on the type of equipment that will be used to turn the composting wastes. Before the windrows are formed organic material is processed by shredding and screening it to approximately 1 to 3 in and the moisture content is adjusted to 50 to 60 percent. High-rate systems are turned up to twice per week while the temperature is maintained at or slightly above 131^0F (55^0C). Turning of the windrows is often accompanied by the release of offensive odors. Complete composting can be accomplished in three to four weeks. After the turning period, the compost is allowed to cure for an additional three to four weeks without turning. During the curing period, residual decomposable organic materials are further reduced by fungi and actinomycetes.

2.2.2 Aerated Static Pile Composting

The aerated static pile composting process was developed by the U.S. Department of Agriculture Agricultural Research service Experimental Station at Beltsville, Maryland; thus, the process is sometimes referred to as the Beltsville or ARS process. Originally developed for the aerobic composting of wastewater sludge, the process can be used the compost a wide variety of organic wastes including yard

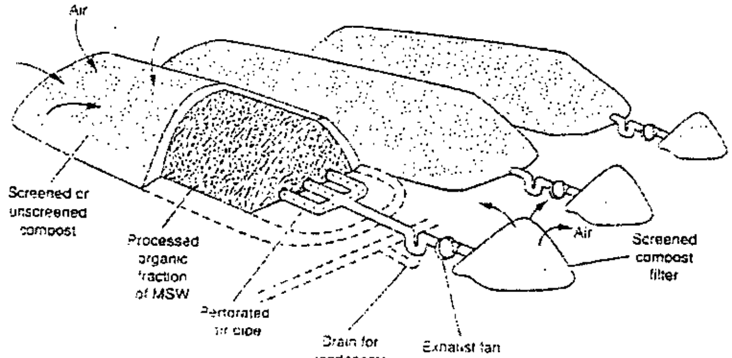


Figure 2.4: Aerated Static Pile Composting System (Tchnobanoglous 1993)

waste or separated MSW. The aerated static pile system, as shown in Fig. 2.4, consists of a grid of aeration or exhaust piping over which the processed organic fraction of MSW is placed. Typical pile heights are about 7 to 8 ft (2 to 2.5m). A layer of screened compost is often placed on top of the newly formed pile for insulation and odor control.

Each pile is usually provided with an individual blower for more effective aeration control. Disposable corrugated plastic drainage pipe is used commonly for air supply. Air is introduced to provide the oxygen needed for biological conversion and to control the temperature within the pile. Blower operation is typically controlled by a timer or in some systems by a microcomputer to match a specific temperature profile. The material is composted for a period of three to four weeks. The material is then cured for a period of four weeks or longer. Shredding and screening of the cured compost usually is done to improve the quality of the final product. For improved process and odor control, all or significant portions of the system in newer facilities are covered or enclosed.

2.2.3 In-Vessel Composting Systems

In-vessel composting is accomplished inside an enclosed container or vessel (Tchobanoglous 1993). Every imaginable type of vessel has been used as a reactor in these systems, including vertical towers, horizontal rectangular and circular tanks, and circular rotating tanks. In-vessel composting systems can be divided into two major categories: plug flow and dynamic (agitated bed). In plug flow systems, the relationship between particles in the composting mass stays the same throughout the process, and the system operates on a first-in, first-out principle. In a dynamic system, the composting material is mixed mechanically during the processing.

Mechanical systems are designed to minimize odors and process time by controlling environmental conditions such as air flow, temperature, and oxygen concentration. The popularity of in-vessel composting systems has increased in recent years. Reasons for this increased use are process and odor control, faster throughput, lower labor costs, and smaller area requirements. The detention time for in-vessel systems varies from 1 to 2 weeks, but virtually all systems employ a 4- to 12 weeks curing period after the active composting period.

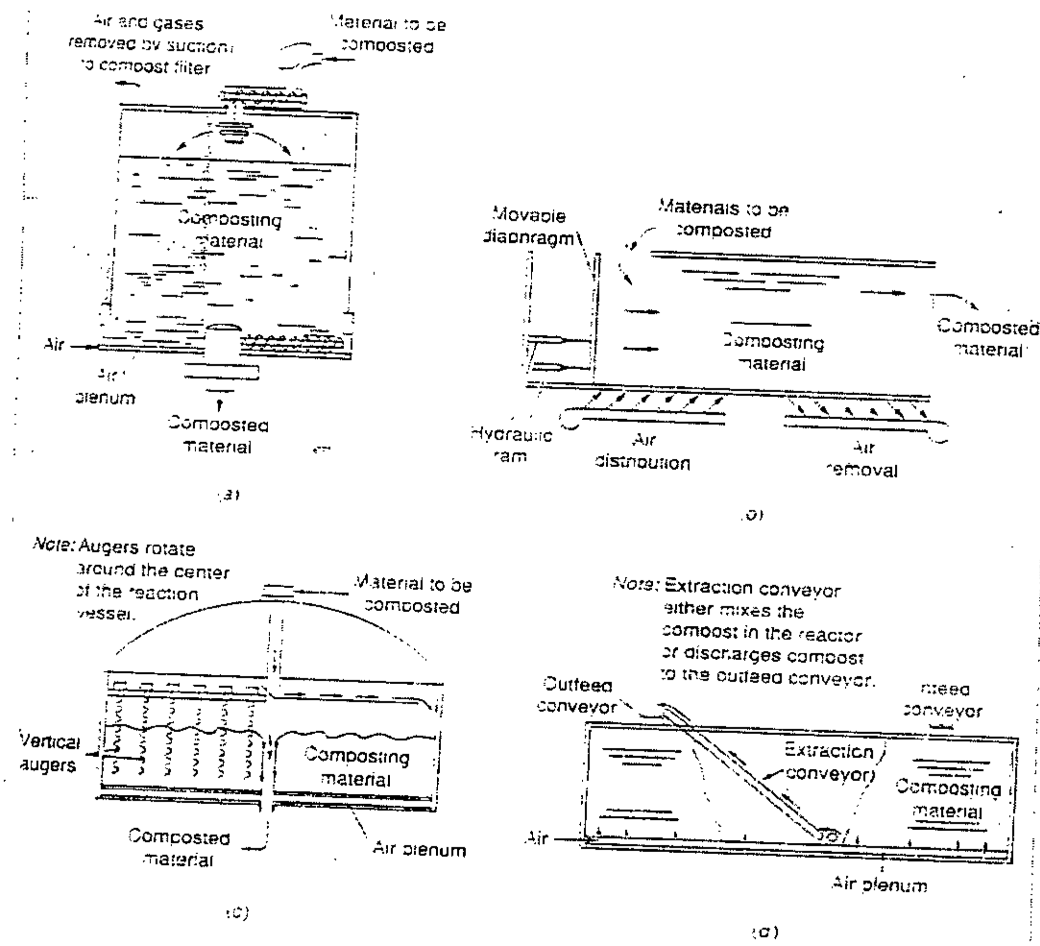


Figure 2.5: In-Vessel Composting Units: a) Unmixed Vertical Plug Flow Reactor B) Unmixed Horizontal Plug Flow C) Mixed Vertical Reactor D) Mixed Horizontal Reactor (Tchobanoglous 1993)

2.2.4 Vermi-Culture and Vermi Composting

Vermi-compost is a co-friendly fertilizer prepared by farm and organic residue with the help of earthworm. This is helpful for soil to retain its original value and texture without harming the production level. Composting with worms avoids the needless disposal of vegetative food wastes and enjoys the benefits of high Quality compost. It is done with “red worms” (Eisenia foetida) who are happiest at temperatures between 10 degree and 20 degree C. It is best to avoid putting bones, seats, fish, or

Oily fats in the worm box as they emit odors and may attract mice and rats. When cared for properly, worms process food quickly and transform food wastes into nutrient-rich "castings". Worm castings are an excellent fertilizer additive for garden potted plants.

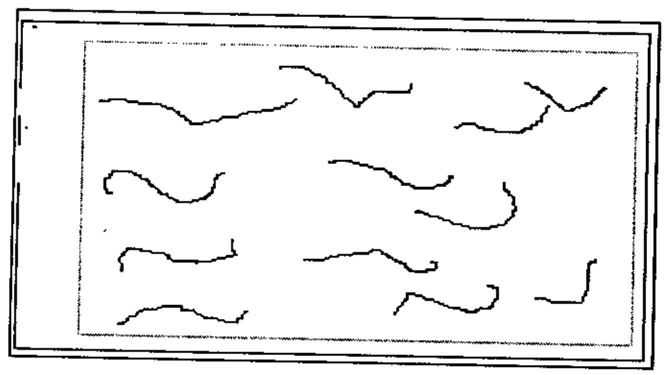


Figure 2.6: Vermi Composting in a Box

The red worms are placed in a box or bin, which can be built or purchased, along with "bedding" of shredded cardboard or paper moistened to about 75% water content. The container should be wide enough so that food scraps can be buried in a different location each time. The dimensions of the container and the amount of worms required initially will depend on how much organic food waste will need to be composted each week. The worms will gradually reproduce or die according to the amount of food they receive. A sudden addition of a large amount of food waste may attract fruit flies, so increases should be made gradually. In a healthy box, worms can build large populations and consume four to six pounds of food scraps per week. About four to six months after the box has been started, the worms will have converted all of the bedding and most of the food waste into "castings" which will need to be harvested so the process can begin again.

2.2.5 Barrel Type Composting

Due to rapid growth of Dhaka's population, large influx of rural-urban migration and severe shortage of adequate housing have led to the mushroom growth of slums and squatter settlements in Dhaka. Municipal services and already over burdened, and simply can not provide services to the slum dwellers, leaving the residents to their own devices for sanitation and other basic services, resulting in unhygienic and filthy living condition. In an attempt to search for an alternative low-cost and sustainable solid waste management facility for slums the NGO initiated pilot barrel type-composting projects in Mirpur slum areas, with support from Donors. Moqsud (2003) initiated a barrel type composting in Gazipur area to assess the parametric study of composting.

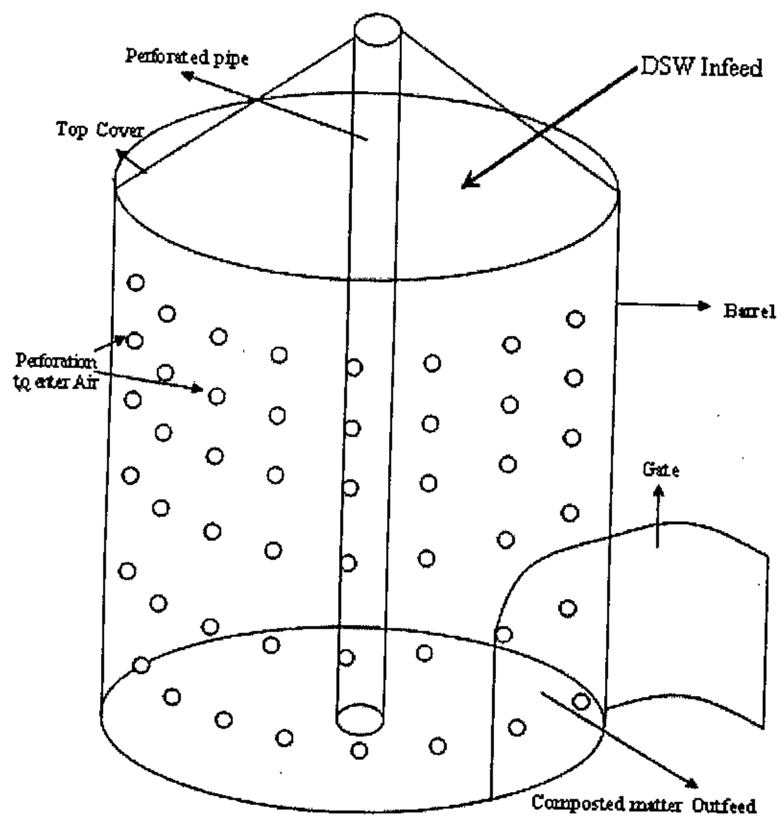


Figure 2.7 : Barrel Type Composting

2.3 CONTROL PARAMETERS OF COMPOSTING

There are several important parameters, which have to be in desirable conditions for efficient aerobic composting to occur at high temperatures. Some of these parameters are

- Moisture content
- Carbon-Nitrogen ratio
- Oxygen requirement
- Temperature
- Surface area
- Volume
- pH

2.3.1 Moisture Content (M.C.)

Moisture management requires a balance between these two functions: microbial activity and oxygen supply. Moisture is essential to the decomposition process, as most of the decomposition occurs in thin liquid films on the surfaces of particles. However, mixtures can be too wet, thereby reducing the oxygen supply. Excess moisture will fill many of the pores between particles with water, limiting oxygen transport. Oxygen diffusion, the movement of oxygen due to differences in concentration, is 10,000 times slower in water than in air. If too little oxygen gets to the center of the compost, anaerobic (without oxygen) decomposition will result. While anaerobic activity normally occurs to a limited extent in the interior of particles within an other-wise aerobic system, high levels of anaerobic metabolism can generate a wide range of unpleasant and pervasive odors and other by-products. Decomposition slows dramatically in mixtures under 40 to 45 percent moisture, which can lead facility operators to prematurely assume compost is stabilized and ready to sell. A minimum moisture content of 50 to 55 percent is usually recommended for high rate composting of MSW. (http://compost.css.cornell.edu/Composting_homepage.html). MSW collection programs which include paper are often drier than this, and water or sludge should be added to bring moisture into the optimum range. The heat and airflow generated during composting evaporate significant amounts of water and tend to dry the material out. During the active composting phase, additional water usually needs to be added to prevent premature drying and in-complete stabilization. MSW compost mixtures usually start at about 52 percent moisture and dry to about 37 percent moisture prior to final screening and marketing.

