Seasonal Variation on Extent of Stabilization of Faecal Sludge for Safe Disposal during Co-composting in Forced Aeration and Passively Aeration Process

by

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Declaration

This is to certify that the thesis work entitled *"Seasonal Variation on Extent of Stabilization of Faecal Sludge for Safe Disposal during Co-composting in Forced Aeration and Passively Aeration Process."* has been carried out by *Md. Alamin* in the Department of *Civil Engineering*, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above thesis work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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This is to certify that the thesis work submitted by *Md. Alamin* entitled *" Seasonal Variation on Extent of Stabilization of Faecal Sludge for Safe Disposal during Co-composting in Forced Aeration and Passively Aeration Process."* has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh in November 2017.

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ABSTRACT

In many developing countries, a large proportion of municipal wastes especially organic solid wastes and Faecal Sludge are not properly disposed. Co-composting of Faecal Sludge (FS) and Organic Solid Waste (OSW) can contribute as efficient waste management tool and allows recycling of nutrients into agriculture thereby closing the nutrient circle. This study was conducted to investigate the effect of temperature variation and mass balance of forced and passive aeration on Co-composting process with different stages in wet and dry seasons. Degree and extent of degradation were determined through different composting process in first, second and third stage with different mix proportion of Faecal Sludge in both seasons. Degradation rates were analysed in composting for Faecal Sludge and solid waste mixture. For conducting experiment, suitable organic solid wastes were collected from a student's hall and other sources. Organic solid waste was prepared according to waste proportion (vegetable wastes: food wastes: waste paper: sawdust) as 40:35:10:15. The Faecal sludge was collected from a septic tank. Always OSW and FS were mixed at four different ratios as 90:10, 85:15, 80:20 and 75:25 (OSW : FS). In wet season the number of reactors used in first, second and third stage were 32, 24 and 16 respectively with total 72 number reactors. Similarly for dry season a total of 72 reactors were used for the experiment. In another run 60 more reactors were used for degradation rate analysis. To investigate the effect of initial moisture content on volatile solids degradation and temperature parameters another were used. Therefore, total 218 reactors were used for whole research work. Forced aeration and passively aeration composting tests were done using series of reactors as described above according to a planned experimental program. Composting tests were performed in three stages of 15–30 days duration each. Maximum temperature of passively and forced aeration tests were 65 ºC and 67 ºC which raised within 5 days. In third stage the temperature was not increase much because in this stage the compost become stable and contain very less biodegradable volatile solids (BVS). In both seasons the peak temperature of all the passively aerated and forced aerated composting tests were almost same. It means that the Co-composting process can be applied smoothly over the year in Bangladesh to manage FS without any interruptian of seasonal effect. Results of both seasons showed that, the moisture content and volatile solids always decrease after composting in most of the composting process. For passively aerated process, the average percent reduction of volatile solids of first stage, second stage and third stage were 27.6%, 12.4% and 8.2% respectively and for forced aerated process, the average percentges were 30.8%, 13.6% and 9.2% respectively. Percentage degradation of volatile solids in third stage was less because in this stage the compost become stable and contain very less BVS. In wet season, the absolutely total BVS degradation of the passively and forced aeration process were ranged in between 80 % to 92 %. In dry season the ranged were 73% to 91%. According to the mass balance, the volatile solids degradation in composting process using forced aeration was more than passively aeration process. The average maximum area under curve $T\text{-}T_a$ of first stage and second stage was found 10764 °C.h and 9864 °C.h respectively. For every set of reactor for first and second stage, the total percentage of degradation was almost same. For detemination of optimum moisture content, the area under the temperature curve in °C.h and %VS reduction was highest in the initial moisture content range between 55% and 70%. The temperature dependence of the reaction rates of different satge passive and forced aeration composting tests clearly followed the Arrhenius equation. The actual reaction rates provided good correletion with reaction rates. Percentage degradation of volatile solids depending on temperature could be predicted well using a first order reaction model. Compost produced in first and second stage were stable with stability index of II to IV. All compost of third stage were more stable than first and second stage with stability index of IV to V according to LAGA (1985). The Temperature pattern, during composting, Degradation of biodegradable volatile solids and Stability index of produced compost were almost same in passive and forced aeration Co-composting process. Passive aeration composting system are economical in operations and maintenance and produce good quality compost. Therefore, the passively aeration Co-composting process can be applied smoothly in Bangladesh round the year to manage Faecal Sludge.

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NOMENCLATURE

ADB	Asian Development Bank
BARC	Bangladesh Agricultural Research Council
BVS	Biodegradable Volatile Solids
DPHE	Department of Public Health Engineering
DSK	Dustha Shystha Kendra
FS	Faecal Sludge
FSM	Faecal Sludge Management
IGES	Institute for Global Environmental Strategies
KCC	Khulna City Corporation
KU	Khulna University
KUET	Khulna University of Engineering & Technology
KWASA	Khulna Water Supply and Sewerage Authority
LGED	Local Government Engineering Department
MC	Moisture Content
NGO	Non-Government Organization
OSW	Organic Solid Waste
PSTC	Population Services and Training Centre
SWM	Solid Waste Management
TM	Total Mass
TS	Total Solids
UNCRD	United Nations Center for Regional Development
VS	Volatile Solids

CHAPTER I

Introduction

1.1 General

A significant challenge confronting engineers and scientists in developing countries is the search for appropriate solutions to the collection, treatment, and disposal or reuse of domestic solid waste. Waste is an unavoidable by product of human activities. Economic development, urbanization and improving living standards in cities, have led to an increase in the quantity and complexity of generated waste. Solid waste disposal poses a greater problem because it leads to soil pollution if openly dumped, water pollution if dumped in low lands and air pollution if burnt. Rapid growth of population and industrialization degrades the urban environment and place serious stress on natural resources, which undermines equitable and sustainable development. Inefficient management and disposal of solid waste is an obvious cause of degradation of the environment in most cities of the developing world and it is one of the most immediate and serious environmental problems confronting local governments. Solid waste, if just dumped on a landfill site, is a misplaced resource causing further environmental problems. Integrated waste management focuses on recycling and reuse of different waste types. Composting is the best option for solid waste management. However, composting offers a cost-effective sustainable solution for the biodegradable organic wastes. This is a very effective process for recovering waste materials and for minimizing environmental emission by stabilizing the organic wastes in the shortest period of time. In practice, the main biological process applied for solid wastes is composting (Haug, 1993). The use of organic solid waste has a long history mainly in areas of the world. The biodegradable portion could be managed either by recycling and recovering through biological treatment, or disposal to landfills. Solutions for effective and sustainable Faecal Sludge Management (FSM) presents a significant global need. FSM is a relatively new topic, however, it is developing rapidly and gaining acknowledgement. FSM can be managed together with composting process and the find process is usually named as Co-composting.

Co-composting is a resource recovery technique resulting in production of soil conditioner from the combined organic solid waste and Faecal Sludge. Co-composting is the term used to indicate the composting of two different materials together. In this case Faecal Sludge (FS) and organic solid waste (OSW), both are composted together. Other organic materials, which can be used or subjected to Co-composting, comprise animal manure, sawdust, wood chips, bark, slaughter, sludges and solid residues from food and beverage industries. Co-composting of Faecal Sludge and organic solid waste is advantageous as these two materials complement each other. Faecal sludge is relatively high in nitrogen content on the other hand organic solid waste is high in Carbon content. Both materials can be converted into a useful product by doing Co-composting. High temperatures attained in the composting process are effective in inactivating excreted pathogens contained in the FS and will convert both wastes into a hygienically safe soil conditioner-cum-fertilizer. The technologies chosen for aerobic Co-composting will depend on the location of the facility the capital available and the amount and type of waste delivered to the site. There are two main types of systems namely 1) open systems such as windrows and static piles, 2) closed systems such as vessel systems. The effective use of such compost in agriculture depends among other factors on its quality. Quality is affected by the type of initial material, the process of composting and the maturity of the final product. The key factors affecting the biological decomposition processes are carbon to nitrogen ratio, moisture content, oxygen supply, aeration, particle size, pH, temperature, turning frequency, microorganisms and invertebrates, control of pathogens, degree of decomposition and nitrogen conservation (Strauss et al, 2003). Therefore, in this study, temperature variation with different stage in wet and dry season was investigated with bench-scale tests, in order to obtain a better understanding of the above mentioned and other important factors and to extent the findings for better design of future composting plants. This research study involves the Co-composting of Faecal Sludge and organic solid waste, also their mixing ratio that will exhibit better result regarding specific use. Therefore an attempt has been under taken in this research to know the extent of stabilization of Faecal Sludge for safe disposal during Co-composting in forced aeration and passively aeration process.

1.2 Objectives of the Study

The specific objectives of this study are outlined as below:

- To observe temperature variation of Co-composting process in first, second and third stage with different mix proportion of Faecal Sludge in wet and dry season.
- To establish the mass balance before and after different Co-composting process.
- To determine extent of degradation after first, second and third stages with different mix proportion.
- To analyze degradation rate of Faecal Sludge and Solid Waste mixture.

1.3 Organization of Thesis

Chapter 1: Includes general introduction, objectives of this study. In Chapter 2: past and present composting practices are reviewed, (i) the factors affecting the composting process and their interrelated effects; and (ii) measurement techniques of product quality, Theoretical respects which form the basis for prediction of organic waste degradation during composting are reviewed. In Chapter 4: Detailed experimental programs and analytical methods for physico-chemical parameters are presented. Experimental programs of Chapter 4 include pilot-scale composting tests, bench-scale composting tests and self-heating tests to assess the product quality. In Chapter 5: contains the results of the experiments extent of degradation, product stability and on other physico-chemical parameters. Kinetic analysis of the experimental results, based on the theoretical considerations. Chapter 6. A general discussion on the findings of the study, conclusions and a number of recommendation for the future study are provided.

CHAPTER II

Literature Review

2.1 Historical Overview

The growth of world's population, rising standards of living, increasing urbanization, and technological developments all responsible in both the amount and the variety of solid wastes generated by industrial, domestic and other activities. The problems of dealing with greater volumes of often more dangerous-waste materials are particularly acute in developing countries where these changes have been met by improvements in waste-management technologies.