In Gazipur domestic waste composting, 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 becomes slow. The figure 2.8 represents the variation of moisture content during composting in Gazipur area. (Moqsud 2003)

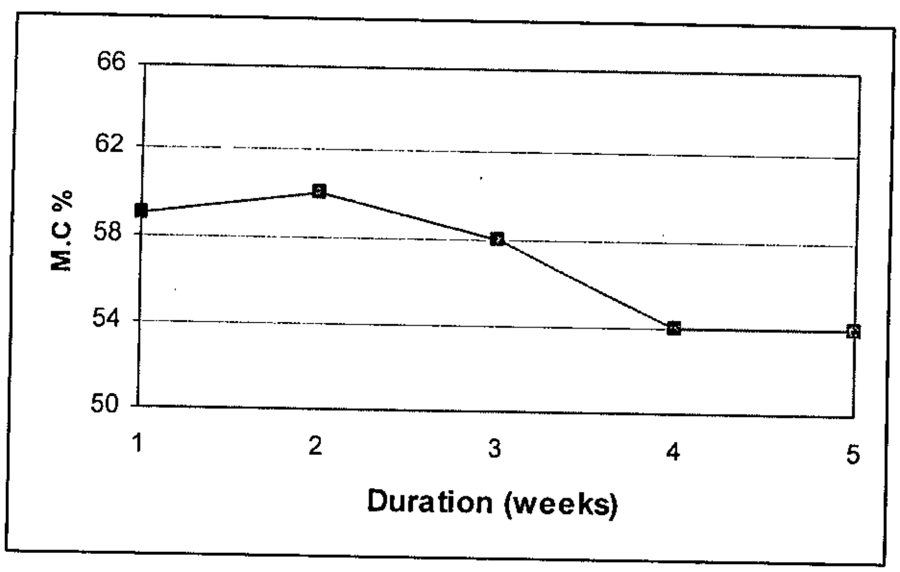


Figure 2.8: Moisture Content Variation During Composting

2.3.2 Carbon-Nitrogen Ratio (C / N ratio)

An optimum balance between carbon (C) and nitrogen (N) content is necessary because the bacteria need a minimum supply of nutrients to survive. Bacteria use carbon as an energy source and nitrogen for cell building. The initial C/N ratio is a deciding factor in the speed at which decomposition takes place. The ideal initial ratio is between 30: 1 and 35: 1 and if it exceeds 50, the time required increases considerably. At lower ratios ammonia is given off. Biological activity is also impeded at lower ratios. In solid wastes the main source of nitrogen is the vegetables / putrescible matter which has a C/N ratio of about 24: 1 and paper is the main source of carbon. Thus the higher the ratio of paper to vegetable/ putrescible matter, the higher C/N ratio is.

Table 2.2: Shows the C/N Ratio of Different Matters

Nitrogen content and nominal C/N ratios of selected compostable materials (dry basis)

Material	Percent N	C/N ratio
Food processing wastes		
Fruit wastes	1.52	34.8
Mixed slaughterhouse waste	7.0-10.0	2.0
Potato tops	1.5	25.0
Manures		
Cow manure	1.7	18.0
Horse manure	2.3	25.0
Pig manure	3.75	20.0
Poultry manure	6.3	15.0
Sheep manure	3.75	22.0
Sludges		
Digested activated sludge	1.88	15.7
Raw activated sludge	5.6	6.3
Wood and straw		
Lumber mill wastes	0.13	170.0
Sawdust	0.10	200.0-500.0
Wheat straw	0.3	128.0
Wood (pine)	0.07	723.0
Paper		
Mixed paper	0.25	173
Newsprint	0.05	983
Brown paper	0.01	4490
Trade magazines	0.07	470
Junk mail	0.17	223
Yard wastes		
Grass clippings	2.15	20.1
Leaves (freshly fallen)	0.5-1.0	40.0-80.0
Biomass		
Water hyacinth	1.96	20.9
Bermuda grass	1.96	24

(Source: Spoken solid 1996)

If the excess of carbon over nitrogen is too great, reproduction and growth decline in proportion to the exhaustion of nitrogen from the substrate. They cease when no nitrogen is available. It should be emphasized that although bacterial activity is slowed, it does not entirely cease simultaneously with the disappearance of nitrogen. However, as cell age die off, manifestations of activity (heat and CO_2 generation diminish proportionately).

Eventually, a waste having a high C/N reaches a lower ration because with each cycle of microbial growth, two-thirds of the carbon consumed is given off as CO_2 while the other third is combined with nitrogen in the living cell (Tchobanoglous 1985). Upon death of the microbe, fixed nitrogen and carbon again become available, but their utilization once more necessitates the oxidation of a fraction of the carbon to CO_2. Thus, the amount of carbon is reduced by way of partial conversion to CO_2, while nitrogen continues to be recycled.

In anaerobic situations, an overabundance of carbon may lead to excessive acid formation and consequent lowering of the pH to a level at which sensitive microbes cannot survive. Less drastically, an imbalance results in an inhibition of microbial activity.

Optimum C/N is to some extent a function of the molecular nature of the organic matter in the wastes, especially of the carbonaceous component. If the carbon is bound in compounds that are resistant to biological attack, carbon accordingly would be only slowly available. Therefore, as far as the microbes are concerned, only a fraction of the carbon is available at any one time. However, there is the possibility that the abundance of carbon in a waste, despite being difficulty available, could be such that the C/N optimum for that waste might be higher than normal. In other words, the optimum C/N would be higher than it would bed if the carbon were in a more readily available form. Examples of resistant wastes are those that have a sizeable fraction of lignaceous components or of components consisting of certain physical forms of cellulose, i.e., newspaper stock, straw, corn stalks).Except for the small amount of nitrogen in keratin and similar resistant nitrogenous compounds, most of the nitrogen in wastes in readily available. Consequently, the optimum C/N ratio is rarely affected by reason of difficulty available nitrogen. Results of the cumulative experience of practitioners in composting lead to the conclusion that a C/N of about 30 parts of carbon to 1 of nitrogen is optimum for most types of waste, especially MSW and food waste. This is about what one would expect, inasmuch as living organisms utilize about 30 parts of carbon for each part of nitrogen. If the waste has a large percentage of woody material (e.g. tree trimmings, shrubbery pruning) or newsprint, the permissible ratio can be as high as 35/1 and perhaps 40/1 inasmuch as not all of the carbon is available at any one time.

As stated earlier, the only observable penalty for a C/N lowers than 20/1 is loss of nitrogen. Conditions in an actively composting pile are conducive to the volatilization of NH_4-N. These conditions are elevated temperature and a pH above 7. The loss is accentuated when the material is turned or disturbed.

In Gazipur area, the Carbon-Nitrogen ratio of composting varies in the range of 12 to 15, which is presented in the figure 2.9 (Moqsud 2003)

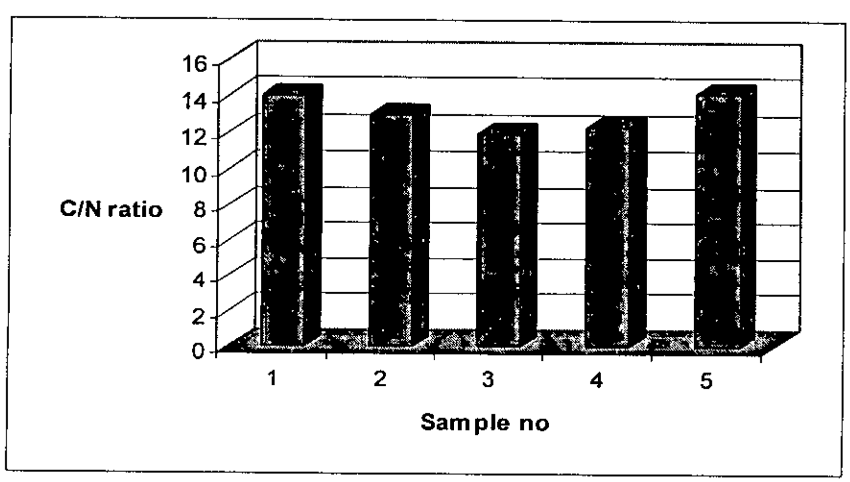


Figure 2.9: Comparison of C/N ratio compost

2.3.3 Oxygen Requirement

The availability of air is the key to the aerobic process of composting. 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.

The amount of oxygen required (Tchobanoglous 1985) for the complete aerobic stabilization of municipal solid wastes can be estimated by using the following formula :

$$C_aH_bO_cN_d + \frac{4a+b-2c-3d}{4}O_2 \rightarrow aCO_2 + \frac{b-3d}{2}H_2O + dNH_c \text{ ....(2.1)}$$

where, a, b, c, d are constants.

if the ammonia, NH_3, is to be oxidized to nitrate NO_3^-, the amount of oxygen required to accomplish this can be computed with the following equation.

$$NH_3 + 2O_2 \rightarrow H_2O + HNO_3 \text{ ....(2.2)}$$

2.3.4 Temperature

Temperature is also a key factor affecting biological activity. The broad range of optimum temperatures for the composting process, 45-65^{0}C, helps a large variety of microorganisms to participate in the process (Huang et al 2000). The temperatures generated by the thermophilic bacterial activity lead to the destruction of the disease-causing organisms. Higher temperatures e.g., 60-70^{0}C for about 24 hours should be maintained for pathogen destruction. The variation of temperature during composting in Gazipur area is presented in the figure 2.10. (Moqsud 2003)

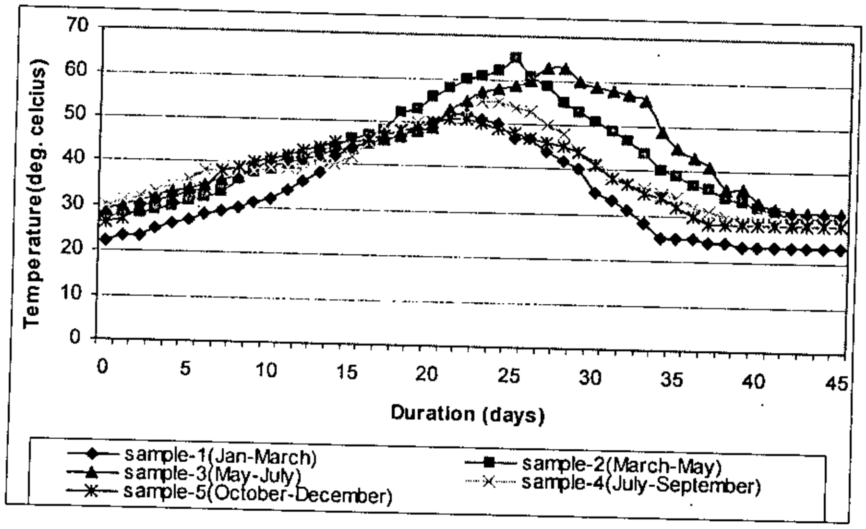


Figure 2.10: Comparison of Seasonal Variations of Temperature During Composting

2.3.5 Surface Area

Decomposition by microorganisms is in contact with air. Increasing the surface area of the material to be composted can be done by chopping, shredding, mowing or breaking up the material. The increased surface area means that the micro organisms are able to digest more material, multiply more quickly, and generating more heat. It is not necessary to increase the surface area when composting, but doing so speeds up the process. Insects and earthworms also break down materials into smaller particles that bacteria and fungi an digest.

2.3.6 Volume

A large compost pile will insulate itself and hold the heat of microbial activity. Its center will be warmer than its edges. Piles smaller than 3 feet cubed 27 cu-ft will have trouble holding this heat while piles larger than 5 feet cubed 125 cu. ft don't allow enough air to reach the microbes at the center. These proportions are of importance only if the goal is fast hot compost. The variation of volume in Gazipur area during composting is presented in the figure 2.11. (Moqsud 2003)

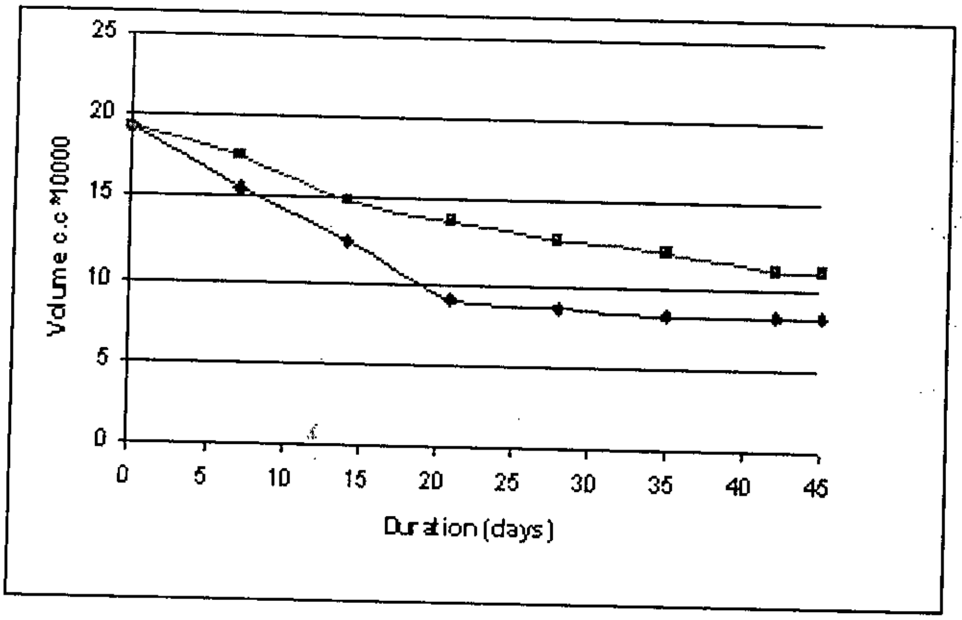


Figure 2.11 Comparison of Volume Change during Composting

2.3.7 pH Control

Organic materials with a wide range of pH values from 3 to 11 (Tchobanoglous 1993) can be composted, but the more desirable pH range for composting is between 5.5 and 8.5. The pH varies with time during the composting process and is a good indicator of the extent of decomposition within the compost mass. The optimum pH range for most bacteria is between 6.0 and 7.5. During the initial period (first 2 to 3 days) pH drops to 5.0 or less and then beings to rise to about 8.5 for the remainder of the aerobic process. If the digestion is allowed to become anaerobic, the pH will drop to about 4.5. To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above 8.5.

Some important design parameters for composting process are shown in Table 2.3

Table 2.3: Important Design Considerations for Aerobic Composting Process

Item	Comment
Particle size	For optimum results the size of solid wastes should be between 25 and 75mm (1 and 3in).
Carbon-to-nitrogen (C/N) ratio	Initial carbon to nitrogen ratios (by mass) between 25 and 50 are optimum for aerobic composting. At lower ratios, ammonia is given off. Biological activity is also impeded at lower ratios. At higher ratios, nitrogen may be a limiting nutrient.
Blending and seeding	Composting time can be reduced by seeding with partially decomposed solid wastes to the extent of about 1 to 5 percent by weight. Sewage sludge can also be added to prepared solid wastes. Where sludge is added, the final moisture content is the controlling variable.
Moisture content	Moisture content should be in the range between 50 and 60 percent during the composting process. The optimum value appears to be about 55 percent.
Mixing/turning	To prevent drying, caking, and air channeling, material in the process of being composted be mixed or turned on a regular schedule or as required. Frequency of mixing or turning will depend on the type of composting operation.
Temperature	For best results, temperature should be maintained between 122 and 131^{0}F (50 and 55^{0}C) for the first few days and between 131and 140^{0}F (55 and 60^{0}C) for the remainder of the active composting period. If temperature goes beyond 151^{0}F (66^{0}C), biological activity is reduced significantly.
Control of pathogens	If properly conducted, it is possible to kill all the pathogens, weeds, and seeds during the composting process. To do this, the temperature must be maintained between 140and 158^{0}F (60 and 70^{0}C) for 24h.
Air requirements	The theoretical quantity of oxygen required can be estimated using Air with at least 50 percent of the initial oxygen concentration remaining should reach all parts of the composting material for optimum results, especially in mechanical systems.
P^H control	To achieve an optimum aerobic decomposition, P^H should remain at 7 to 7.5 ranges. To minimize the loss of nitrogen in the form of ammonia gas, P^H should not rise above about 8.5.
Degree of decomposition	The degree of decomposition can be estimated by measuring the final drop in temperature, degree of self heating capacity, amount of decomposable and resistant organic matter in the composted material, rise in the redox potential, oxygen uptake, growth of the fungus Chaetomium gracilis, and the starch-iodine test.
Land requirement	The land requirements for a plant with a capacity of 50 ton/d will be 1.5 to 2.0 acres. The land area required for a larger plant will be less on a ton/d basis.

Source: Moqsud 2003

2.4 SOLID WASTE CHARCATERISTICS OF GAZIPUR CITY

The total solid waste generated is mainly organic with compare to small amount of inorganic. Among the organic waste the vegetables waste are dominant. The various types of solid waste generated are shown in the Figure 2.12 (Moqsud 2003).

Again the physical properties of residential or domestic solid waste at Gazipur is shown in the Figure: 2.13 (Moqsud 2003) .It is observed that food waste is the dominant of the total waste. It is different from other developed city of the world. The solid waste generation rate is increased with respect to the increased per capita income. It is due to the higher purchasing capacity of the people of increased income Group.

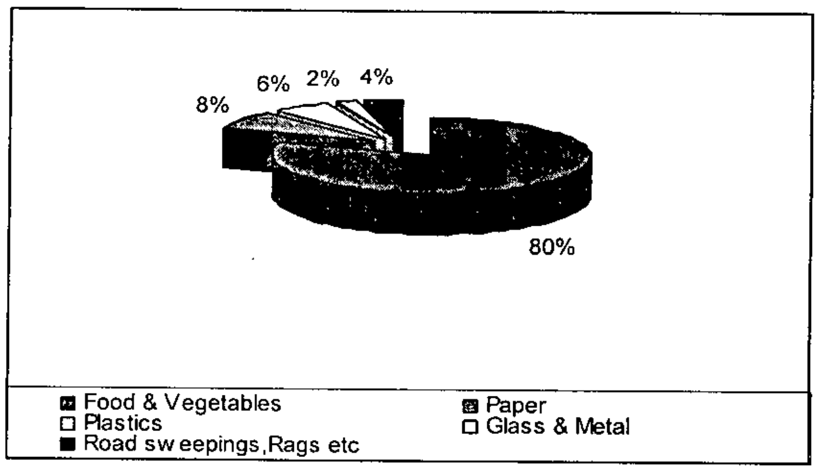


Figure 2.12: Characteristics Analysis of Municipal Solid Waste at Gazipur

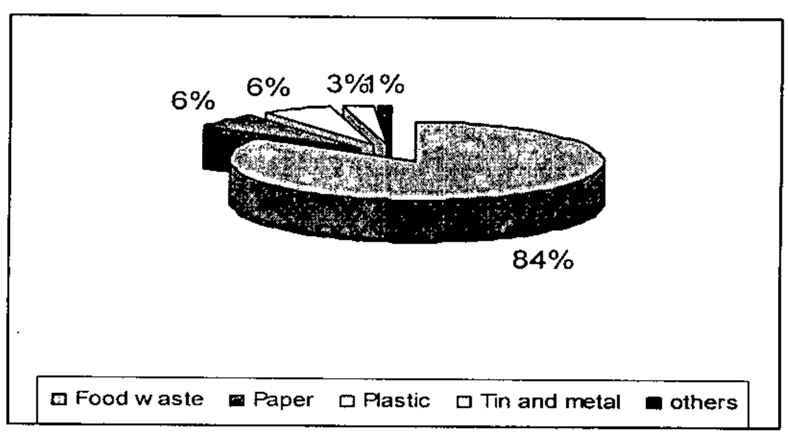


Figure 2.13: Physical Composition of Domestic Waste at Gazipur

2.5 STATISTICAL MODELING OF COMPOSTING

In the past, there have been numerous studies on the determination of optimum microbial-growth environments and operating conditions of solid waste composting. Many of them have worked on the statistical analysis of behavior of composting of domestic waste. Koenig and Bari (2000) worked on forced aeration composting where he judged that temperature dependence of the reaction rates of different aeration mode composting tests clearly followed the Arrhenius equation, independent of aeration mode. Bari et al (2000) have contributed kinetic modeling of thermophilic composting using composting reactor.

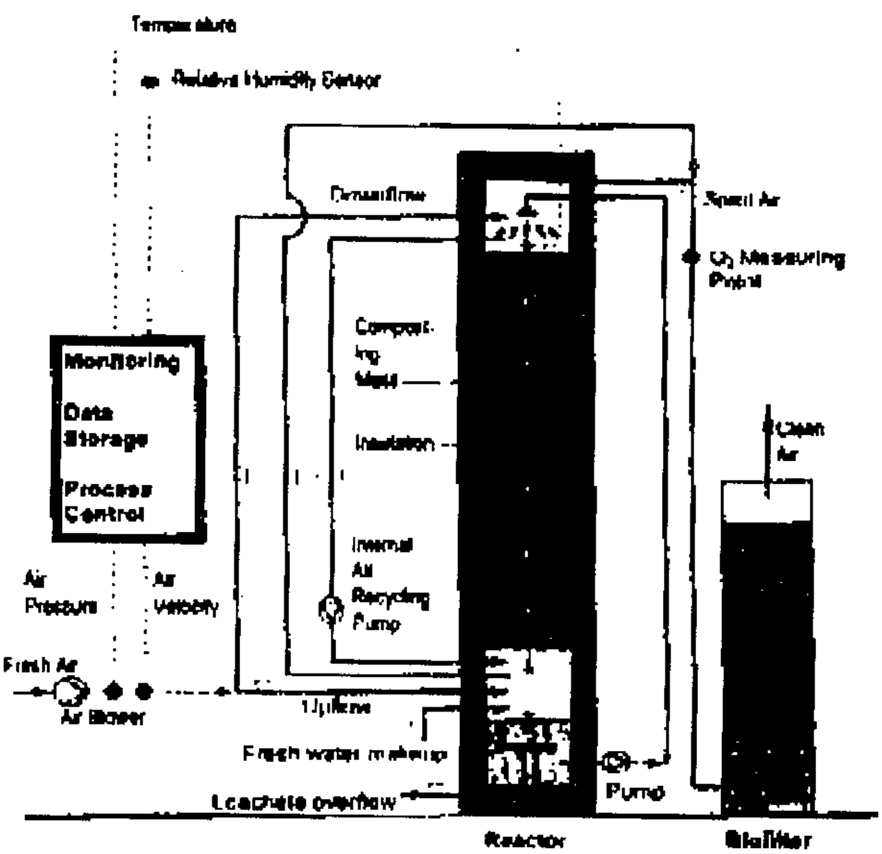


Figure 2.14 : Schematic diagram of experimental pilot-scale composting reactor (Koenig et al 1996)

Laboratory-scale temperature controlled reactors were used to generate experimental data of thermophilic composting of vegetable waste (Huang et al 2000). By fitting an experimental data of thermophilic composting, the obtained empirical model appeared to be a quadratic form.

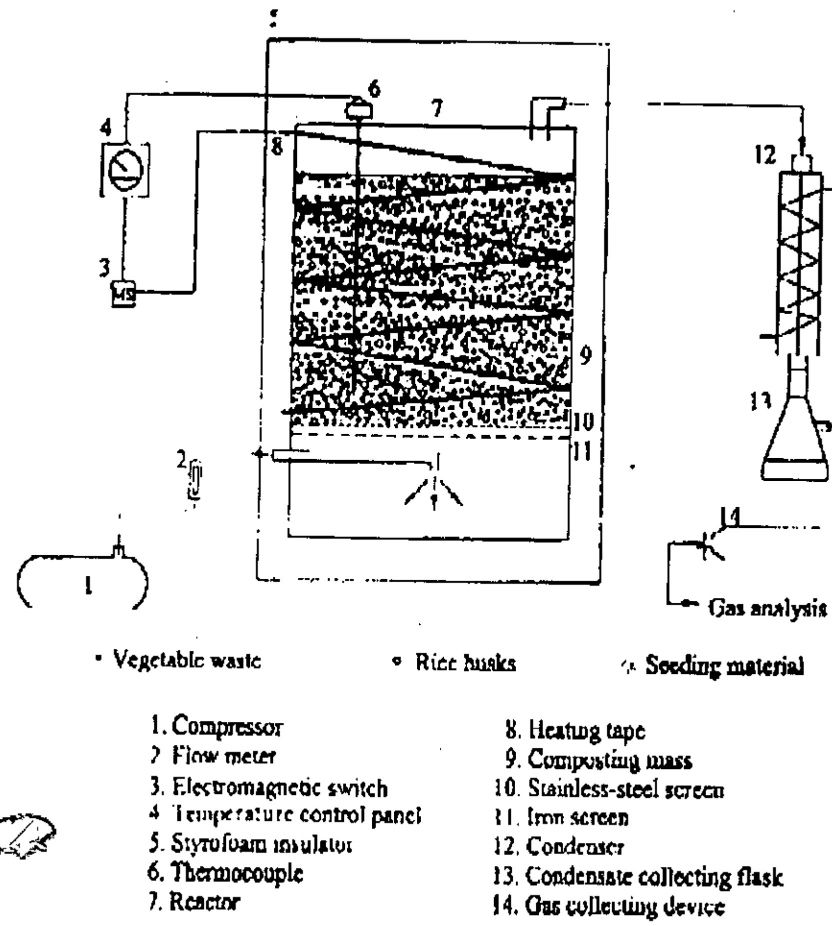


Figure 2.15 : Schematic diagram of experimental pilot-scale composting reactor (Huang et al 2000)

VanderGheynst et al (1997) states that within a static bed degradation process there exists considerable temporal and spatial variation in state variables such as O_2 concentration, temperature and moisture content.

The Chemical and physical characteristics of solid wastes (constituents, pH and moisture) and operating conditions of solid waste composting (C/N ratio, aeration rate reaction temperature and time) impose significant effects on an ecological succession of microorganisms (Faure 1991; Vallini et al 1993). In addition, the decomposition of the biodegradable part of solid wastes is influenced by microbial-growth environments (de Bertoldi et al. 1982; Bach et al 1985; Nakasaki et al.1987; Vallini and Pera 1989; Yu et al. 1991; Martinez-Inigo and Almendros 1994) and seeding conditions. Therefore,, it is extremely difficult to derive a deterministic model that takes into account all complex physicochemical and biological interactions involved in solid waste composting.

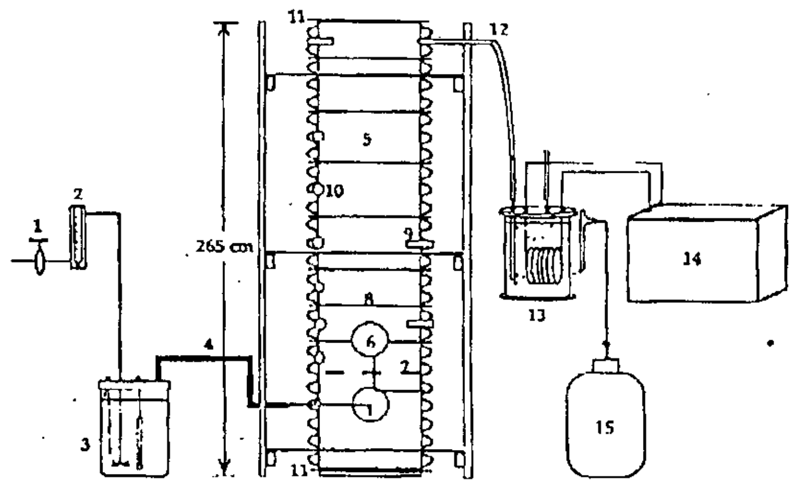


Figure 2.16 : Schematic diagram of experimental pilot-scale composting reactor (VanderGheynst et al 1997) where

1. **Pressure regulator**
2. **flow meter**
3. **humidifier**
4. **insulated inlet air line**
5. **HDPE pilot scale reactor**
6. **unloading and cleaning port**
7. **perforated plate**
8. **stainless steel tubes containing thermocouples and gas sampling lines**
9. **oxygen sensors**

10. **sampling port**
11. **angle iron flange**
12. **exhaust line**
13. **condenser**
14. **refrigeration unit**
15. **condensed vapour collection**

The statistical F-test is widely used to verify the model of composting. (Huang et al 2000). Considering degrees of freedom of all the parameters of composting experiments with the association of 95% confidence level is statistically assessed in this test. The F- value can be calculated using Statistical software 'SPSS for Win 10.0.5', which needs to compare with the F chart which is presented in the table 2.4.