The worlds' population is increasing and concentrating in urban centers. This trend is particularly intense in developing countries, where an additional 2.1 billion people are expected to be living in cities by 2030. These cities produce billions of tons of waste every year, including faecal sludge (FS). Waste generation rate of the world is increasing along with the population and development of the region. Management of this is one of the prime concerns of the countries around the world.

A good solid waste management system is like good health. Managing solid waste well and affordably is one of the key challenges of the 21st century, and one of the key responsibilities of a city government. It may not be the biggest vote-winner, but it has the capacity to become a full-scale crisis and a definite vote-loser, if things go wrong. The safe removal and subsequent management of solid waste sits alongside the management of human excreta (sanitation) in representing two of the most vital urban environmental services. Other essential utilities and infrastructures, such as water supply, energy, transport and housing, often get more attention (and much more budget); however, failing to manage properly the 'back end' of the materials cycle has direct impacts on health, length of life, and the human and natural environment. (United Nations Human Settlements Programme, 2010).

Composting and Co-composting provides many benefits. It not only diverts organic materials from disposal in landfills, it also helps to return nutrients and organic matter to the soil, providing a valuable material for agriculture, horticulture and landscaping. This research paper is prepared to provide practical guidance and the latest knowledge related to Co-composting of organic waste from municipal waste streams, including human excreta, in order to support planners, researchers, development experts and practitioners in their work. It offers an in-depth review of framework conditions, methods and relevant process parameters that govern Co-composting with special attention on the reuse of sensitive input materials such as faecal sludge, manure and municipal organic waste that influence compost quality and offer significant co-benefits for sanitation and agriculture (Cofie et at, 2016).

2.2 Brief on Solid Waste and Faecal sludge Management

2.2.1 The Waste Situation in Developing Countries

Solid Waste Management (SWM) and Faecal sludge Management (FSM) are relevant public tasks to enable sustainable and healthy human settlements, but they are severely constrained by various issues in many developing countries. Waste generation and the complexity of waste composition is steadily increasing due to population growth, urbanization and economic development, especially in larger cities. Although emerging innovations such as mechanical and biological waste treatment, waste-to-energy technologies, engineered landfilling and others are available and have proven effective in industrialized countries, they are not ready for uptake in most low income countries. In this context, composting, as a low cost technology, is a valid and relevant option to enhance waste management in developing countries where the bulk of collected solid waste is organic in nature but recycling rates are still low (UNEP 2011; D-Waste 2013).

Current municipal solid waste generation on a global scale is estimated to be approximately 1.3 billion tons/year, and is expected to increase to approximately 2.2 billion tons year in 2025 (Hoornweg and Bhada-Tata 2012; D-Waste 2013). Based on this forecast, a significant increase in per capita waste generation rates will occur within the next 15 years. At present, average waste generation in industrialized countries varies between 1 and 2 kg/person/day, while waste generation in low income countries is usually much lower with generation rates of 0.4 to 0.8 kg/person/day (UNEP 2011; Simelane and Mohee, 2012; Hoornweg and Bhada-Tata 2012, D-Waste 2013). Global Trends in Solid waste generation are represent as shown in Figure 2.1.

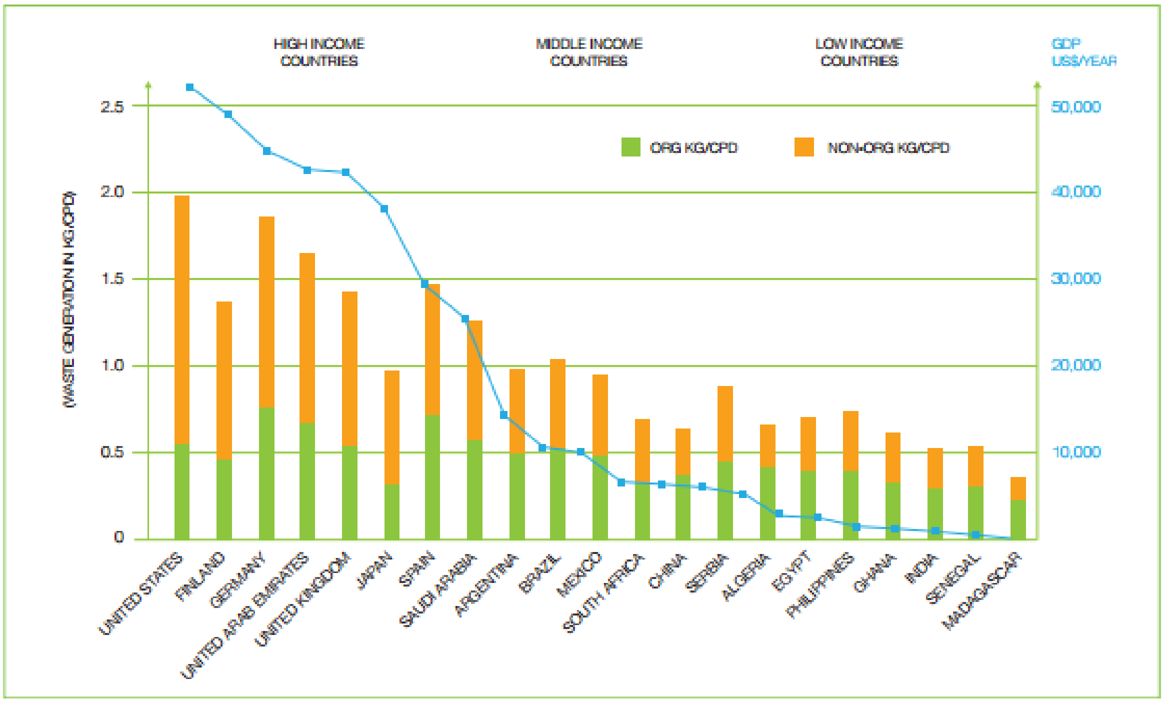


Figure 2.1: Global Trends in Solid waste generation (UN-ESA 2011, 2013; D-Waste 2013)

2.2.2 Challenges of Solid Waste Management

In developing countries, amounts of collected solid waste are usually less than half of what is generated. Most of it is neither contained nor recycled (Simelane and Mohee, 2012). Instead, it is often disposed of indiscriminately at illegal dump sites, at the periphery of urban centers, buried in backyards, along roads or thrown into drainage systems, idle land or waterways. The magnitude of such malpractices in waste management correlates with the efficiency of available waste collection services, whereas lack of service increases illegal waste dumping, scattered waste burning and pollution of land, drainage systems and waterways. As a result, the aesthetic value of settlements decreases (Simelane and Mohee, 2012). Moreover, uncollected waste is a nuisance and could serve as breeding ground for various disease-causing vectors such as mosquitoes, insects and rodents. It also endangers public health, contaminates water sources, causes emissions of odors and greenhouse gases and discourages tourism (USEPA, 2002; UNEP, 2005). Furthermore, due to clogging of drainage systems through solid waste disposal local flooding might increase. Impacts from waste disposal operations especially concern residents who live in the vicinity of dump sites but likewise threaten informal waste pickers who work on these dumps. Waste pickers are recognized as a marginalized and vulnerable group of around 15 million people worldwide (Durand, 2013).

2.2.3 Challenges of Faecal sludge Management

Generally, when faecal sludge (FS) or excreta are collected from on-site sanitation installations, the extracted sludge would need to be treated prior to disposal. However, common practice in many developing countries is to transport FS from tank cleaning directly to dump sites or treatment plants or to dispose it in the vicinity into dug pits, drainage systems, natural depressions, rivers or other water bodies. FS is also being used without further treatment on farmlands, discharged into fish ponds and lakes or discarded on backyards in private compounds (Jiménez *et al.*, 2010). These predominant methods of excreta disposal are applied by most urban dwellers in Africa and Asia as well as in many communities of Latin America.

Safe FS and wastewater recycling is not only a viable way of tackling increasing urban waste management issues in developing countries, but it also provides additional job opportunities. To date, the up scaling of promising initiatives is hindered by various barriers such as poor planning, low market development, lack of expertise, equipment and funding as well as unhygienic conditions for waste workers. Furthermore, poor stakeholder participation, lack of sectorial policies and enforcement mechanisms, bureaucracy and weak government collaboration may hinder or delay replication of innovative FSM approaches.

2.2.4 Faecal sludge Management in Bangladesh

Generally, faecal sludge management is unsystematic, unplanned, poorly regulated and mostly provided by individuals or informal private service providers. However, in recent years there has been increasing interest in FSM in Bangladesh. The recently approved National Water Supply and Sanitation Strategy, 2014, provides specific strategic directions to address faecal sludge related issues and design, and to implement a comprehensive faecal sludge management programmed. There are also a number of ongoing initiatives to carry out faecal sludge management programmers at a small scale or on a pilot basis at local levels. For example, the Department of Public Health Engineering (DPHE), with Asian Development Bank (ADB) assistance, is executing a project for water and sanitation services in secondary towns. Under this project, FSM facilities will be introduced in 11 towns. Sludge treatment plants will be constructed on the outskirts of towns, into which the sludge will be disposed.

In Dhaka city, two NGOs – Dustha Shystha Kendra (DSK) and Population Services and Training Centre (PSTC) – with financial and technical support from Water Aid have been providing mechanical faecal sludge emptying services. Different fees are charged for different economic groups; low-income groups in slums get a subsidized rate.

In Khulna city, under an ADB-funded project, the Khulna City Corporation (KCC) uses two tank Lorries towed by tractors and equipped with suction pumps for mechanical emptying purposes. While the corporation charges a fee from households for providing services, the collected sludge is usually deposited into open water. In Faridpur town, the municipality provides a mechanical emptying service using a Vacutug purchased through funds provided by the municipality and the INGO Practical Action. The Local Government Engineering Department (LGED) has taken up an urban sanitation strategy preparation task with ADB financing. The National Forum for Water Supply and Sanitation has recently assigned ITN-BUET with the task of coordinating the ongoing initiatives. SNV Netherlands Development Organization, with funding from the Bill & Melinda Gates Foundation, took the initiative to reform FSM practices in southern Bangladesh in partnership with Khulna University of Engineering & Technology (KUET), Khulna University (KU), Khulna Water Supply and Sewerage Authority (KWASA) and Water Aid. A baseline survey was conducted with the intention of creating a foundation stone for this FSM modernization scheme, which will offer city-wide, pro-poor, safe and sustainable faecal sludge management services (Base line Survey report, 2014).