Table 2.4:

F-Distribution of the 95th percentile

95th Percentile Values of the F-Distribution.
To read this table:
1. The percentile, p, such that 1-p is in the right-hand tail of the distribution is 95.
2. The critical F value is at the intersection of the column and row labeled m and n, respectively.
m = degrees of freedom in the numerator.
n = degrees of freedom in the denominator
For example, if the degrees of freedom in the numerator are 5 and the degrees of freedom in the denominator are 6, then the critical value of F is 4.39 If the calculated value of F exceeds 4.39, you can reject the null hypothesis.

					m											
n	1	2	3	4	5	6	7	8	9	10	12	15	20	24	30	inf.
1	161	200	216	225	230	234	237	239	241	242	244	245	248	249	250	254
2	18.5	19.0	19.2	19.3	19.3	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.4	19.5	19.5	19.5
3	10.1	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79	8.74	8.70	8.66	8.64	8.62	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96	5.91	5.86	5.80	5.77	5.75	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74	4.68	4.62	4.56	4.53	4.50	4.37
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06	4.00	3.94	3.87	3.84	3.81	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64	3.57	3.51	3.44	3.41	3.38	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35	3.28	3.22	3.15	3.12	3.08	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14	3.07	3.01	2.94	2.90	2.86	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98	2.91	2.85	2.77	2.74	2.70	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85	2.79	2.72	2.65	2.61	2.57	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75	2.69	2.62	2.54	2.51	2.47	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67	2.60	2.53	2.46	2.42	2.38	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60	2.53	2.46	2.39	2.35	2.31	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54	2.48	2.40	2.33	2.29	2.25	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49	2.42	2.35	2.28	2.24	2.19	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45	2.38	2.31	2.23	2.19	2.15	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41	2.34	2.27	2.19	2.15	2.11	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38	2.31	2.23	2.16	2.11	2.07	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35	2.28	2.20	2.12	2.08	2.04	1.84
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32	2.25	2.18	2.10	2.05	2.01	1.81
22	4.30	3.44	3.05	2.82	3.66	2.55	2.46	2.40	2.34	2.30	2.23	2.15	2.07	2.03	1.98	1.78
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27	2.20	2.13	2.05	2.01	1.96	1.76
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25	2.18	2.11	2.03	1.98	1.94	1.73
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24	2.16	2.09	2.01	1.96	1.92	1.71
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22	2.15	2.07	1.99	1.95	1.90	1.69
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20	2.13	2.06	1.97	1.93	1.88	1.67
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19	2.12	2.04	1.96	1.91	1.87	1.65
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18	2.10	2.03	1.94	1.90	1.85	1.64
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16	2.09	2.01	1.93	1.89	1.84	1.62
inf	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83	1.75	1.67	1.57	1.52	1.46	1.00

All the researches on numerical modeling of composting are based on control environment using mechanical reactors. But, none of the researcher has look forward to express numerical modeling of composting based on natural environment.

2.6 LAND REQUIREMENT IN COMPOSTING PROCESS

The core issue to replicate the model of community based composting is availability of potential vacant land in different zones of Dhaka City Corporation. Against the aforesaid backdrop a study was undertaken by Waste Concern, to explore whether enough vacant land is available in Dhaka City for solid waste management and composting. The findings are presented in Table 2.5

Based on the analysis, a 3-ton capacity composting plant at the community level capable of serving 2,000 households (based on per capita domestic waste generation rate of 0.3 kg/capita/day) will require only 2,800 sft vacant land, Considering 3 ton capacity as a module for all DCC zone at community level, required area of composting plants in different zones is summarized.

Table 2.5: Land Required for Composting Plants in Different Zones in DCC Area

DCC Zone	Household No. (In 2000)	Required area in acre
1	1,24,892	4.01
2	1,24,892	4.01
3	64,457	2.07
4	1,07,632	3.46
5	1,28,457	4.13
6	69,149	2.22
7	1,25,385	4.02
8	36,173	4.37
9	78,687	2.53
10	2,43,285	0.78
Total	9,84,109	31.60

Source: Waste Concern (2000)

To serve the households in all ten zones of DCC, 31.6 acre of vacant land is the estimated requirement for community based composting plants.

On the basis of secondary database, a random sample survey was conducted within DCC area, with particular importance to DCC vacant land and vacant land of different agencies such as WASA and Bangladesh Railway. The survey team (Waste concern) within their limited resources located seventeen (17) potential sites. It is evident from the study that all organic waste generated in Dhaka from domestic and commercial source can be easily composted using community based composting process .

2.7 COMPOSTING IN DIFFERENT COUNTRIES

Composting process is an ancient process but it is practiced first in India. In Indoor method of composting in India, a layer of course refuse is first placed at the bottom of a pit to a depth of 0.15-0.25 m. which is 0.075 m deeper for a 0.25 m width at the pit edges. Night-soil is poured to a thickness of 0.05m in the depressed portion and the elevated edges prevent its draining to the sides. On top of it a second layer of refuse is spread which sandwiches the night –soil layer. Such alternate layers of refuse and night soil are repeated till it reaches a height of 0.3 m above the edges of the pit. The top layer of refuse is at least 0.25-0.3 m thick and refuse mass is rounded to avoid rainwater entering the pit. About 0.6 m longitudinal side of pit is not filled with refuse or night-soil for starting the turning operation. The first turning is manually carried out after 4-7 days and the second turning after 5-10 more days.

In Chinese cover pile system ,a grid about 1m x 1m x1m of wooden or bamboo pole is laid on top of organic waste bed of about 0.15 m high and the vertical poles are attached at the crossover point. The waste is placed within the grid so that the total height of the windrow is about 1 m .Then the windrow is covered with a layer of clay. The poles are removed when the clay layer is dried .These holes help promote airflows within the system. It apparent from Diaz et al (1996) that the composting process takes about 3 weeks during summer and 4 weeks during winter to be completed in Tianjin, Chaina. In Canada, generally composting is done in a rotating drum for a relatively short residence time, and then the mass is heaped as windrows for longer period to complete composting process. Aerator is used mechanically by the use of fans or other equipment. The long drums may be divided into several small chambers. Instead of using horizontal rotating drum, vertical cylinders are used as reactors. It is shorter residence time for tower system (about 2-5 weeks) and end products can be used without further maturation outside reactors. This system minimizes odor problems.

Vermi-composting sometimes called vermi-culture or composting with worms or worm composting, uses worms and microorganisms to break down organic materials, under aerobic condition, but relatively at a lower temperature, to nutrient rich end product compost. Sovadec plant in La Voulte, France has been in operation since 1991. It produces mixed house hold waste 20 ton/d. Separation process involves meshes, magnets, air blowers and manual sorting ,and removes metal, glass, plastics, textiles, papers and cardboard for recycling. The waste is first composted in ordinary composting process at about 70 degree C, and then further composted via lombricubateurs (earth worm) to produce nutrients rich compost, meeting the stringent European standard requirements.

A large-scale vermin-composting operation in Banglore, Kerala, India processes about 100 ton per day of domestic waste. The production is now under cover in units about 1 m deep, 2m wide and 10 m long. The units are aerated and vermicompost is obtained using Eudrilus eugeniae and compost is sold as organic conditioner of soil.

2.8 COMPOSTING IN BANGLADESH

Though composting has not been considered on a large scale in Bangladesh, small scale practice is common in some parts of the country. For example, in Rajshahi human waste in mixed with garbage and is processed and the product sold to farmers. Recently, 'Waste Concern', an NGO has established a pilot scale compost plant at Mirpur and Dhalpur in Dhaka, where solid wastes are collected from selected households and are aerobically processed to produce compost. ‘Prodipon’ another NGO has started composting project at Khulna city (Alamgir 2003). Moqsud (2003) implemented barrel type composting in Gazipur area where domestic waste had been collected from door to door and hence composted under natural environment. The digestion process was aerobic.

The major considerations for composting of solid wastes in Bangladesh are as follows:

- availability and suitability of wastes;
- socio-economic conditions;
- technological access;
- marketing for compost;
- affordable prices for farmers;
- environmental legislation and enforcement;
- present disposal cost;
- institutional support.

Preliminary assessment indicates that a good demand exists for compost for vegetable growing around urban centers. Due to the continuous depletion of humus content of agricultural lands due to intensive agriculture in Bangladesh, soil conditioner is needed to sustain productivity. Selected wastes can be converted to organic manure by composting to meet this growing demand. The composition of solid wastes in Bangladesh is favorable for composting, with a higher percentage of organic matter, precisely the right moisture content and C/N ratio slightly higher but adjustable.

The organic manure and soil conditioners produced by composting are environmentally friendly and widely used by both industrialized and developing countries. The scope and importance of conversion of municipal wastes into organic manure from both agricultural and environmental viewpoints demonstrate the need for undertaking large scale composting as well as marketing the product.

CHAPTER THREE

EXPERIMENTAL WORKS

3.1 INTRODUCTION

This chapter describes the experimental procedure of the various stages of thesis and also the design set up of the barrel type composting. The various controlling parameters of composting in different spans are observed. Hence an empirical equation has been reported depending upon the various parametric data of domestic waste composting.

3.2 EXPERIMENTAL SETUP OF COMPOSTING PLANT

To investigate the controlling parameters a small sized barrel composting plant is set in DUET campus. The 200 liter capacity perforated barrels with a cover in the top and an opening in the bottom are used as a composting barrel. The height and diameter of the barrel are 34 inch and 21 inch respectively. The half inch diameter openings in the surrounding of the barrel is provided and one inch diameter perforated pipe is attached to the base of the barrel to maintain aerobic condition. The conical shaped cover protects the waste from sunlight and rain water. The base is six inch above from the earth to save the barrel from water during rainy season. The 10 inch by 12 inch opening is provided to harvest the compost from the barrel and to make it continuous process.

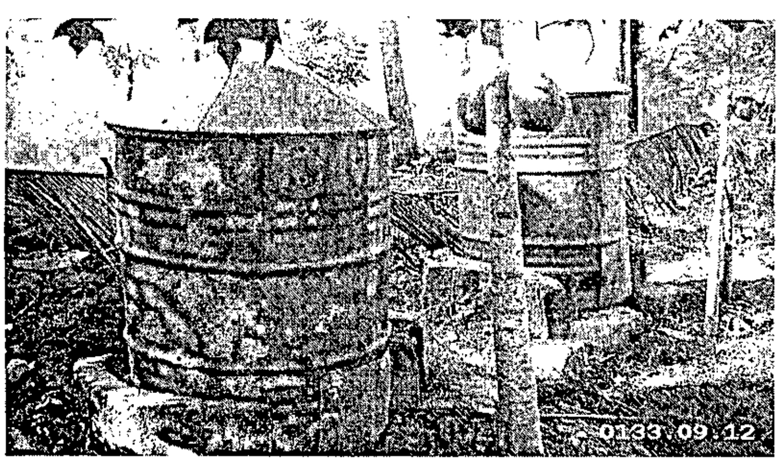


Figure 3.1:Setup a Small Scale Barrel Type Composting Plant at DUET,

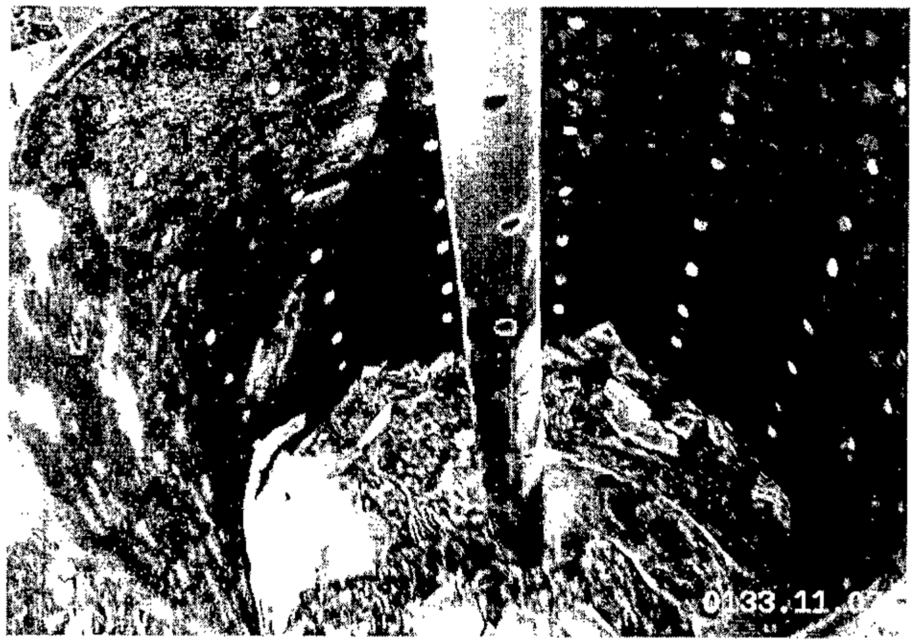


Figure 3.2: Domestic Solid Waste in Barrel Type Composting Plant 3.3

PARAMETRIC STUDY OF SOLID WASTE COMPOSTING

In this work, a barrel type composting experiment was first carried out to identify the proper range of operating conditions, consisting of the moisture content, reaction temperature and time, for thermophilic composting of domestic waste. After that, thermophilic composting experiments were performed to assess the parameters those affect composting process. Hence, the effects of operating conditions on thermophilic composting of domestic waste be determined and an empirical model of thermophilic composting also be derived by fitting in experimental data and confirmed by F-test.

To derive an empirical model of thermophilic composting of domestic waste, the selecting influencing parameters (independent variables) included the moisture content, the reaction temperature and time. The selected corresponding parameter (dependent variable) included percentage of volume loss.

After a series of thermophilic composting experiments had been completed, the software SPSS for Windows 10.0.5, which is commonly used in statistics for engineers, was applied to derive an empirical model of thermophilic composting by fitting in experimental data.

3.4 COMPOSTING PROCESS

The domestic waste has been collected door to door basis using bucket. The waste has been segregated at the origin as different colors of baskets have been used to separate organic and inorganic waste by the consumers. The separated solid wastes are collected and the organic portion of the waste is deposited in the composting barrel regularly. Before deposition in the barrel the waste is sorted and pulverized into small pieces for quick composting process. Then the regular observation of temperature, moisture content and volume reduction are taken during composting. It is very important that the regular observation is made so that the controlling parameters do not exceed the tolerable limit which has been stated earlier. After two

Figure 3.3: Regular Monitoring and Observation During Composting Process

to three weeks, the decomposing organic wastes are harvested from the bottom opening of the barrel and spread for maturing. During the rainy season the maturing is done under the shed but during the summer the maturing can be done in open sunlight for one to two weeks. To observe the seasonal variations of various parameters of composting process the experiment has been performed five times in different season of the year. The first experiment has been performed during the month June-July, the second one is from August to September, the third one is in October-November, the fourth and the fifth one is in the December-January period.