2.3 Composting

2.3.1 General Review of Composting

Composting is a biological process that involves microorganisms which decompose organic matter under controlled predominantly aerobic conditions. The resulting end product is stabilized organic matter that can be used as a soil conditioner. It also contains nutrients which can have a benefit as a long-term organic fertilizer. There are two types of composting systems, open and closed, of which open systems are lower in capital and operating costs but typically require more space. In an open composting system, raw organic matter is piled up into heaps (called windrows) and left for aerobic decomposition. To increase space efficiency, the heaps of waste can also put into walled enclosures which is called box composting. If untreated waste feedstock is placed in a closed container this is called in-vessel or closed drum composting and is considered in the category of closed systems.

2.3.2 Composting Substrates

The organic matters that are biodegradable are known as composting substrates
Organic matter

- Food wastes
- Vegetable wastes
- Waste paper
- Saw dust
- Wood saw
- Faecal Sludge

2.3.3 Composting Microorganisms

During the composting process, microorganisms break down organic matter and produce carbon dioxide, water, heat and humus, the relatively stable organic end product. Under optimal conditions, composting proceeds through three stages in a batch system:

1. The mesophilic, or moderate-temperature stage, which lasts for a couple of days.
2. The thermophilic, or high-temperature stage, which can last from few days to several months, and finally
3. A several-month cooling and maturation stage.

The various composting phases are predominated by different communities of microorganisms. Initial decomposition is carried out by mesophilic microorganisms, which rapidly break down the soluble, readily degradable compounds. The heat produced causes the compost temperature to rapidly rise. As the temperature rises above 40ºC, the mesophilic microorganisms become less competitive and are replaced by others that are thermophilic, or heat-loving. At temperatures of 55ºC and above, many microorganisms that are human or plant pathogens are destroyed. Because temperature above 65ºC kill many forms of microbes and limit the rate of decomposition, compost managers use aeration and mixing to keep the temperature below this point. During the thermophilic stage, high temperatures accelerate the breakdown of proteins, fats and complex carbohydrates like celluloses and hemicelluloses, the major structural molecules in plants. Since the process of supplying of these high-energy compounds becomes exhausted, the temperature of the compost gradually decreases and mesophilic microorganisms once again take over for the final stage of “curing” or maturation of the remaining organic matter (Rahman and Al-Muyeed, 2010).

2.3.4 Basic Composting Process

Composting is the biological degradation of highly concentrated biodegradable organic waste in the presence of oxygen to carbon dioxide (CO_2) and water (H_2O), whereby the biologically generated waste heat is sufficient to raise the temperature of the composting mass to the thermophilic range (50-65º C). The final product of the composting is stable humus like materials known as compost.

$$\text{Organic Waste} + O_2 \xrightarrow{\text{Micro-organism}} \text{Compost} + CO_2 + H_2O + NH_3 + \text{Heat}$$

Composting is the process of bacterial conversion of organic solid and semi-solid wastes into compost which can be handled, stored and transported without any adverse environmental effect and can be used as organic manure for improvement of soil quality and fertility. Composting is an ancient resource recovery process practiced, though less frequently, in both developing and industrialized part of the world (Ahmed and Rahman, 2000). Aerobic processes are net energy users because oxygen must be supplied for waste conversion, but they offer the advantage of relatively simple operation and, if properly operated, can significantly reduce the volume of organic portion of solid wastes.

$$mC_aH_bO_cN_d + nO_2 \Longrightarrow xCO_2 + yH_2O + zNH_3$$

$$NH_3 + 2O_2 \Longrightarrow H_2O + HNO_3$$

The operation of anaerobic processes is more complex than that of aerobic processes. Different stages in the composting process as related to temperature was present in

Figure 2.2. However, anaerobic processes offer the benefit of energy recovery in the form of methane gas and thus are net energy producers (Tchobanoglous et al. 1993).

$mC_aH_bO_cN_d + nH_2O \Longrightarrow xCO_2 + yCH_4 + zNH_3$

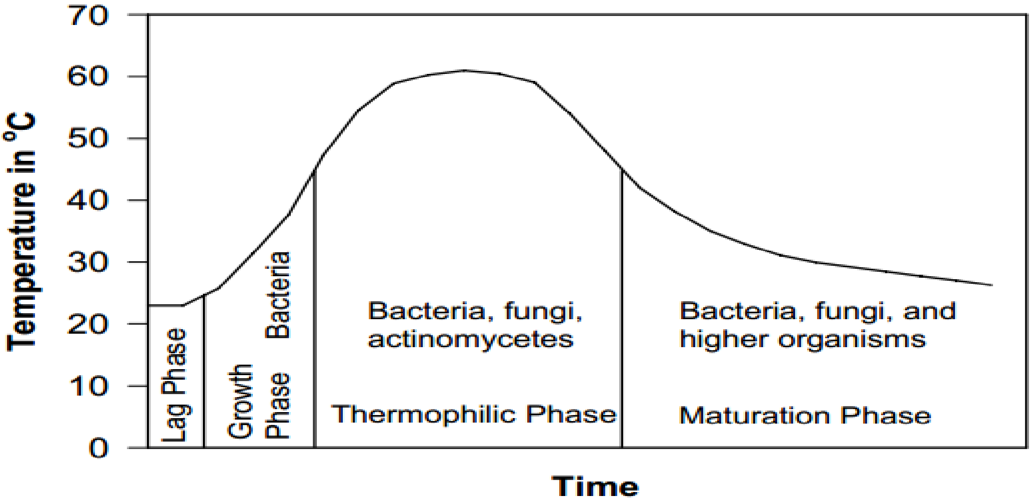


Figure 2.2: Different stages in the composting process as related to temperature (Bari, 1999).

2.4 Factors affecting the Composting Process

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

2.4.1 Moisture Content

Moisture supports the metabolic processes of the micro-organism. The range of optimum moisture content for aerobic composting is 50 to 60 percent. Water is the medium for chemical reaction. Biological activity ceases below 30% (Bari & koning, 2001) moisture content and in the theory activity is optimal when material are saturated. At moisture levels above 65 percent, 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 (Ahmed and Rahman, 2000).

If adequately aerated, composting material with moisture content between 30% and 100% will be aerobic. In practical aerobic composting, however, high moisture content must be avoided because water displaces air from the interstices between the particles causing anaerobic conditions. However, too low moisture content deprives organisms of water needed for their metabolism, and inhibits their activity.

2.4.2 Temperature

In aerobic composting proper temperature is important. Heat is released in the process. Since composting material has relatively good insulation properties, a composting mass large enough (3’ x 3’) will retain the heat of the exthermo-biological reaction and high temperatures will develop. Microorganisms generate heat as they decompose organic material. A compost pile with temperatures between 32 ºC to 60 ºC is composting efficiently. Temperatures higher than 60 ºC inhibit the activity of many of the most important and active organisms in the pile (Nakasaki, 1985). Rapid rate of composting occurred in high temperature. The rate of composting will inevitably slow during the winter season in cold climates. Some microorganisms will continue the decomposition process in cold climates but the rate of decomposition is slow.

2.4.3 Nutrients and Carbon Nitrogen (C: N) ratio

The microbes involved in composting use carbon for energy and nitrogen for protein synthesis. The proportion of these two elements required by the microbe’s averages about 30 parts carbon to 1 part nitrogen (dry weight basis). Adding 3-4 pounds of nitrogen material for every 100 pounds of carbon should be satisfactory for efficient and rapid composting. The composting process slows if there is not enough nitrogen, and too much nitrogen may cause the generation of ammonia gas which can create unpleasant odors. Leaves are a good source of carbon; fresh grass, manures and blood meal are sources of nitrogen. The Carbon Nitrogen (C: N) ratio is very near to ideal value of plant life (BRAC, 1997). The compost produced from kitchen garbage in different seasons in Bangladesh has very good nutrient values and also very good microbial quality and can effectively be used as soil conditioner (Moqsud and Rahman, 2004).

2.4.4 Particle Size, porosity, structure and texture

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

2.4.5 pH

Another important parameter is control of pH to evaluate the microbial environment and waste stabilization. As like as temperature, the pH value of compost varies with the time during the composting process. The initial pH of the organic fraction of municipal solid waste (MSW) is typically 5 and 7. After about three days the temperature reaches a thermophilic stage, and the pH begins to rise to approximately 8 or 8.5 for the remainder of the aerobic process. The pH value falls slightly during the cooling stage and reaches to a value in the range of 7 to 8 in the mature compost. If the degree of aeration is not adequate, anaerobic conditions will occur, the pH will drop to about 4.5, and the composting process will be retarded (Tchobanoglous et al. 1993). Total organic carbon and moisture content obviously declined with the increase of composting time, and the content of NO_3-N increased. pH, electrical conductivity, NH^+_4-N, cellulose and urea activities originally increased and then declined (Wang et al. 2012).

2.4.6 Surface Area

Decomposition by microorganisms in the compost pile takes place when the particle surfaces are 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 microorganisms are able to digest more material, multiply more quickly, and generate 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 can digest (Strauss et al., 2003).

2.4.7 Oxygen/Aeration

If there is insufficient oxygen, a different set of anaerobic microorganism dominates the degradation process and produce odorous intermediate products such as methane, organic acids and hydrogen sulphide. A constant supply of oxygen will give the aerobic microorganisms an advantage over the anaerobic microorganisms. Approximately a 5% minimum concentration of oxygen is required within the pore spaces in the media. Aeration is the process of providing oxygen into the composting material. This will also provide a platform to remove water vapour, gases and excess heat trapped within the material. Aeration is common practice with high rate large scale composting facilities (Strauss et al., 2003).

2.5 Classification of Composting Systems

Various classifications of composting technologies are mentioned in different references including some additional terms such as mesophilic composting, thermophilic composting, vermi-composting, passively aerated composting, etc. However, the technologies are often classified into two broad groups, namely, open (non-reactor system) and closed (in-vessel or .reactor system) system (Haug 1993, Rothenberger S. et al. 2006, Lardinois et al., 2001). Sometimes, a combination of these systems is also practiced. Mostly, the closed system is used for the initial high decomposition stage and after that maturation or curing takes place in the open system. Detailed classifications of composting systems are given Figure 2.3.