3.5 TEMPERATURE VARIATION DURING COMPOSTING

Temperature is raised during composting as heat is generated. The temperature is measured with a thermometer (range $0\,^{0}$ to$100\,^{0}$ C) regularly during composting by inserting the thermometer in the middle portion through openings for 10 minute in the barrel. It is observed that the temperature rises from the initial day, after two or three weeks it becomes to reduce and after three to four weeks it becomes constant. Though the temperature varies during season to season, but seasonal temperature has less impact to change the temperature of the composted material in the barrel.

3.6 VOLUME REDUCTION

It is one of the main objectives of composting to reduce the volume of the organic waste. The waste volume starts to reduce from its initial volume during composting process. After few weeks the waste reduction rate becomes constant. The wastes are digested in aerobic condition (Moqsud 2003).

3.7 MOISTURE CONTENT

The moisture content is another important parameter for composting. The variation of moisture content has been determined by comparing the initial water in the compost to the initial total weight of the compost. To determine the moisture content the sample is placed in the oven at 85 degree Celsius for 24 hrs (Jackson 1973). It is expressed as percentage. The results of moisture content variation are shown in chapter four. The moisture content is determined by using the following formula (Jackson 1973).

$$M.C = 100 \times \frac{\text{Initial water in the sample}}{\text{Initial weight of the sample}}$$

So, the operating conditions, consisting of the moisture content, reaction temperature and time, for thermophilic composting of domestic waste are assessed during experimental process and analyzed statistically with the assessed information.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

Results of the experimental works of composting are presented in this chapter. Particular emphasis has been given on the various controlling parameters which are generally affected the composting process of solid waste in this study. The change of various physical parameters during composting is observed. The seasonal variations of the data are shown and compared in this chapter. Again the variations of the data are shown and compared using statistical model to find out which parameter has the most influence on composting. The model has been tested with the information collected from literature review. Furthermore, this model has been verified by F-test. Further more, the graphical presentation of the empirical model has been reported to ease the calculation.

4.2 TEMPERATURE VARIATION OF COMPOSTING PROCESS

The temperature variation during composting is shown in the Fig: 4.1. It is apparent that the temperature rises from the initial day and it rises to maximum between 3 or 4 weeks. (Fig 4.1). After that the temperature becomes to fall and within some days the variation becomes insignificant. The broad range of optimum temperatures in this experiment process is 45-65^{0}C, helps a large variety of micro-organisms to participate in the process. These variation of temperatures, shown in Fig 4.1 are in good agreement with the curve of temperature variation of composting presented in the figure 2.10 The temperatures generated in thermophilic composting bacterial activity lead to the destruction of diseases causing microorganisms that minimizes the spread of diseases. It is evident from the figure 4.1 that the variation of temperature within the barrel during composting does not vary more than 20% at the same duration during different season whereas the natural temperature outside of the barrel is varied 75% at the same duration during different season. So the variation of external temperature is insignificant in composting process.

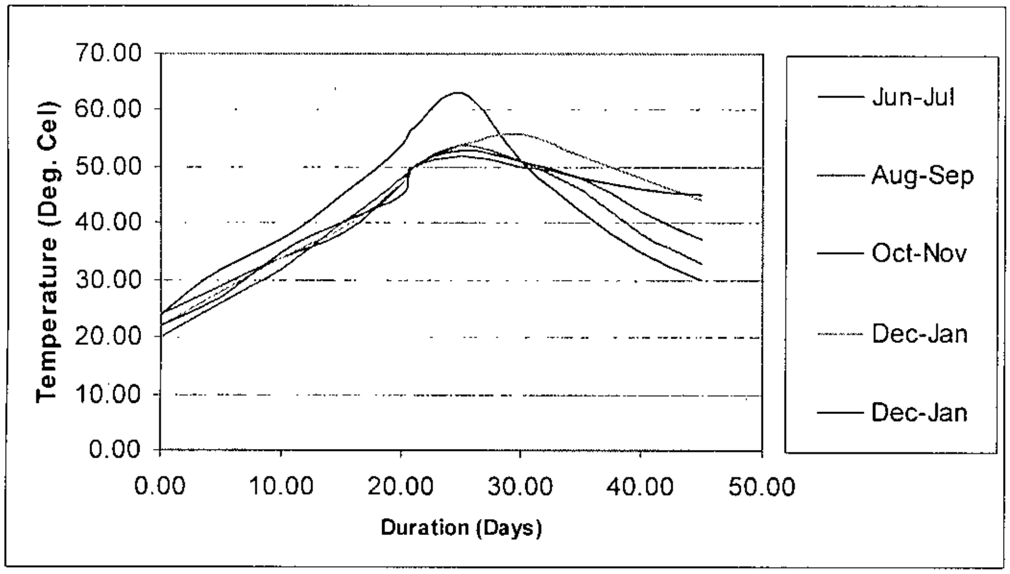


Figure 4.1: Comparison of Seasonal Variations of Temperature During Composting

4.3 MOISTURE CONTENT VARIATION DURING COMPOSTING

The optimum value of moisture content is 55% during the composting. At moisture levels nearly 70%, water begins to fill the interstices between the particles of the wastes, reducing the interstitial oxygen and causing anaerobic conditions (Tchobanoglous 1993). This results in a rapid fall in temperature and at the same time production of offensive odors. When the moisture contents drops much below 55 %, the composting process becomes slow. The moisture content of compost is measured by standard formula. In Figure 4.2 the moisture content variation is shown, which follows the same nature of curve presented in the Figure 2.8. It is observed that the maximum moisture content reaches at 67 % which is very close to the maximum range for maintaining aerobic condition. So, without further treatment e,g, adding moisture or drying, the domestic waste of Gazipur area can be composted aerobically.

4.4 CHANGE IN VOLUME DURING COMPOSTING

One of the major objectives of the composting is to reduce the volume of solid waste. The rate of changing the volume of solid waste is shown in the Fig: 4.3. After the composting is completed the volume becomes less than 40-50 % of the original volume. It is apparent from the figure 4.3 that after nearly 3 weeks, the variation of volume loss in the composting process is insignificant which can be used as retention time for digester design in composting process.

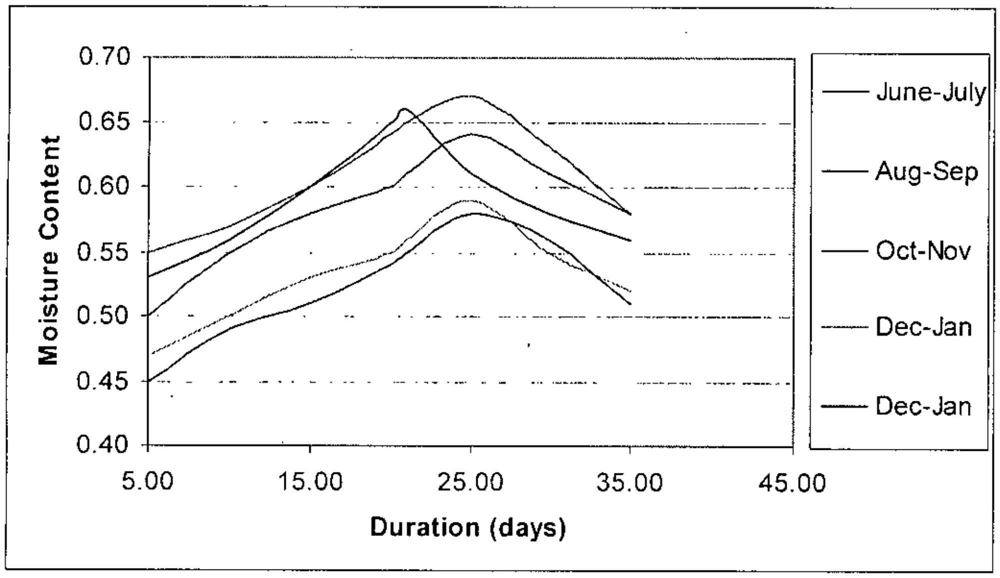


Figure 4.2: Moisture Content Variation During Composting

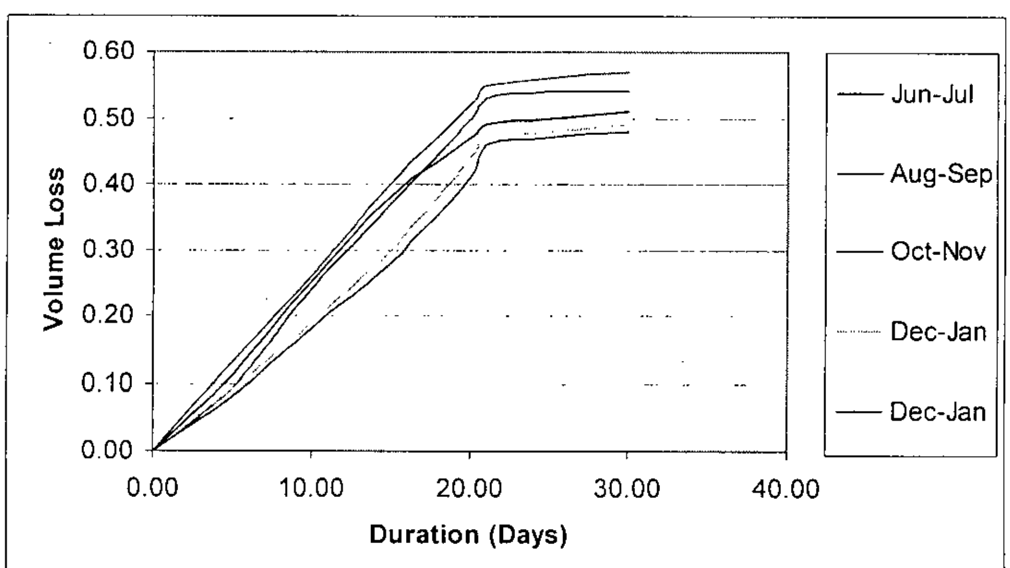


Figure 4.3: Volume Reduction During Composting

4.5 DERIVATION OF EMPIRICAL MODEL OF THERMOPHILIC COMPOSTING

To derive an empirical model of thermophilic composting of domestic waste, three operating parameters (moisture content in percentage, reaction temperature and retention time) were selected as independent variables, and the corresponding parameter (percentage volume loss) was selected as dependent variable. To simplify regression analyses, each independent variable was assumed to be independent to the others. By observing the trend of data , the relationship between independent and dependent variables appears to be a quadratic form (second degree algebraic equation). From a theoretical viewpoint, when the operating condition reaches an improper range of microbial-growth environments (e.g., reaction temperature of 0 deg or 100 deg), the corresponding parameter (volume loss) should approach zero. Accordingly, the relationship between independent and dependent variables can be expressed.

$$y = \frac{kx}{1 + ax + bx^2} \quad \text{......(4.1)}$$

where y = volume loss (%), x = moisture content (%), reaction temperature (deg cel) or retention time (days); and k, a and b = constants.

By performing 2 stage least squares regression analysis of experimental data for each of the independent variables, x_1, x_2 and x_3, the empirical model can then be written as

$$y = \frac{kx_1x_2x_3}{(1 + ax_1 + bx_1^2)(1 + cx_2 + dx_2^2)(1 + ex_3 + fx_3^2)} \quad \text{......(4.2)}$$

when, volume loss = ∫ (Moisture content, Temperature and Retention Time)

To analyze the most influenced parameter of equation (4.2), some trials were performed varying the selected parameters. Accordingly,

$$y = \frac{kx_1x_2}{(1 + ax_1 + bx_1^2)(1 + cx_2 + dx_2^2)} \quad \text{......(4.3)}$$

when, volume loss = ∫ (Moisture content, Temperature) or

$$y = \frac{kx_1 x_3}{(1 + ax_1 + bx_1^2)(1 + ex_3 + fx_3^2)} \quad \text{..........(4.4)}$$

when, volume loss = ∫ (Moisture content and Retention Time)

or

$$y = \frac{kx_2 x_3}{(1 + cx_2 + dx_2^2)(1 + ex_3 + fx_3^2)} \quad \text{..........(4.5)}$$

when, volume loss = ∫ (Temperature and Retention Time)

or

$$y = \frac{kx_3}{(1 + ex_3 + fx_3^2)} \quad \text{..........(4.6)}$$

when, volume loss = ∫ (Retention Time)

or

$$y = \frac{kx_1}{(1 + ax_1 + bx_1^2)} \quad \text{..........(4.7)}$$

when, volume loss = ∫ (Moisture content)

or

$$y = \frac{kx_2}{(1 + cx_2 + dx_2^2)} \quad \text{..........(4.8)}$$

when, volume loss = ∫ (Temperature)

in all the equations (4.2), (4.3), (4.4), (4.5), (4.6), (4.7) and (4.8), y = percentage of volume loss, x_1 = moisture content (%), x_2 = reaction temperature (deg cel), x_3 = retention time (days); and k, a, b, c, d, e, f = constants.

To determine the constant values in all the equations (4.2), (4.3), (4.4) (4.5), (4.6), (4.7) and (4.8), trial and error has been done using multi regression analyses for the three independent variables with their corresponding dependent variables having 16 sets of experimental data. The result is presented in table 4.1

Table 4.1 : Values of constants using Multiregression for parametric functions of independent variables to their corresponding dependent variable

a	B	c	d	e	f	k	R^2	Volume loss (y) is function of
0.04136	0.02677	0.02256	0.01562	0.01471	0.0015	0.068	0.77481	MC, T, RT
0.02895	0.01072	0.01069	0.00389			0.1902	0.74549	MC, T
0.03428	0.02035			0.0129	0.00238	0.0923	0.73929	MC, RT
		0.0386	0.0239	0.0159	0.00321	0.08201	0.66156	*T, RT*
				0.0578	0.0245	0.3125	0.59435	*R T*
0.0321	0.0129					0.8627	0.73594	*MC*
		0.02136	*0.00976*			*0.2678*	*0.24728*	*T*

Now, using the above mentioned constants, the volume loss is calculated using 40 sets of experimental data which are illustrated as predicted volume loss and compared with the experimental volume loss in figure 4.4, figure 4.5, figure 4.6 figure 4.7, figure 4.8, figure 4.9, and figure 4.10.