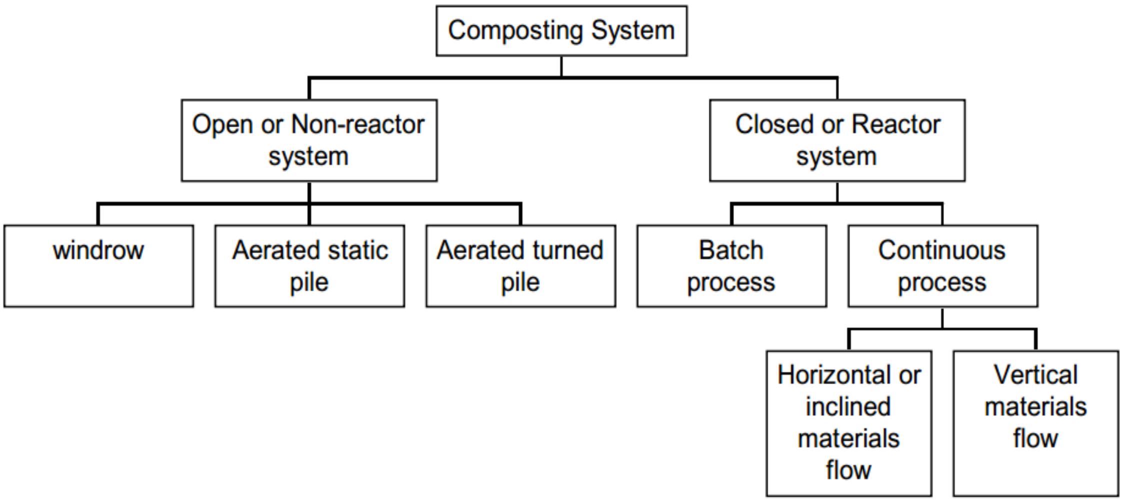


Figure 2.3: Detailed classification of composting systems (Bari, 1999)

The selection of aerobic composting process depends on certain criteria: funds available, amount and type of waste, location of the facility. Mainly two types of process are considered. These are: (a) Open System (windrows or heap, bean, trench); (b) Closed System (vessel or reactor).

a) Open System

Open" systems are the ones most frequently used in developing countries (Rothenberger. et al. 2006). In this system the organic waste material can be arranged in piles or windrows. Each system consists of the following steps: the piles are aerated to ensure adequate levels of oxygen and the material is sieved either before or after decomposition to remove non organic materials (Lardinois et al., 2001).

- **Windrow or heap**

In this process wastes are generally piled up or gathered into heaps or elongated heaps or windrows. The heat generation is ensured by the size of the heap and aeration is controlled by periodic turning or ventilation. When the wastes are seldom turned the process is called static pile. Leachate control is done by slopping or by sealing or using impervious composting bed (Rouse et al., 2008 and Rothenberger. et al. 2006).

- **Bean Composting**

Bean system is enclosed by constructed structure (wood, tin, brick or mesh compartment) all four or three sides. Main advantage of this system is the efficient use of space. Other systems (i.e. aeration, temperature control) are same as heap system (Rouse et al., 2008 and Rothenberger. et al. 2006).

- **Trench or Pit**

In trench system the whole system is contained under the earth surface. Aeration is done by turning. But if the trench is too deep turning operation become difficult. Leachate control is also very complicated in this process (Rouse et al., 2008).

b) Closed System

System can be static or movable closed structures. Temperature, aeration and moisture are controlled by mechanical means. This system often requires external energy supply which results in extra costing of operation. In-vessel or "reactor" systems can be static or movable closed structures where aeration and moisture is controlled by mechanical means and often requires an external energy supply (Rothenberger et al., 2006).

2.6 CO-COMPOSTING OF FAECAL SLUDGE AND OTHER ORGANIC SOLID WASTES

2.6. 1 General Overview on Co-composting

Composting is the biotransformation of organic substrates in the presence of oxygen. The composting of organic material or waste allows the recovery of nutrients and organic matter for use in agriculture. Composting is a biological transformation that includes mineralization and humectation of organic materials under controlled conditions into humus, whereas the latter represents a complex group of macromolecular organic compounds with high stability for safe use in agriculture (Cofie, .et al., 2016). Co-composting of FS with OSW is best implemented with sludge that has undergone dewatering (e.g. settling-thickening tanks or drying beds). In the case of dewatered sludge, FS with a total solids (TS) content higher than 20% is mixed together with MSW in compost piles (Koné et al., 2007). The main advantage of Co-composting is formed by the thermophilic conditions and the resulting pathogen inactivation. Figure 2.4 displays presents the general material flow in a Co-composting process. It starts with input materials on the upper left and progresses to pre-treatment activities such as sorting, drying and mixing, the Co-composting process and final product distribution for either farm application or for other uses.

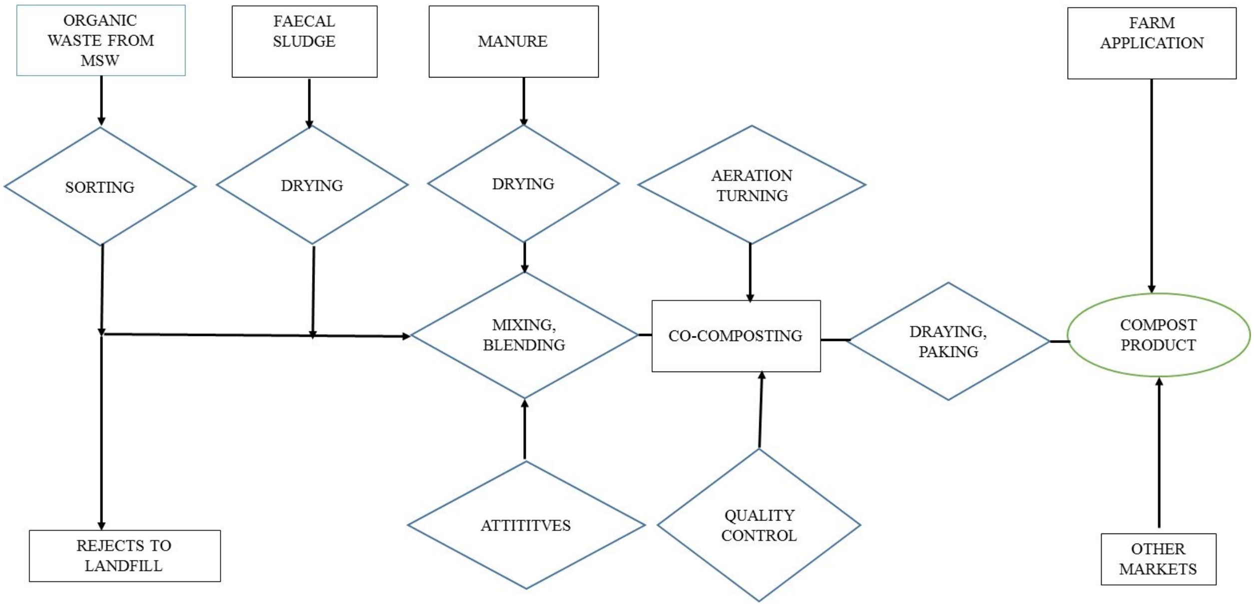


Figure 2.4. General material flow and main process components of Co-composting (Cofie, .et al., 2016)

2.6.2 Waste Pretreatment for Co-composting

2.6.2.1 Faecal Sludge Pretreatment

Depending on the source of FS, some form of pretreatment will be needed prior to Co-composting. Usually human excreta from public toilets and septic tanks are too high in moisture content (95-97%) and need to be dewatered prior to composting with organic solid waste to ensure aerobic composting. This requires the use of solid-liquid separation systems such as drying beds, constructed wetlands or thickening/settling tanks. The effluent from these systems must be treated (for example in facultative and maturation ponds, constructed wetlands) to meet discharge guidelines before being discharged into receiving water bodies.

2.6.2.2 Solid Waste Sorting

As solid wastes could have negative impacts on the final compost quality, it is important to ensure proper separation of organic from inorganic and especially hazardous materials. Usually an organic fraction of household waste, market waste or agro-industrial waste is recommended for use in Co-composting. The solid waste should be mixed with the pretreated (e.g., dewatered FS) in the appropriate proportion to ensure an optimal composting process (Cofie et al. 2009)

2.6.3 Co-composting Technology

Two main types of composting systems are generally distinguished: 1) open systems such as windrows and static piles and 2) closed 'in-vessel' systems. The in-vessel or 'reactor' systems can be static or movable closed structures where aeration and moisture are controlled by mechanical means. Such systems usually require an external energy supply, either by electricity or through decentralized electricity generators, whereas the latter is often provided by diesel engines. In general, in-vessel or reactor systems require higher investment compared with static pile systems and are also more expensive to operate and maintain. Static pile composting systems on the other hand, require much lower investments and are hence the preferred option for composting or Co-composting in developing countries. In windrow composting process wastes are generally piled up or gathered into heaps or elongated heaps or windrows. The heat generation is ensured by the size of the heap and aeration is controlled by periodic turning or ventilation. Among them, windrow composting is the most commonly applied system.

2.7 Utilization of Composted Products

Compost has been used as:

- fertilizer,
- soil conditioner,
- feed for fish in aquaculture,
- landfill material
- Horticultural medium on parkland, ornamental and recreational areas and in highway right-of-ways.

Screening, grinding, or combination of similar processes should be done to remove plastics, glass, and other materials from the compost that might be objectionable in its use. For some uses such as land filling and land reclamation, compost needs not be finished or processed further. For general agriculture/aquaculture, a coarse grind is satisfactory, whereas for horticulture and luxury gardening, the compost product must be finer. Compost to be used as fertilizer or soil conditioner is usually mixed with chemical fertilizers to make its nutrient contents suitable for crop growth.

2.8 Case Studies on Co-composting

2.8.1 *Septage Co-composting – Massachusetts, U.S.A* (Lombardi., 1977)

A septage Co-composting pilot plant was commissioned in the state of Massachusetts in 1977 to test the feasibility of Co-composting for septage collected from three neighboring towns. The initiative followed prohibition by the authorities to continue the admixing of septage to the wastewater treatment plant. Septage of approximately 4 % TS was mixed with sawdust, woodchips and cow or horse manure. Mixing ratios are reported, yet conflicting Figures render it difficult to know what actually used ratios were. Both forced and naturally vented, static windrows were used. Reported temperature development, however, indicates that aeration was secured and thermophilic conditions were achieved, with temperature rising to 73 °C at windrow centres within 8 days of pile formation. They levelled of to about 50° C after 50 days. Capital cost for a full-scale septage Co-composting plant serving the three towns and treating 60 m 3 of septage p. day were estimated at $ 240,000 (1977 base). The procuring of sawdust as liquid absorber was found to constitute a major operation and management cost item. The authors do not avail of information whether the system is still operational, or if a full-scale system was built and has become operational as a result of the pilot works.