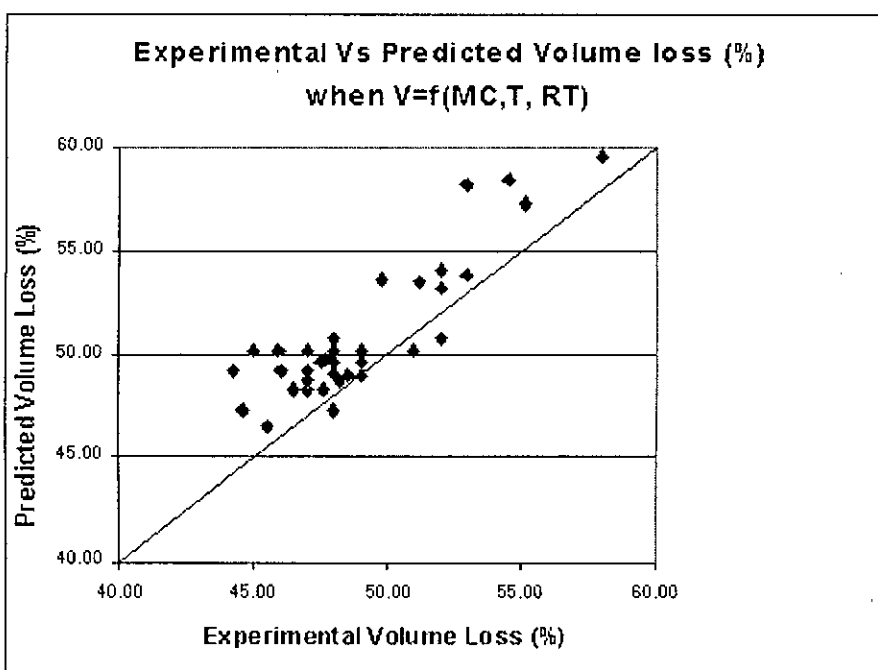


Figure 4.4 : Experimental Vs. Predicted Volume Loss

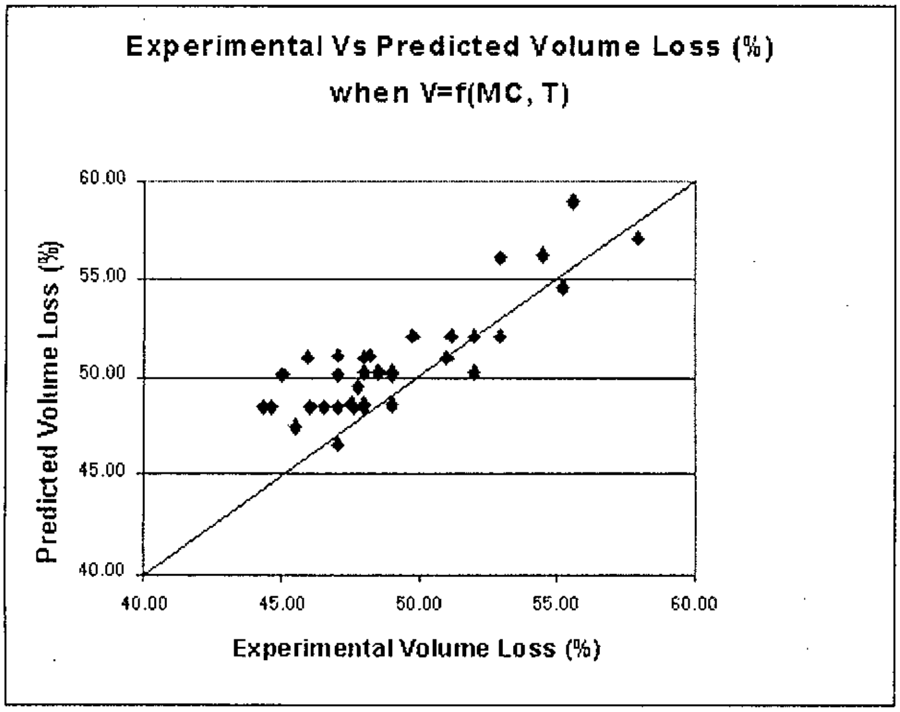


Figure 4.5 : Experimental Vs. Predicted Volume Loss

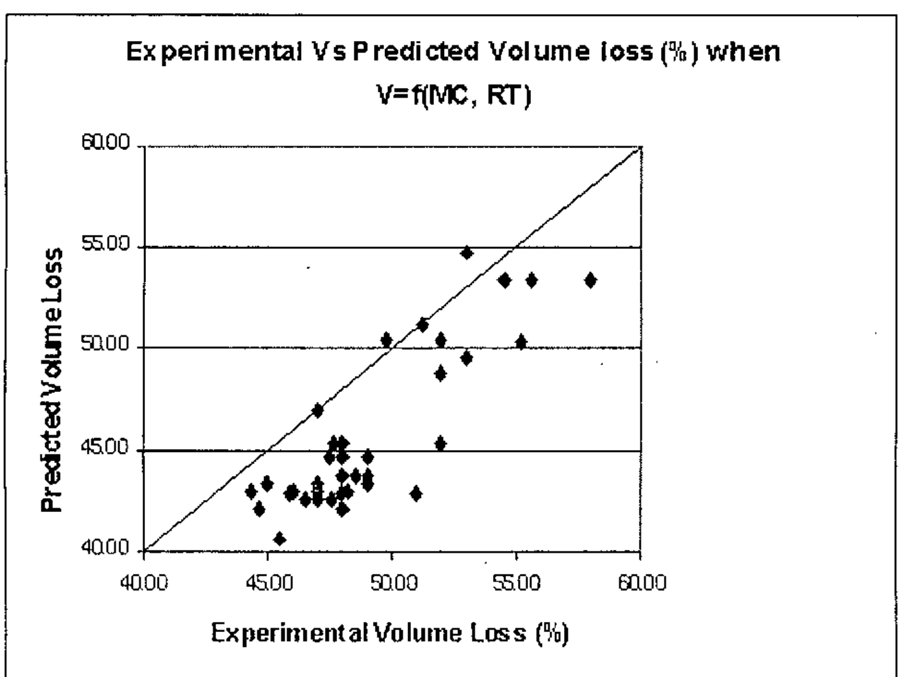


Figure 4.6 : Experimental Vs. Predicted Volume Loss

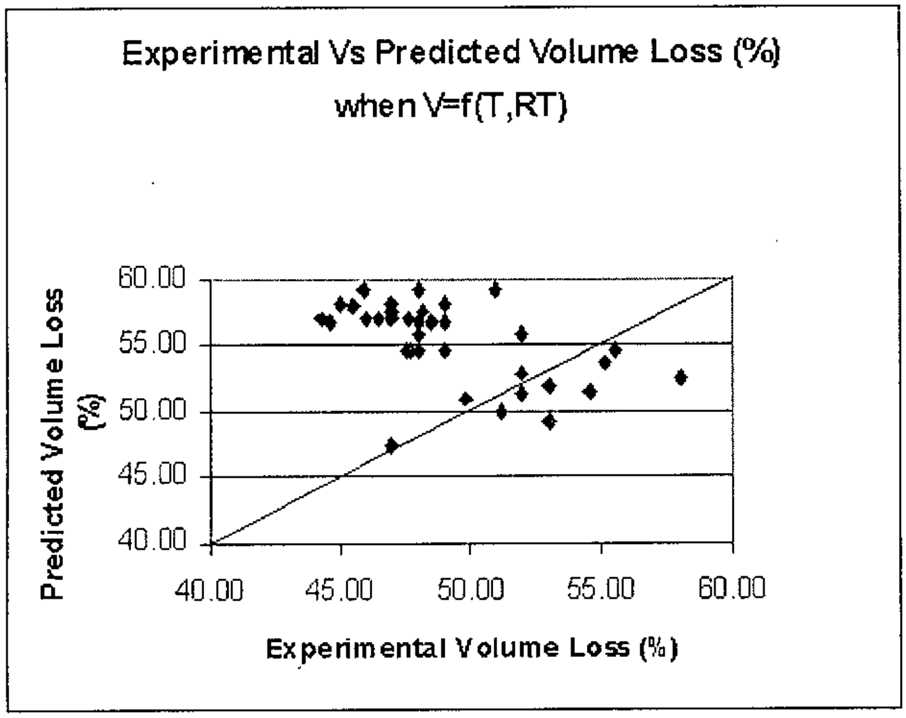


Figure 4.7 : Experimental Vs. Predicted Volume Loss

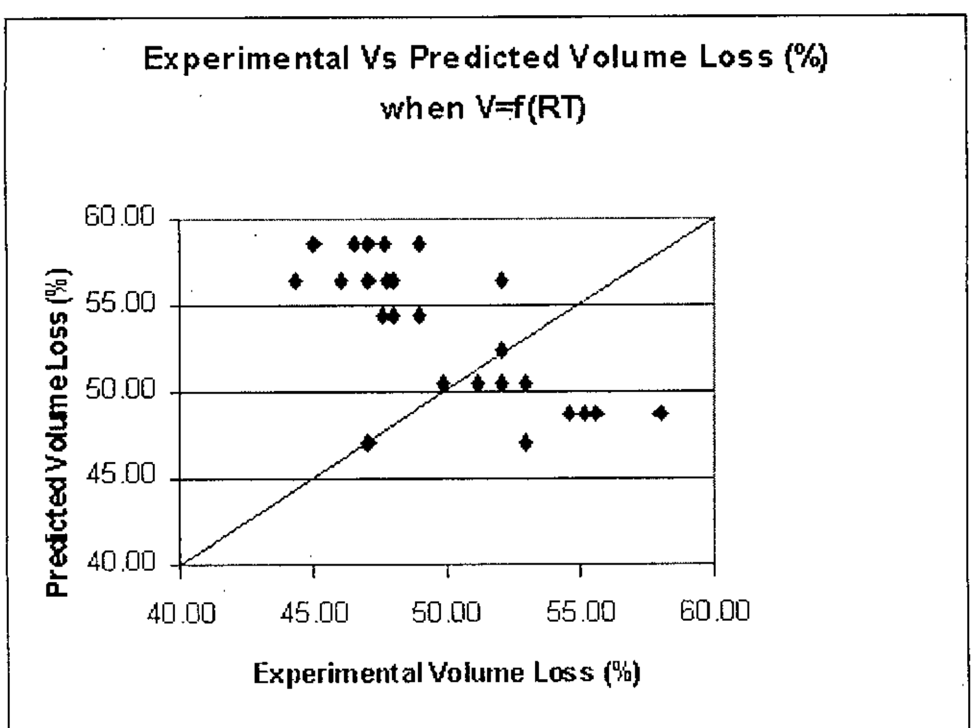


Figure 4.8 : Experimental Vs. Predicted Volume Loss

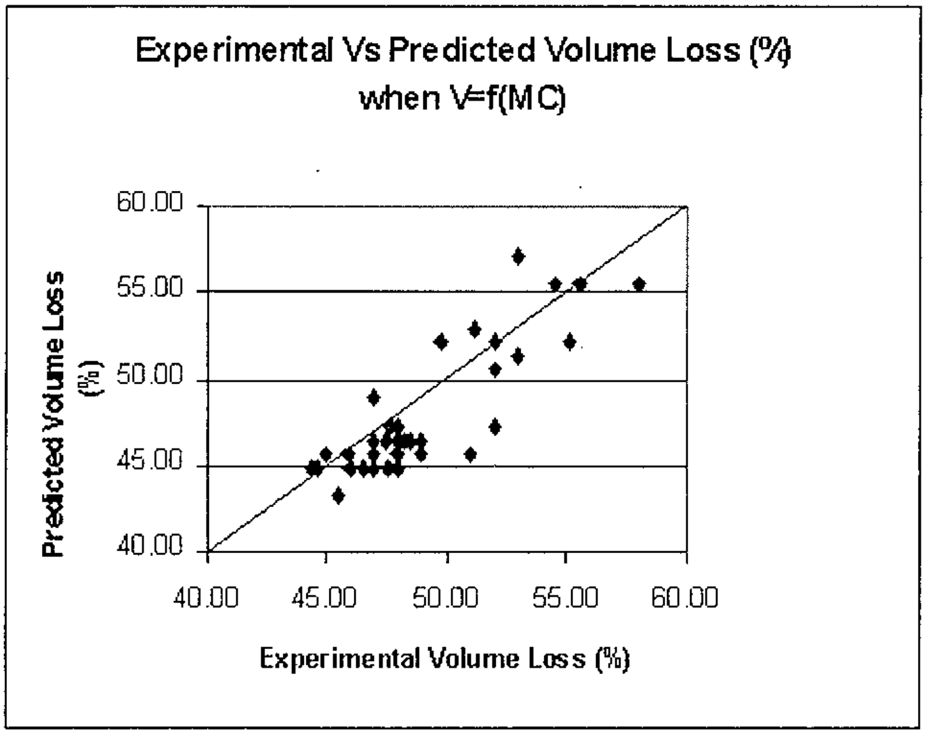


Figure 4.9 : Experimental Vs. Predicted Volume Loss

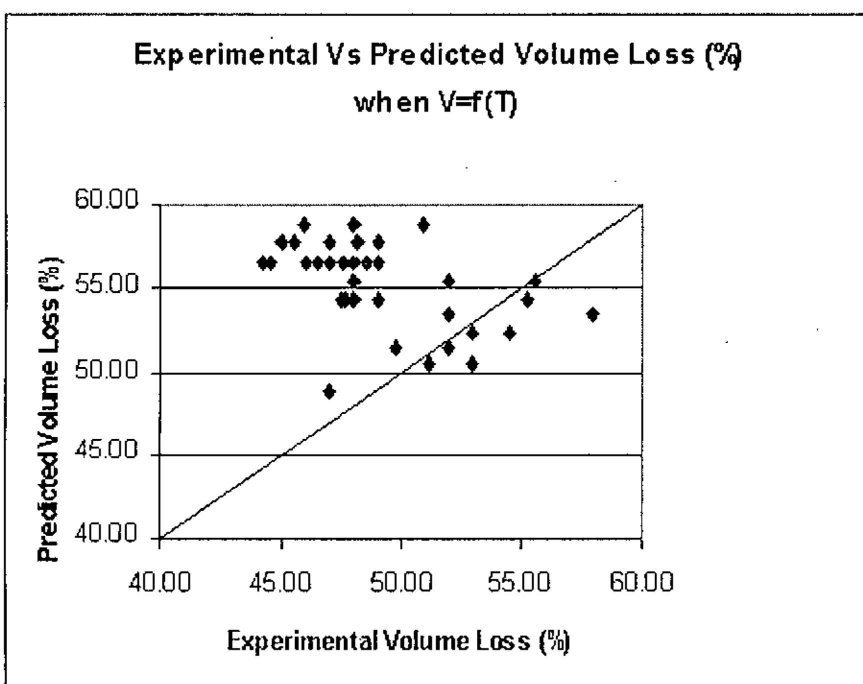


Figure 4.10 : Experimental Vs. Predicted Volume Loss

To establish the parametric study of different independent variables, the above constants are also used to verify the equation using 40 sets of data provided by Moqsud (2003) and hence the figure 4.11, figure 4.12, figure 4.13 figure 4.14, figure 4.15, figure 4.16, and figure 4.17 illustrate predicted and experimental volume loss (%) composting process.

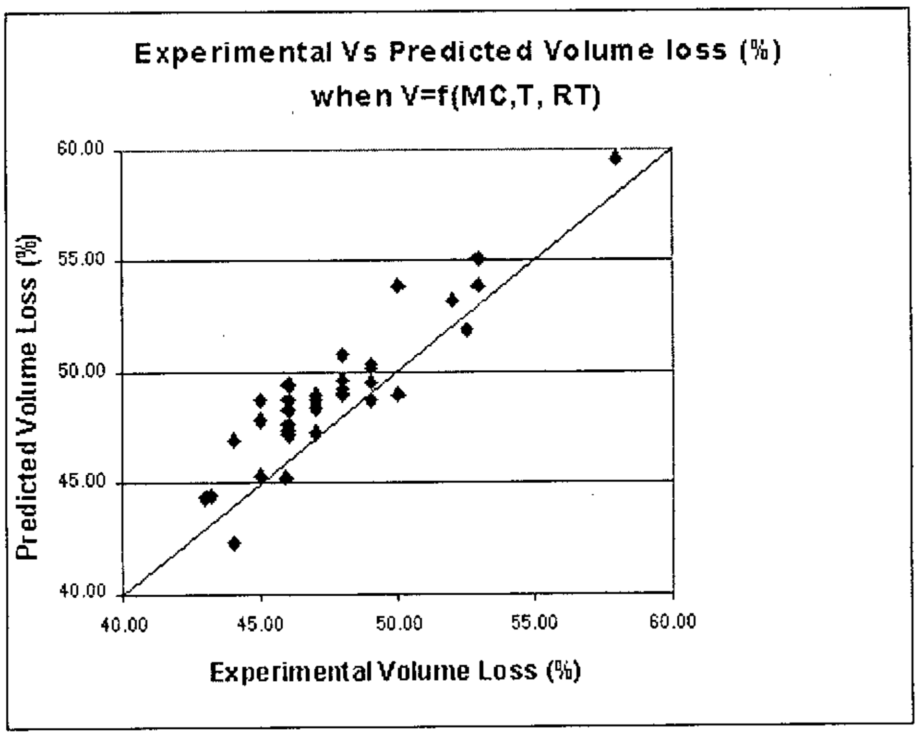


Figure 4.11 : Experimental Vs. Predicted Volume Loss

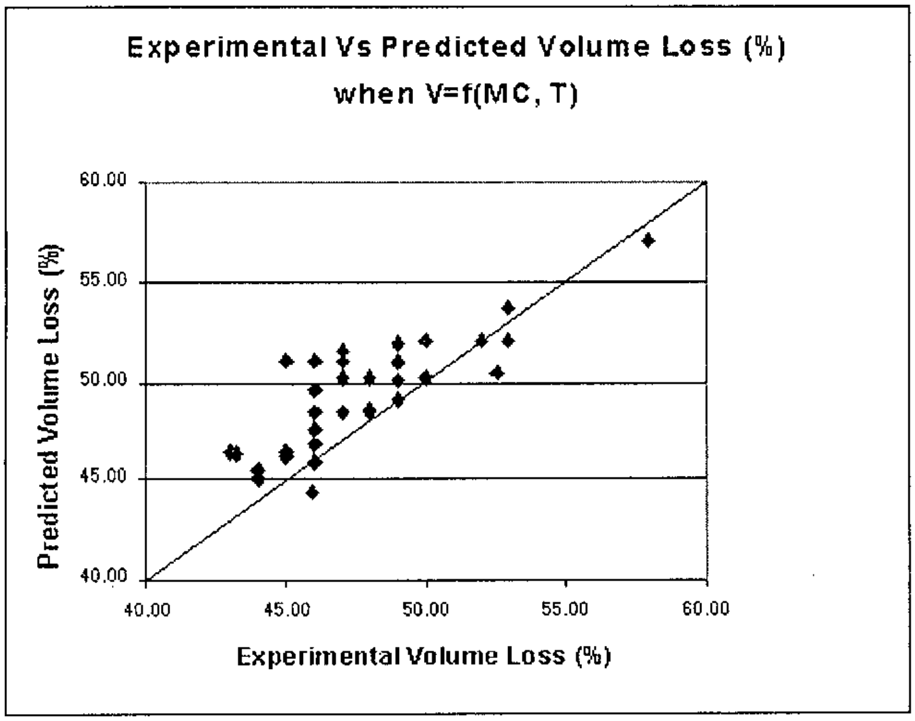


Figure 4.12 : Experimental Vs. Predicted Volume Loss

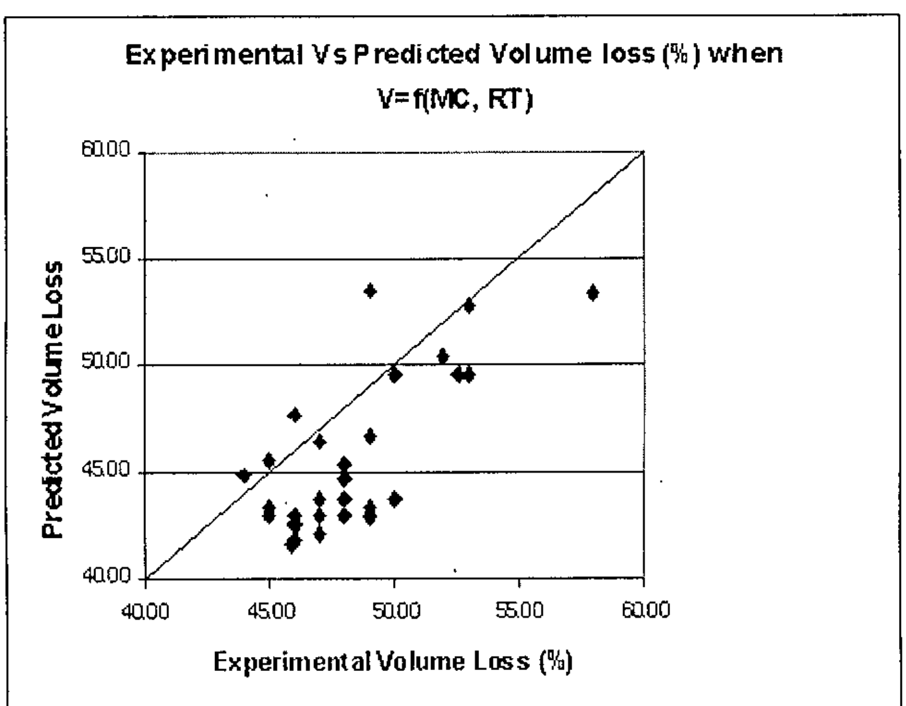


Figure 4.13 : Experimental Vs. Predicted Volume Loss

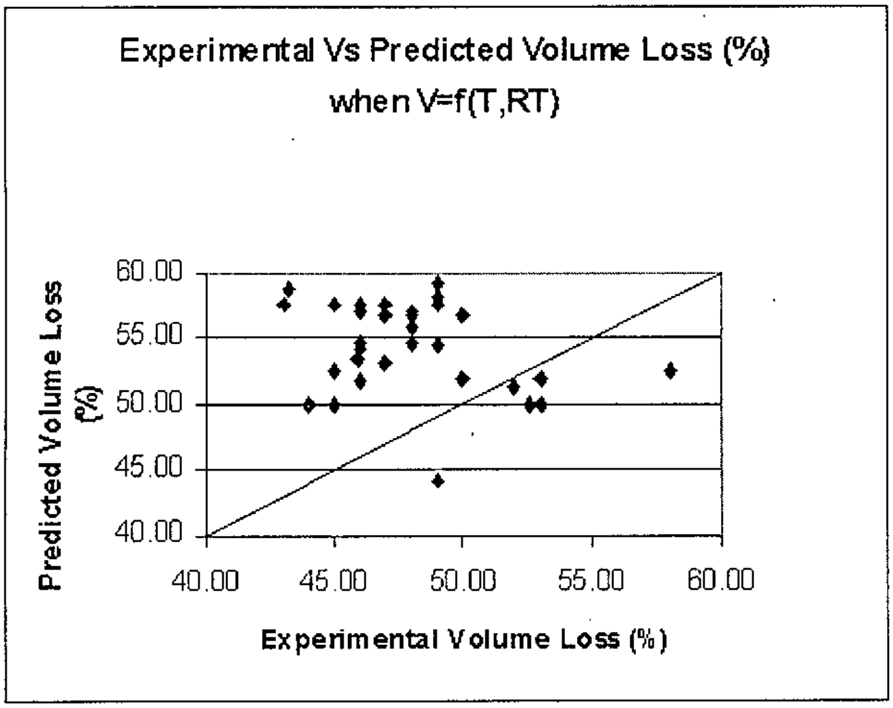


Figure 4.14 : Experimental Vs. Predicted Volume Loss

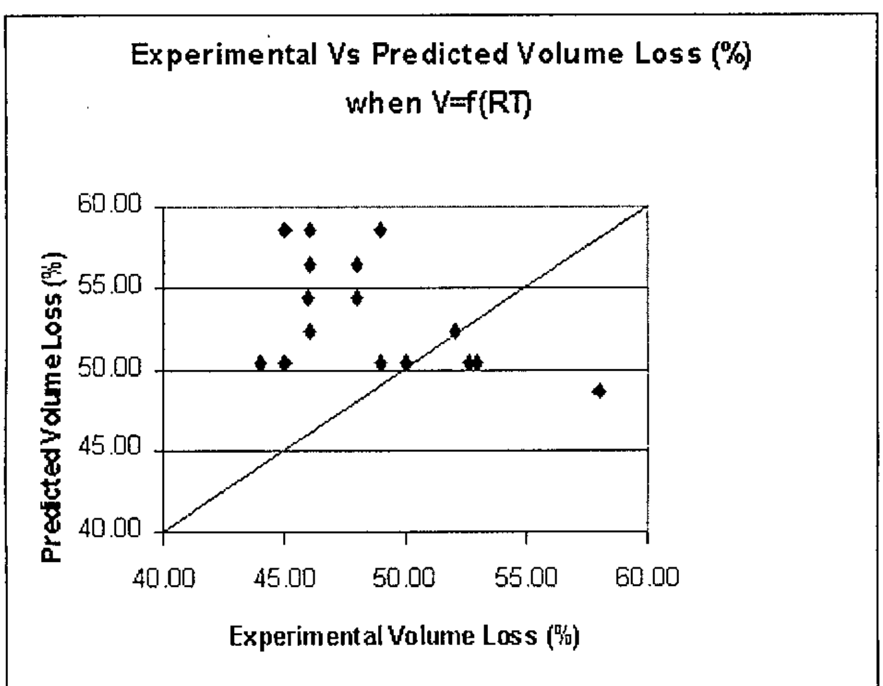


Figure 4.15 : Experimental Vs. Predicted Volume Loss

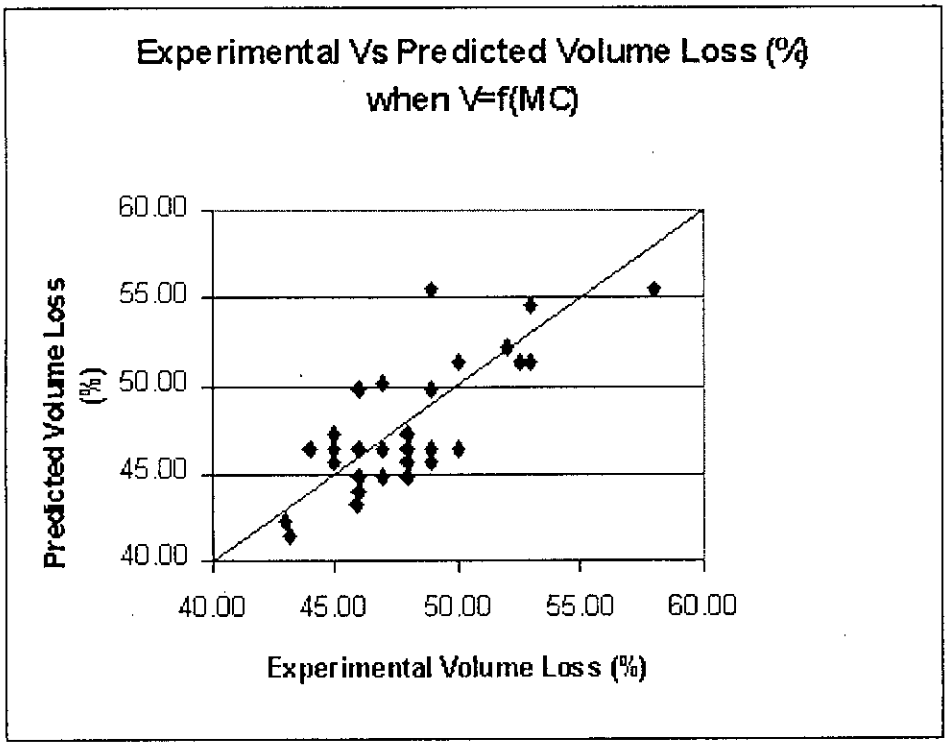


Figure 4.16 : Experimental Vs. Predicted Volume Loss

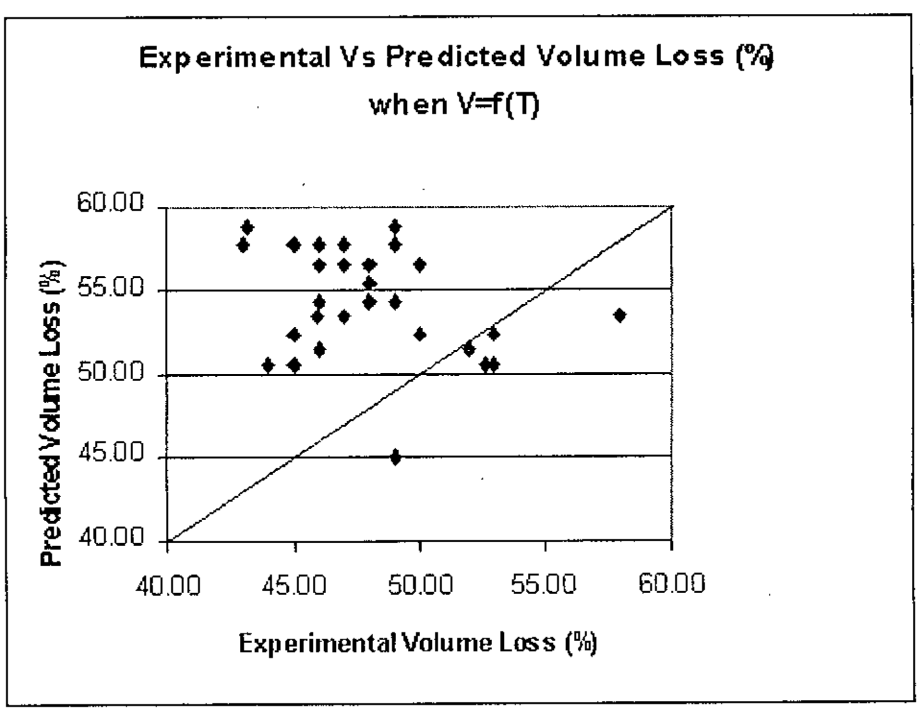


Figure 4.17 : Experimental Vs. Predicted Volume Loss

Now, considering the predicted volume loss is the function of experimental volume loss, the values of R^2 are presented in Table 4.2 for different parametric studies.