2.8.2 Co-composting Faecal Sludge and Organic Solid Waste Kumasi, Ghana (strauss., 2003)

A Co-composting plant of faecal sludge and organic solid waste has been established at Buobai, 15 km east of city Centre of Kumasi, Ghana. The construction of the pilot plant started in October 2001 and the operation started in February 2002. The plant has been in operation ever since then. Over the years, considerable knowledge was gained and large quantities of compost were produced for field trials. The drivers for this project were IWMI and Sandec together with the project partners, led by IWMI. The plant is seen as a facility to gather useful information for future up scaling by the municipal assembly. The plant is currently not operational because the research funds for this project are currently depleted and KMA has not taken the pilot plant over. Therefore, no more composting is taking place since January 2009. IWMI still keeps one worker in charge while IWMI develops the next research steps on the one hand and engages the waste management department in discussion for next steps. Total land area covered by the project is 500 m^2. The faecal sludge treatment rate is $45m^3$/month and the initial investment was 16500 EUR. The basic technology chosen for this project consists of two main process steps:

- Faecal sludge drying on unplanted drying beds and
- Windrows Co-composting of dried faecal sludge (FS) and organic solid waste (OSW).

2.8.3 ***Co-composting in Bangladesh***

Faecal Sludge Management in Kushtia Municipality: A Co-compost Fertilizer Approach *(*Enayetullah., 2015)

Kushtia Municipality with the support from institute for Global Environmental Strategies (IGES) and UNCRD (United Nations Center for Regional Development) in partnership with the Department of Environment, Ministry of Environment and Forest, has introduced 3R (reduce, reuse and recycling of waste) initiatives in Kushtia Pourashava through a number of interventions (i.e. source separation of waste, awareness and training programs, decentralized Co-composting etc.) in 2008. The municipality has established a co-compost plant at Baradi, about 3.5 km from city center. The plant has a full time supervisor and 8 fulltime labors in its own to run the plant effectively. Now through three vacutug (a machine of collecting faecal sludge) operations, the municipality is regularly collecting faecal sludge from the pit latrines and septic tanks of the city dwellers and using it for Co-composting which ultimately produces good quality co-compost fertilizer. Figure 2.5 shows the co-compost plant at Khustia.

Figure 2.5: Co-compost plant at Khustia municipality

2.9 Pathogen Inactivation

The waste heat biologically produced during composting can reach a temperature of about 60°C which is sufficient to inactivate most pathogenic bacteria, viruses and helminthic ova, provided that this temperature is maintained for at least 1 day. Therefore, the compost can be safely disposed of on land or used as fertilizers/soil-conditioners. Figure 2.6 shows the influence of time and temperature on die-off of selected pathogens in night soil and sludge. The higher the temperature the shorter the time required for pathogen die-off.

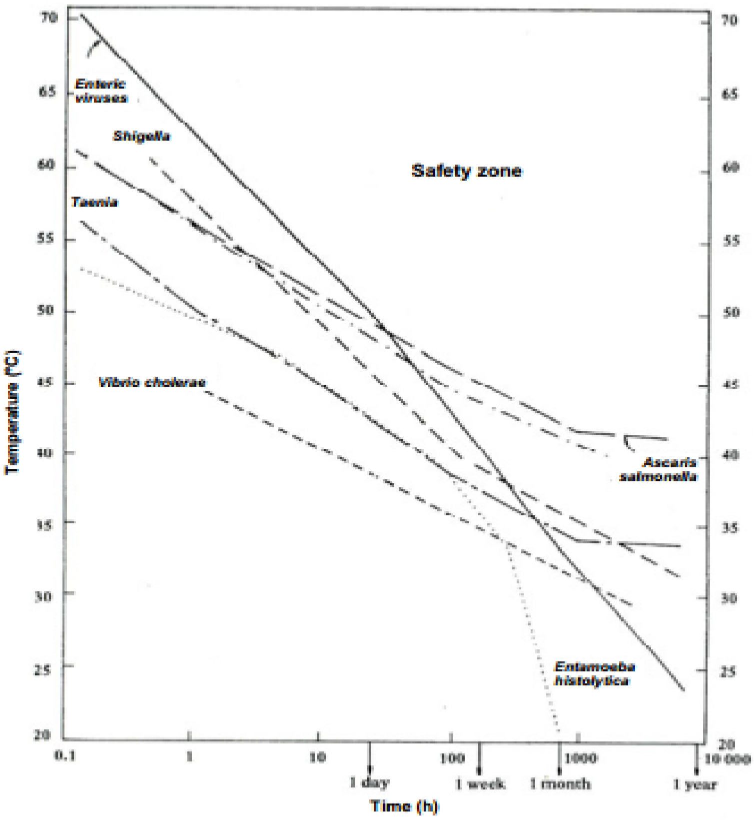


Figure 2.6: Influent of time and temperature on selected pathogens in night soil and sludge (Feachem *et al.* 1983).

The time represents conservative upper boundaries for pathogen death that is, estimates of time-temperature combinations required for pathogen inactivation. A treatment process with time-temperature effect falling within the "safety zone" should be lethal to all excreted pathogens (with the possible exception of hepatitis A virus – not included in the enteric viruses in the Figure – at short retention time). Indicated time-temperature requirements are at least: 1 h at ≥ 62°C, 1 day at ≥50°C and 1 week at ≥ 46°C.

2.10 Product Stability

The main objective of composting is to produce a biologically stable or mature and pathogen free humus-like end product i. e. compost, which can be beneficially used as a soil conditioner or for other purposes. The biological stability or maturity of compost affects its successful utilization in agriculture. A compost with a very low decomposition rate, after a thermophilic stage where easily decomposable organic compounds are completely oxidized, can be described as stable. It should be noted that a strict distinction between the terms stability and maturity is not possible and they are often used interchangeable. If the compost is not sufficiently stabilized, it will cause subsequent problems in storage, transportation, utilization and in the final disposal site (Cofie, .et al., 2016).Instable compost emits offensive odor, decreases plant growth due to the presence of phytotoxic substances (basically ammonia, ethylene oxide and organic acids, etc.). A number of physical, biological and chemical methods have been suggested and evaluated to measure the degree of stability of compost (Bari,1999). Among those, the self-heating test, temperature decline, color and odor, microbial respiration, seed germination and plant growth, C/N ratio, pH and other chemical tests are significant.

2.11 Self-heating Test

The self-heating test was applied to determine the degree of biological stability of the waste after composting (Koenig and Bari, 1998; LAGA, 1985). In the self-heating test, suitably prepared waste samples of optimally adjusted moisture content are loosely filled into Dewar bottles (volume=1.5 l, inner diameter=100 mm) open to the atmosphere. A temperature sensor is inserted for monitoring. The bottles are then kept at room temperature of approximately 23°C. If the waste is not yet biologically stable, it will further degrade aerobically, generating heat which will cause a temperature rise. Usually, the maximum temperature T_{max} is reached after 2–5 days. The test ends after T_{max} is culminated and rapidly declining temperatures are observed, at the latest after 10 days as shown in Figure 2.7. T_{max} attained is used as an indicator of biological stability to define the stability index SI. The SI of waste is classified in degrees from I to V, in ascending order of biological stability, and ranges from raw, unstabilized waste (SI=I) to completely stabilized waste (SI=V). T_{max} also corresponds approximately to the area under the temperature curve A_{72} (after 72 h) as shown in Table 2.1 (LAGA, 1985).

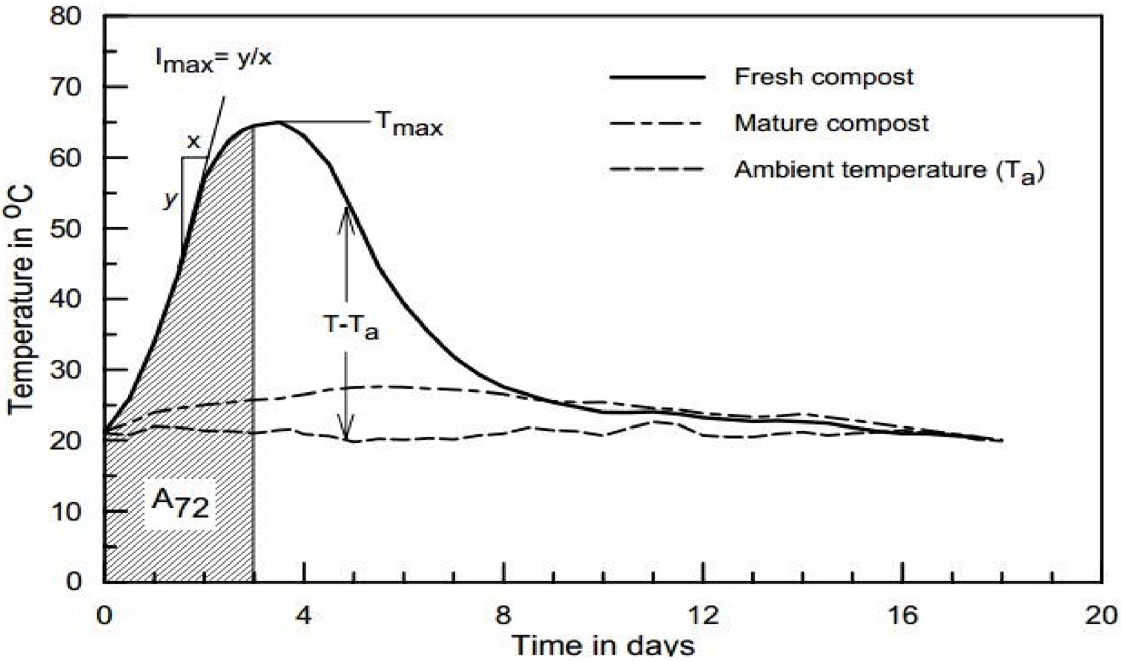


Figure 2.7: The temperature curve of a typical self-heating test for fresh compost, matured compost, T_{max}, A_{72} and I_{max} are shown (Koenig and Bari., 2000).

Table 2.1: Classification of waste according to degree of biological stability

Degree of biological stability (stability index SI)	V Stable	IV	III	II	I	I unstable
T_{max}	20-30	30-40	40-50	50-60	60-70	> 70
I_{max}	< 0.3	0.3-0.45	0.45-0.8	0.8-1.4	1.4-2.0	>2.0
Area A_{72} (°C.h)	<1700	1700-2000	2000-2500	2500-3000	3000-3500	>3500

T_{max} = maximum temperature, I_{max} = maximum temperature increase, A_{72} = area under temperature curve after 72h.

2.12 Reaction Rates

In order to describe the changes that occur in the waste material during composting, and the extent of these changes, it is important to know the reaction rates or degradation rates. The reaction rates are significant for designing or optimizing a composting process because they directly affect the processing time, size of the reactor or pile area and the product quality. A high degradation rate indicates lower capital and operational cost for a composting plant. Finstein and Miller (1985) noted that, for any given processing duration, the higher the rate the more stable and easily handled the residue and this facilitates storage, transport, and final disposal with a minimal cost. The rate of water vaporization is directly related to the rate of waste decomposition and water removal is an objective in sludge treatment because dry residue is more easily managed (Finstein *et al.*, 1986b). The elevated temperature from 55 to 60 ^{o}C for a longer period is vital in sanitization and this can be maintained by the higher degradation rates. Rapid decomposition of the putrescible material may help to control odor at the composting site. In addition, by using the reaction rates a simple model to predict the extent of degradation could be worked out. The reactions which occur in a composting process may be considered as a change in the quantity of biodegradable volatile solids (BVS). The daily BVS change can be determined by monitoring daily oxygen consumption, since this is proportional to the BVS degradation rate. The proportionality constant or ratio of kg oxygen consumed per kg BVS degraded would be different for different types of wastes. Haug (1993) reported that the stoichiometric demand for oxygen varies from a low of about 1 kg O_2/kg organic matter for highly oxygenated substrates such as starch and cellulose to a high of about 4 kg O_2/kg organic matter for saturated hydrocarbons. Koenig and Tao (1996) indicated that an average of 1.2 kg O_2 were consumed per kg of VS degraded for a mixture of canteen wastes and waste paper. However, the O_2 consumption rate correlates with the BVS degradation rate (Bari, 1999).

The general equation to define the rate of three different types of reaction, namely, zero, first, and second order is

$$-\frac{\mathrm{dBVS}}{\mathrm{dt}} = \mathrm{KBVS}^{n} \qquad \text{------------------------} \qquad (2.1)$$

Where, BVS = biodegradable volatile solids, in kg

t = time, in days

$-\frac{\mathrm{dBVS}}{\mathrm{dt}}$ = Rate of change in mass of BVS (the negative sign indicates that the quantity of BVS decreases with time)

n = reaction order, 0, 1, or 2

k = rate constant, units depend on reaction order

2.13 First Order Reaction

First order reactions proceed at a rate which is proportional to the quantity of remaining BVS. From Equation (2.1) for first order reaction, substituting n = 1

$$-\frac{\mathrm{dBVS}}{\mathrm{dt}} = \mathrm{KBVS}^1 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (2.2)$$

Where k = first order rate constant, in day^{-1}

Integrating Equation (2.2) and substituting for BVS = BVS_0 at t = 0, it follows that

$$BVS_t = BVS_0\, e^{-kt} \qquad \text{--------------------------------} \qquad (2.3)$$

If k is not constant over time, the numerical solution according to (Bari and Koening., 2001) is

$$BVS_t = BVS_0 . e^{-k_1\Delta t} . e^{-k_1\Delta t} . e^{-k_2\Delta t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots e^{-k_n\Delta t} \qquad (2.4)$$

$$BVS_t = BVS_0 . e^{-(k_1+k_2+\cdots\ldots\ldots+k_n)\Delta t} \qquad (2.5)$$

It can be shown that for small exponents $e^{-k_1\Delta t}$ is approximately $(1-k_1\Delta t)$

or $e^{-kt} = (1-k_1\Delta t)(1-k_2\Delta t)\ldots\ldots\ldots(1-k_n\Delta t)$

Therefore, the percentage degradation of BVS after time t is

$$\frac{BVS_0-BVS_t}{BVS_0} * 100$$

$$=100(1-e^{-kt}) \qquad (2.6)$$

$$=100[1-(1-k_1\Delta t)(1-k_2\Delta t)\ldots\ldots\ldots(1-k_n\Delta t)] \qquad (2.7)$$

2.14 Effect of Temperature on Reaction Rates

The rate of biological reactions increases with temperature up to a limited range, suitable for microorganisms. Above this range of temperature the activity of enzymes, responsible for mediating the biological reaction, decreases due to enzyme denaturation. A frequently quoted rule of thumb known as the van't Hoff rule states that the reaction rate doubles for a 10 °C temperature rise. Equation 2.7 proposed by the Swedish chemist Arrhenius, has been used to estimate the effect of temperature over a limited range for biological reactions. The Arrhenius equation is:

$$\frac{d(lnk)}{dT} = \frac{E_a}{RT^2} \qquad (2.8)$$

Where k= reaction rate constant

E_a= activation energy, kJ/mol

R=ideal gas constant, $8.314*10^{-3}$ kJ/mol

T= absolute temperature, °K

Equation (2.8) can be integrated to give the expression

$$\ln k = \ln C - \frac{E_a}{R}\left(\frac{1}{T}\right) \tag{2.9}$$

Where C = frequency factor, a constant

From Equation (2.9), it can be shown that the plot of ln k versus 1/T will be a straight line. Equation (2.9) can be formulated for practical application as

$$k = e^{\left(lnc - \frac{E_a}{RT}\right)} \tag{2.10}$$

$$\text{or } k = C.\, e^{-\frac{E_a}{RT}} \tag{2.11}$$

The reaction rate constant k at any temperature can be obtained by Equation (2.11)

CHAPTER III

Methodology

3.1 General

The Co-composting was performed with different mixing proportions for both of the passively and forced aeration condition in wet and dry season respectively. In wet season the number of reactors used in 1st, 2nd, and 3rd stage were 32, 24 and 16 respectively with total 72 number. Similarly for dry season a total of 72 reactors were used for the experiment. Usually thermoflask of 1 liter is used as a composting reactor. Then forced aeration and passively aeration composting tests were done using series of reactors according to a planned experimental program. In another run 60 reactors were used for degradation rate analysis. The individual solid wastes and faecal sludge are mixed with such proportion to get a homogenous mixture to put into the reactor. The opening of the reactor (flasks) were loosely closed by pieces of cork and the thermometer were inserted into the flask for taking reading time to time until the temperature reached the ambient temperature. Air pumps were connected with forced aerated reactor for providing oxygen into the composting mass. Before and after experiments the selected physico-chemical tests like moisture content, volatile solids and fixed solids were performed. The temperature reading were collected for these reactor for 28 days. The variation of temperature was observed during composting process. Total solids, moisture content, volatile solids and fixed solids were determine and variation in wet and dry seasons are calculated. For degradation rate analysis a series of reactor were used according to log Frame.

3.2 Methodology in Simple Flow Diagram

All the research testing were performed through field and laboratory testing.
Schematically, this study are follow the flow chart in Figure -3.1.

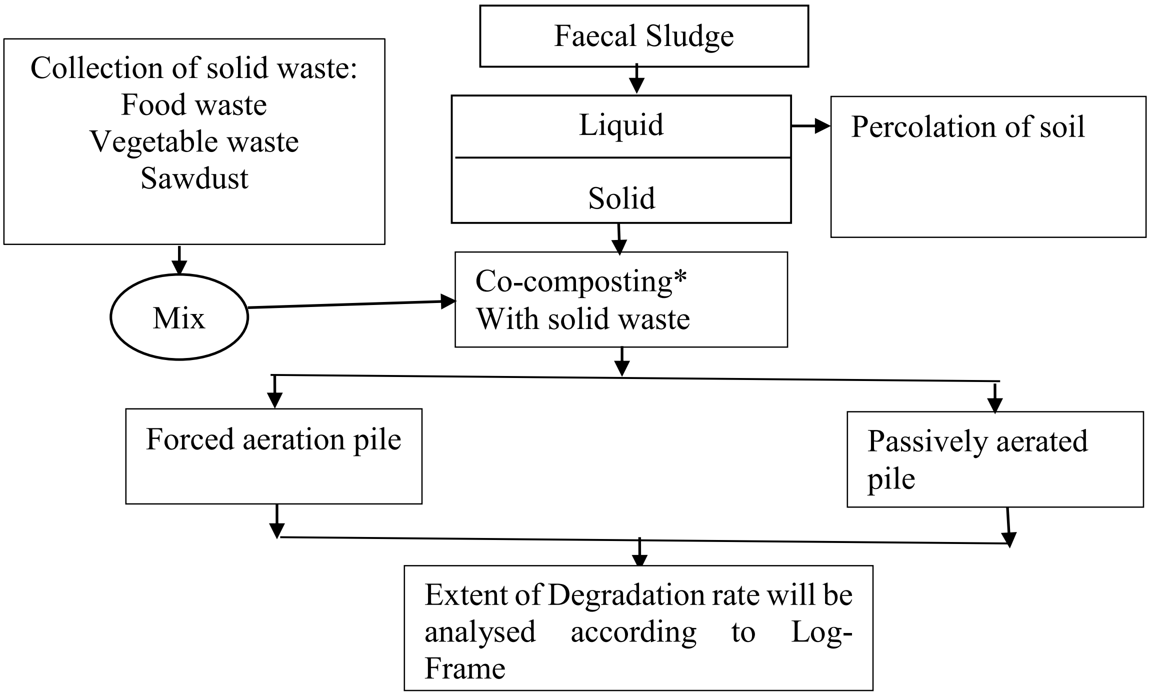


Figure 3.1: Methodology in simple flow diagram

Note:* This proposal research is completely an innovative field for the treatment and effective hygienization of Faecal sludge by doing Co-composting in forced aeration and passively aeration process in different seasons.

3.3 Collection of Faecal sludge

The Faecal sludge was collected from a septic tank of KUET residential area. The faecal sludge sample was collected on 23 July, 2016. Before collecting the sample hand gloves and face mask were used to ensure personal hygiene and safety. Normal buckets were used for the collection. After collecting a bucket full faecal sludge (FS) it was immediately transferred to the drying bed. Location of septic tank and collection of faecal sludge are shown in Figure 3.2.