Table 4.2 : Values of R^2 for different parametric studies

Considered Parameters when Predicted Volume Loss is the function of Experimental Volume Loss	**R^2**
Moisture content (MC), Temperature (T), Retention Time (RT)	0.82595
Moisture content (MC), Temperature (T),	0.70898
Moisture content (MC), Retention Time (RT)	0.60754
Temperature (T), Retention Time (RT)	0.30981
Retention Time (RT)	0.29380
Moisture content (MC)	0.60352
Temperature (T)	0.12538

It is apparent from the table 4.2 that the total volume loss (%) is in good agreement with 40 sets of experimental data when, volume loss is predicted using the equation (4.2) considering

volume loss = $\int$ (Moisture content, Temperature and Retention Time)

The equation is expressed below :

$$y = \frac{kx_1 x_2 x_3}{(1+ax_1+bx_1^2)(1+cx_2+dx_2^2)(1+ex_3+fx_3^2)} \quad \text{.................................(4.2)}$$

Now, to validate the model, F-test has been performed with the 40 sets of experimental data . For each of the independent variables, the number of degrees of freedom (df) has been calculated while multi regression analysis has been done. The F-value with 3 and 2 degrees of freedom and 95% confidence level is 9.28 and 19 respectively (Table 2.4). The table 4.3 represents the verification of the model using F-test.

Table 4.3 : F-values used in multi regression

Volume loss is Function of	df	Multi regression F value	Standard F value with 95% confidence level	Comment
Moisture content (MC), Temperature (T), Retention Time (RT)	03	56.95	9.28	OK
Moisture content (MC), Temperature (T),	02	13.55	19	Not OK
Moisture content (MC), Retention Time (RT)	02	17.82	19	Not OK
Moisture content (MC)	01	57.84	161	Not OK

Therefore, the derived empirical model of equation (4.2) is established by F-test.

So, the empirical model of thermophilic composting can be derived in the quadratic form using barrel type digester under natural environment and maintaining aerobic condition, which is shown below :

$$y = \frac{kx_1 x_2 x_3}{(1 + ax_1 + bx_1^2)(1 + cx_2 + dx_2^2)(1 + ex_3 + fx_3^2)} \quad \text{.................................(4.2)}$$

where,

y = percentage of volume loss,

x_1 = moisture content (%),

x_2 = reaction temperature (deg cel),

x_3 = retention time (days); and

k, a, b, c, d, e, f = constants.

The graphical presentation of the equation (4.2) is presented in the figure 4.11 to ease the calculation to design a barrel type composting using natural environment. This equation (4.2) represents the process of digestion of composting of domestic solid waste of Gazipur area.

The sets of experimental data those are used in the equations are taken just after the 2 weeks of starting the experiment because the digestion process needs some number of days to process.

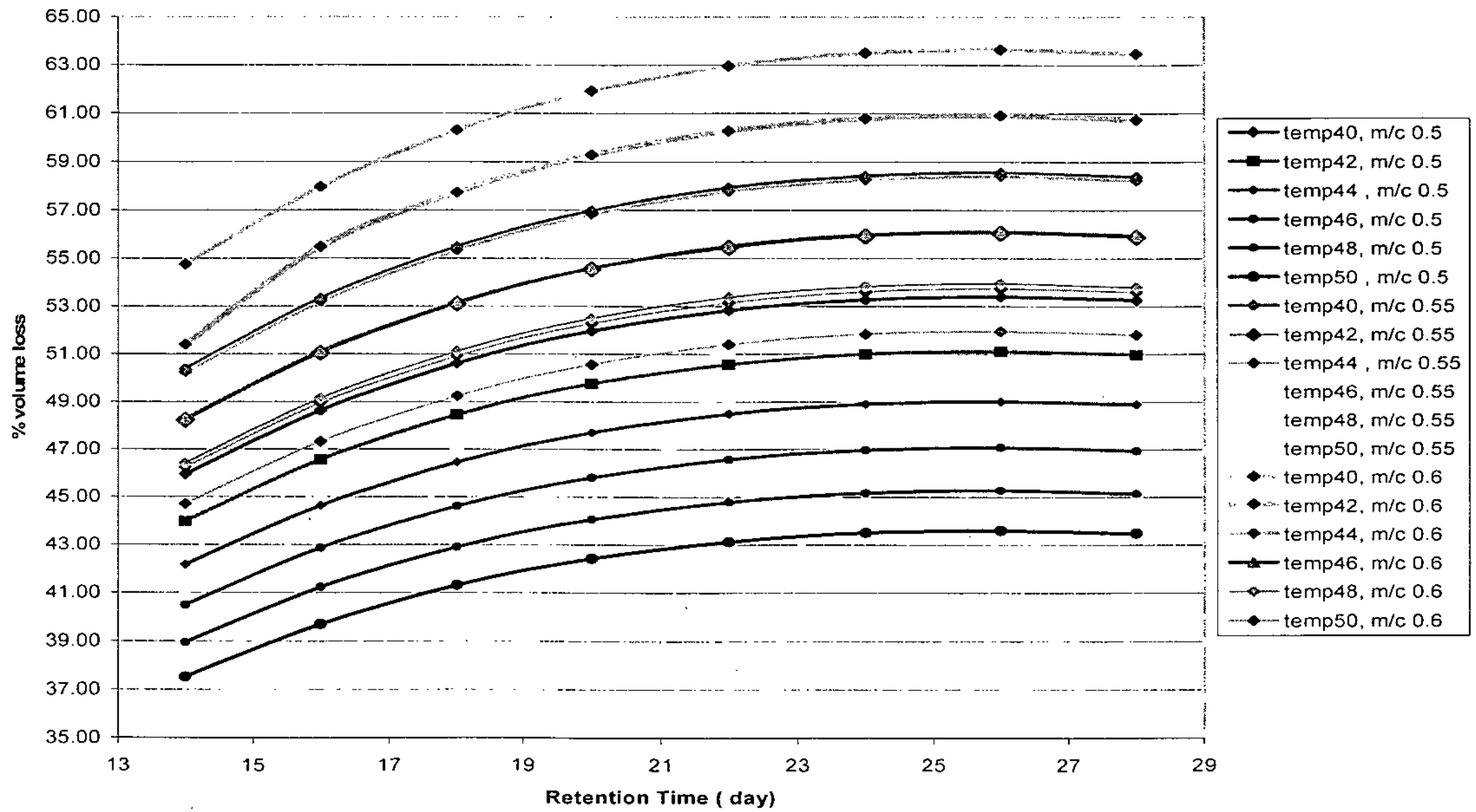


Figure 4.11 : Design Graph of Empirical Model of Thermophilic Composting

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the critical examinations of the previous chapters, the following major conclusions can be drawn:

1. It is evident that after nearly 3 weeks, the variation of volume loss in the composting process is insignificant which can be used as retention time for digester design in composting process in Bangladesh in general and Gazipur in particular.

2. The moisture content of the domestic waste of Gazipur area is suitable for composting and hence without further treatment, the waste can be composted aerobically.

3. The variation of temperature within the barrel during composting does not vary more than 20% at the same duration during different season whereas the natural temperature outside of the barrel is varied 75% at the same duration during different season. So the variation of external temperature is insignificant in composting process.

4. It is extremely difficult to derive a deterministic model that takes into account all complex physicochemical and biological interactions involved in solid waste composting. Accordingly, barrel type composting under natural environment were set up to asses parameters those affect thermophilic composting of domestic waste. The empirical model, which was derived subsequently by fitting in experimental data of thermophilic composting and confirmed by F-test, appeared to conform to a quadratic form. The derived empirical model can be used to predict operating conditions (moisture content, reaction time and temperature) for thermophilic composting of domestic waste.

5.2 RECOMMENDATION FOR FUTURE STUDIES

1. The applicability of the empirical model can be assessed to different types of composting other than barrel type composting.
2. Some other operating conditions of thermophilic composting (e,g, aeration rate etc) can be assessed also as parameters to modify the empirical model.
3. Kinetic behavior of domestic waste composting can also be investigated.

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ANNEXURE

Table: A.1: Variation of Parameters during Composting Process

Set 1 — Period : June-July

Duration (Days)	Moisture	Temperature (Deg. Cel)	Volume loss
0.00		24.00	0.00
5.00	0.53	32.00	0.11
10.00	0.56	37.00	0.25
15.00	0.60	45.00	0.38
20.00	0.65	54.00	0.47
21.00	0.66	57.00	0.49
25.00	0.61	63.00	0.50
30.00	0.58	51.00	0.51
35.00	0.56	42.00	
40.00		35.00	
45.00		30.00	

Set 2 — Period : August-September

Duration (Days)	Moisture	Temperature (Deg. Cel)	Volume loss
0.00		20.00	0.00
5.00	0.55	26.00	0.13
10.00	0.57	32.00	0.26
15.00	0.60	40.00	0.40
20.00	0.64	48.00	0.52
21.00	0.65	50.00	0.55
25.00	0.67	54.00	0.56
30.00	0.63	51.00	0.57
35.00	0.58	46.00	
40.00		38.00	
45.00		33.00	

Set 3 — Period : October-November

Duration (Days)	Moisture	Temperature (Deg. Cel)	Volume loss
0.00		24.00	0.00
5.00	0.50	29.00	0.09
10.00	0.55	34.00	0.24
15.00	0.58	38.00	0.37
20.00	0.60	47.00	0.50
21.00	0.61	50.00	0.53
25.00	0.64	52.00	0.54
30.00	0.61	50.00	0.54
35.00	0.58	48.00	
40.00		42.00	
45.00		37.00	

Set 4		Period : December-January	
Duration (Days)	**Moisture**	**Temperature (Deg. Cel)**	**Volume loss**
0.00		22.00	0.00
5.00	0.47	28.00	0.09
10.00	0.50	34.00	0.19
15.00	0.53	39.00	0.30
20.00	0.55	47.00	0.44
21.00	0.56	50.00	0.47
25.00	0.59	54.00	0.48
30.00	0.55	56.00	0.49
35.00	0.52	52.00	
40.00		48.00	
45.00		44.00	

Set 5 Period :		December-January	
Duration (Days)	**Moisture**	**Temperature (Deg. Cel)**	**Volume loss**
0.00		22.00	0.00
5.00	0.45	27.00	0.08
10.00	0.49	35.00	0.18
15.00	0.51	40.00	0.28
20.00	0.54	45.00	0.41
21.00	0.55	50.00	0.46
25.00	0.58	53.00	0.47
30.00	0.56	51.00	0.48
35.00	0.51	48.00	
40.00		46.00	
45.00		45.00	

Table: A.2: Parameters of Composting Process used in Multiregression.

Col 1 Moisture (%)	**Col 2** Temp (deg cel)	**Col 3** Time (days)	**Col 4** Volume loss (%)
0.62	46	22	0.55
0.60	47	21	0.55
0.58	52	23	0.52
0.68	50	23	0.60
0.66	45	22	0.54
0.62	49	21	0.50
0.63	50	21	0.55
0.66	48	22	0.60
0.56	46	18	0.49
0.53	44	16	0.50
0.55	46	19	0.48
0.54	43	17	0.46
0.53	44	18	0.49
0.54	42	16	0.49
0.53	44	17	0.49
0.56	45	18	0.51

Typical Multiple Regression Analysis Using SPSS for Windows ver 10.0.5 Software

MODEL: MOD_1.

_

Equation number: 1

Dependent variable.. VOL

Listwise Deletion of Missing Data

Multiple R	.97020
R Square	.94128
Adjusted R Square	.92870
Standard Error	.00789

Analysis of Variance:

	DF	Sum of Squares	Mean Square
Regression	3	.01397803	.00465934
Residuals	14	.00087197	.00006228

F = 74.80847 Signif F = .0000

------------------ Variables in the Equation ------------------

Variable	B	SE B	Beta	T	Sig T
MC	.809290	.064226	1.473736	12.601	.0000
TEMP	-.010354	.001264	-1.388701	-8.194	.0000
TIME	.009776	.001371	.845602	7.128	.0000
(Constant)	.340192	.024282		14.010	.0000

Correlation Matrix of Parameter Estimates

	MC	TEMP	TIME
MC	1.0000000	-.7541010	.3460392
TEMP	-.7541010	1.0000000	-.7620876
TIME	.3460392	-.7620876	1.0000000