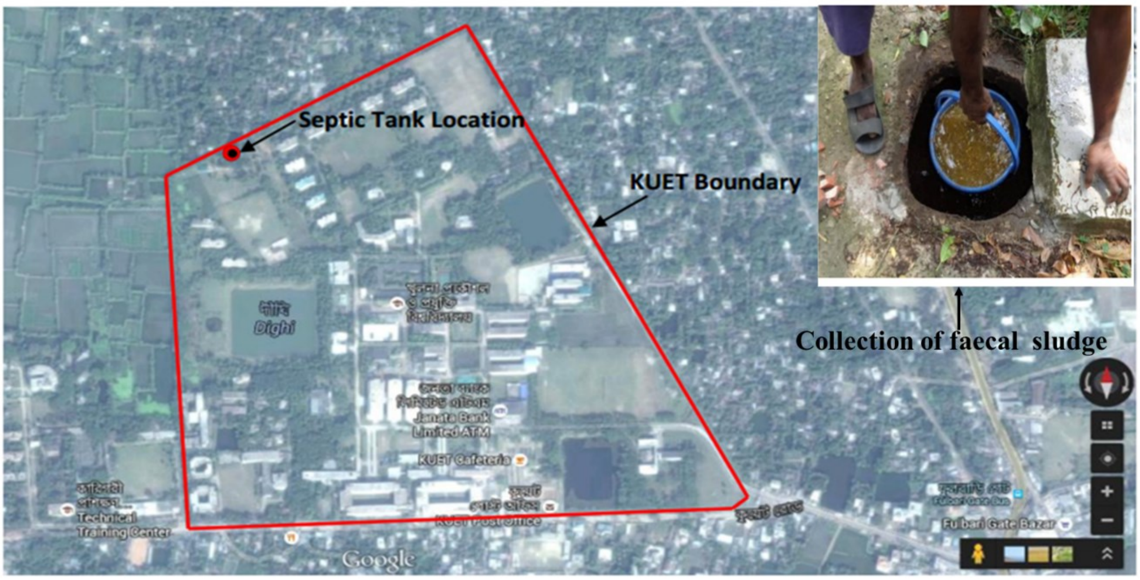


Figure 3.2: Location of septic tank and collection of Faecal sludge

3.4 Dewatering of Faecal Sludge

The purpose of the Faecal Sludge (FS) dewatering step was to facilitate the mixing of sludge with Solid Waste (SW) and to obtain a compost mixture with an adequate water content and structure for aerobic composting. For this purpose, drying bed consisting a layers of gravel and sand were used. At upper part a 3 inch gravel layer was placed and lower part a 1 inch sand layer laid over it. Then a 2 inch layer of faecal sludge was applied as shown in Figure 3.3. Dewatering process was continued for 12 days.

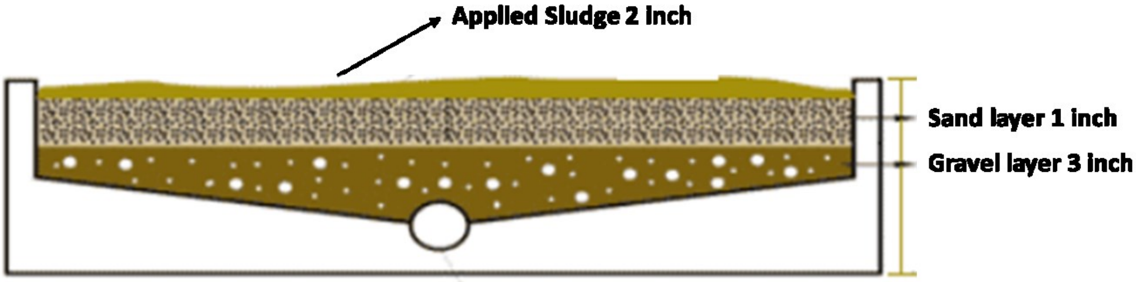


Figure 3.3: Drying bed

3.5 Collection and Sorting of Organic Solid Waste

Organic solid wastes were collected from a student's hall of KUET and solid waste management plant. This management plant collect wastes from the 7 residential halls and all the teachers and officer quarters on daily basis. The large pieces of vegetable wastes and waste paper were cut into small pieces of size 1 to 1.5 cm. Saw dust were collected from a local sawmills and waste paper from offices. Saw dust was used as bulking agent in Co-composting process.

3.6 Preparation of Wastes Mixture

In dry and wet seasons FS and OSW were mixed at four different ratios. These ratios are 90:10, 85:15, 80:20 and 75:25 (OSW: FS) as Table 3.1. Accroding to Shamim (2012), organic solid waste (OSW) was prepared according to waste proportion vegetable wastes: food wastes: waste paper: sawdust as 40:35:10:15. All the wastes were mixed uniformly. In Table 3.1 intial weight of different waste mixture is also given for 32 flasks. Collected different waste was mixed at the roof of the Civil Engineering Department in KUET are shown Figure 3.4.

Table 3.1. Initial waste mixture for different set of experiment

Type of Organic solid Waste and Faecal sludge	90:10	85:15	80:20	75:25
Faecal Sludge(gm)	480	720	960	1200
Vegetable waste(gm)	1728	1632	1536	1440
Food waste(gm)	1512	1428	1344	1260
Paper(gm)	432	408	384	360
Saw dust(gm)	648	612	576	540

Figure 3.4: Collected different waste mixing at roof of Civil Engineering Department in KUET

3.7 Experimental Program of Composting

The study was conducted by means of different mixing proportions of the bench scale reactor in according to specifically designed. Methodology Log-Frame are giving in the following table 3.2 and description of reactor table 3.3. Composting tests were done using a series of reactors, according to a planned experimented program.

Table 3.2: Methodology Log-Frame

Run	Seasons	Process Description for Co-composting		Number of reactors			Number of total reactors
			Mix proportion	1s* 30days	2s* 15days	3s* 18days	
1	Wet Season	Forced Aeration weight proportion Solid Waste: Faecal Sludge	90:10	4	3	2	36
			85:15	4	3	2	
			80:20	4	3	2	
			75:25	4	3	2	
2		Passively Aeration weight proportion Solid Waste: Faecal Sludge	90:10	4	3	2	36
			85:15	4	3	2	
			80:20	4	3	2	
			75:25	4	3	2	
3	Dry Season	Forced Aeration weight proportion Solid Waste: Faecal Sludge	90:10	4	3	2	36
			85:15	4	3	2	
			80:20	4	3	2	
			75:25	4	3	2	
4		Passively Aeration weight proportion Solid Waste: Faecal Sludge	90:10	4	3	2	36
			85:15	4	3	2	
			80:20	4	3	2	
			75:25	4	3	2	
5		Determination of rate of degradation					60
6		Determination of optimum moisture content					14

1s* = first stage,
2s* = second stage
3s* = third stage

Table 3.3: Description of all reactor

Symbol	Description
PF1(90:10)	PF1(90:10)= Passive aeration first stage reactor-1 OSW=90% and FS=10%
PF1(85:15)	PF1(85:15)= Passive aeration first stage reactor-1 OSW=85% and FS=15%
PF1(80:20)	PF1(80:20)= Passive aeration first stage reactor-1 OSW=80% and FS=20%
PF1(75:25)	PF1(75:25)= Passive aeration first stage reactor-1 OSW=75% and FS=25%
FF1(90:10)	FF1(90:10)= Forced aeration first stage reactor-1 OSW=90% and FS=10%
FF1(85:15)	FF1(85:15)= Forced aeration first stage reactor-1 OSW=85% and FS=15%
FF1(80:20)	FF1(80:20)= Forced aeration first stage reactor-1 OSW=80% and FS=20%
FF1(75:25)	FF1(75:25)= forced aeration first stage reactor-1 OSW=75% and FS=25%
PS1(90:10)	PF1(90:10)= Passive aeration second stage reactor-1 OSW=90% and FS=10%
PS1(85:15)	PF1(85:15)= Passive aeration second stage reactor-1 OSW=85% and FS=15%
PS1(80:20)	PF1(80:20)= Passive aeration second stage reactor-1 OSW=80% and FS=20%
PS1(75:25)	PF1(75:25)= Passive aeration second stage reactor-1 OSW=75% and FS=25%
FS1(90:10)	FF1(90:10)= Forced aeration second stage reactor-1 OSW=90% and FS=10%
FS1(85:15)	FF1(85:15)= Forced aeration second stage reactor-1 OSW=85% and FS=15%
FS1(80:20)	FF1(80:20)= Forced aeration second stage reactor-1 OSW=80% and FS=20%
FS1(75:25)	FF1(75:25)= forced aeration second stage reactor-1 OSW=75% and FS=25%
PT1(90:10)	PF1(90:10)= Passive aeration third stage reactor-1 OSW=90% and FS=10%
PT1(85:15)	PF1(85:15)= Passive aeration third stage reactor-1 OSW=85% and FS=15%
PT1(80:20)	PF1(80:20)= Passive aeration third stage reactor-1 OSW=80% and FS=20%
PT1(75:25)	PF1(75:25)= Passive aeration third stage reactor-1 OSW=75% and FS=25%
FT1(90:10)	FF1(90:10)= Forced aeration third stage reactor-1 OSW=90% and FS=10%
FT1(85:15)	FF1(85:15)= Forced aeration third stage reactor-1 OSW=85% and FS=15%
FT1(80:20)	FF1(80:20)= Forced aeration third stage reactor-1 OSW=80% and FS=20%
FT1(75:25)	FF1(75:25)= forced aeration third stage reactor-1 OSW=75% and FS=25%

3.8 Bench Scale Reactor

Bench-scale tests were conducted using vacuum flasks of 1L volume (Shimizu Brand, Japan) as a bench-scale reactor. About 400 g of waste mixtures is necessary to fill each of the reactors. The waste inside the reactor was compacted loosely to provide proper porosity for natural and forced aeration. After putting the waste mixture into the reactor, the inlet was covered by a cork to prevent excessive heat loss and the thermometers were inserted into the flask for taking reading time to time until the temperature reached the 15 ºC of ambient temperature. All reactors were filled of mixture of waste according to table 3.1. The temperature of the waste mixture was continuously monitored. After final declination in temperature close to ambient, the tests were discontinued.

3.8.1 First Stage Bench Scale Test

In wet season the number of reactors used in 1st stage were 32 reactor. Similarly for dry season a total of 32 reactors were used for the experiment. Then forced aeration and passively aeration composting tests were done using series of reactors according to a planned experimental program. The organic solid waste and faecal sludge were weighed separately before mixing and then mixed uniformly. The moisture content of the initial waste mixtures was adjusted to about 50-60% for optimum consistency and porosity by adding sawdust.

3.8.2 Second and Third Stage Bench Scale Test

The fresh compost produced by the first stage composting tests were used as a initial feed material for subsequent second stage composting tests. After first stage composting the product was re-mixed manually using a shovel and adjusted with water, if necessary for the second composting. Compost released from the second stage reactor was mixed properly and used as feedstock for third stage composting.

3.9 Experimental Set Up

Thermometers of temperature range of 120° C were used to monitor the temperature generated in the waste mixture inside the reactors due to composting. The thermometers were inserted into reactor for monitoring the temperature. Every day the temperature was taken manually. The diameter, height and capacity of each reactor were 10cm, 27cm and 1L respectively. The small pieces of polyurethane sheet were placed over the reactor to protect the total system from the leakage of self-generated heat of organic waste mixture during composting inside the reactors. Eight aerators (Super Pump SP-780) were used for forced aeration during composting. The air pipes of diameter of 5mm were used to connect the aerator with the reactors. Four air pipes from each aerator were connected with four reactors. The air was supplied daily at the rate of 500ml/min through the waste mixture inside the reactor for 12 hours in day time. Experimental set up in passively and forced aeration are shown in Figure 3.5

Figure 3.5: Experimental set up in passively and forced aeration

3.10 Physico-chemical Analyses

At the beginning and end of each stage of the composting tests, the initial waste mixture and/or compost were analyzed with regard to the most relevant physicochemical parameters which are discussed in the following section. For waste and compost at least three replicate samples were analyzed for all physicochemical parameters.

3.10.1 Moisture Content (MC)

The large pieces present in waste sample were cut into small pieces. The weight of small can (w_1) was measured using a digital balance. A small amount of waste sample was taken into can. The weight of the wet sample with can (w_2) was measured. The wet sample with can was kept in Oven at 105 ± 2 ºC for 24 hours. Digital mass balance and Oven are shown in Figure in 3.6. The weight of the dry sample with can (w_3) was measured. The desiccator was used to carry the sample from oven to measuring balance. So that moisture content cannot be changed. The moisture content was calculated by the following formula:

Moisture content (M.C.), % = $(w_2 - w_3)/ (w_2 - w_1)$

(a) Measuring of weight of sample (b) Sample in oven

Figure 3.6: Determination of moisture content

3.10.2 Determinations of Volatile Solids and Carbon Content

The oven dried sample with can was kept in Muffle Furnace at 550 ºC for 2.5 hours. The weight of the fixed sample with can (w_4) was measured. The desiccator was used for carrying the sample to protect from the effect of the environmental moisture. Desiccator and muffle furnace are shown in Figure 3.7. The volatile solid was calculated using the following formula:

Volatile Solids (V.S.), % = $(w_3 - w_4) / (w_3 - w_1)$

For most biological materials the carbon content is between 45 to 60 percent of the volatile solids fraction. Assuming 55 percent (Adams *et al.*, 1951), the formula is:
% Carbon = (%VS)/1.8

(a) Burned sample in desiccator (b) Samples in Muffle Furnace

Figure 3.7: Determination of volatile solids

3.10.3 pH and EC

A mixture of compost with water was prepared with a mixing ratio of compost: water = 1:10 (by volume). Then pH and EC in the supernatant suspension were measured using digital measuring instruments.

3.10.4 Determination of Nitrogen

The dried and homogenized material is digested in a suitable Kjeldahl tube with sulfuric acid. To raise the temperature potassium sulfate is added and Selenium powder was used as a catalyst. After adding sodium hydroxide to the digestion solution the produced ammonium from all nitrogen species was evaporated by distillation as ammonia. This was condensed in a conical flask with boric acid solution. The amount was titrated against indicator with sulfuric acid (Janssen and koopmann, 2005).

3.10.5 Determination of Total Kjeldahl Nitrogen (TKN)

The original TKN method was developed by the Danish chemist Johan Kjeldahl in 1883. In this study TKN was determined by the addition of organic nitrogen (Norg) and ammonia nitrogen (NH_3-N).

$$\text{TKN (\%)} = \frac{1.4007\times 0.02\times (A-B)}{gm\ dry\ weight\ of\ sample}$$

$$\text{TKN (mg/kg)} = \frac{280\times (A-B)}{gm\ dry\ weight\ of\ sample}$$

Where, A= Volume of HCl titrated for sample, ml

B= Volume of HCl titrated for blank, ml.

3.11 Determination of Biodegradable Volatile Solids

The biodegradable volatile solids (BVS) for different proportion mixture solid waste bench scale tests were calculated from the sum of VS degraded in the first stage, second stage and third stage in wet and dry seasons. According to Bari (1999), it was estimated that the remaining BVS in the compost, after 63 days of effective degradation in the first stage, second stage and third stage would not be more than 10%. Therefore, the sum of VS degraded is increased by 10% to have a suitable estimation of initial BVS.

3.12 Determination of Volatile Solids Degradation Rate

During the first stage volatile solids degradation rate was determined using the sixty (60) reactors by forced aeration composting process. The sixty reactors was made twenty set. One set have three reactors. The ratio of 80:20 (OSW: FS) is maximum degradation in wet and dry season. Organic solid waste (OSW) was prepared according to waste proportion vegetable wastes: food wastes: waste paper: sawdust as 40:35:10:15. Before filling the reactors air pipes of diameter 5mm from air pump were connected inside of each reactor. The reactors were filled the waste mixture. The openings of the reactors were closed by small pieces of poly eurathane sheet and thermometers were inserted into them for monitoring the temperature variations. The air was passed at the rate of 500 ml/min through the waste mixture inside reactors for 12 hours in day time of everyday without holiday. The total sample weight, moisture content and volatile solids of the waste mixture were determined before and after composting. The temperature readings were taken two times daily for 25 days. The total sample weight, moisture content and volatile solids of the waste mixture were determined at 2, 3, 4 days interval at first two weeks. After two weeks the total sample weight, moisture content and volatile solids of the waste mixture were determined by opening three reactors in each week. One was three days interval and other two reactors were four days from the first one of that week. This procedure was continued up to twenty numbers of reactors. The determination of volatile solids degradation rate was completed within 60 days. Experimental setup for the determination of volatile solids degradation as shown in Figure 3.8.

Figure 3.8: Experimental setup for the determination of volatile solids degradation.

CHAPTER IV

Results and Discussion

4.1 General

The Co-composting experiments were performed using different mixing proportions for both of the passively and forced aeration process in wet and dry season. Temperature variation in Co-composting process of first, second and third stages with different mix proportion of faecal sludge in wet and dry season has been carried out. Mass balance analysis was developed for the passively and forced aeration Co-composting process. Degree and extent of degradation up to maturity of compost were identified through different stages with different mix proportion of faecal sludge in both seasons. The analysis also helps to characterize the compost. Finally degradation rate was analyzed of Co-composting process.

4.2 Initial Composition of Waste Mixtures

The mix ratio and amount (based on the physico-chemical analysis of individual component of waste mixture and faecal sludge of initial composition of the waste materials used in wet and dry season. In different types of experiments mainly two types of waste were used namely food waste (rice and vegetable) and mixed office waste paper. In addition, saw dust was used as a bulking agent. Moisture content, volatile solids of individual waste samples used in different experiment are presented in Table 4.1. The re-mixed and remoistened (if necessary) compost of the first stage test was used as a feed material for the corresponding second stage test. The re-mixed and remoistened (if necessary) compost of second stage test was used as a feed material for the corresponding third stage test. However, in most of the cases water was added to obtain an optimum moisture content. The initial moisture content of the waste mixtures varied between 55 to 62%.

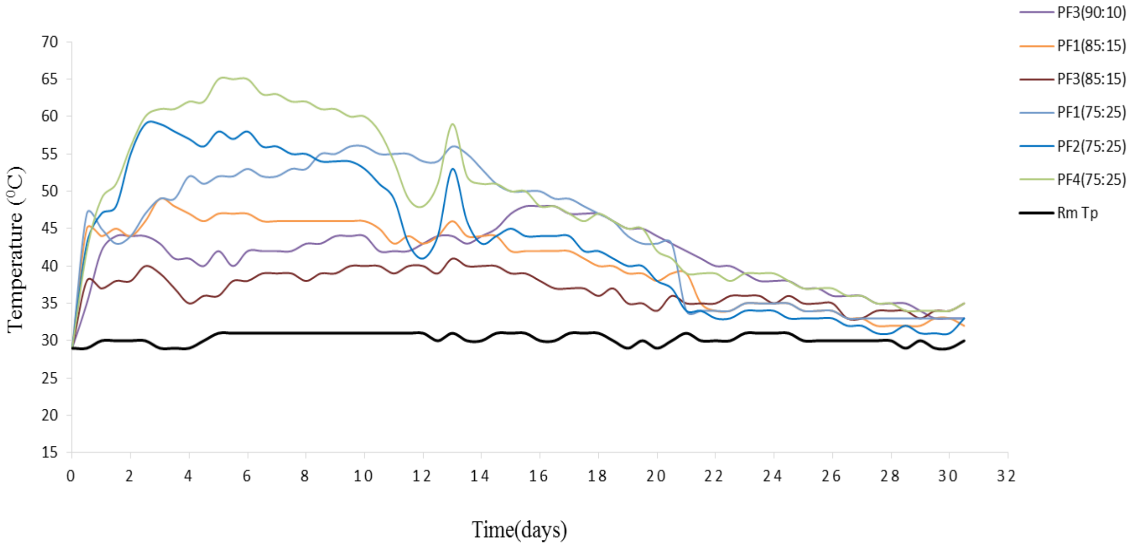
Table-4.1: Physio-chemical parameter of the waste material used for composting

Parameter	Unit	Food waste	Vegetable waste	Waste paper	Saw dust	Faecal Sludge
Moisture content	%	79	94.5	9.2	37.8	63.6
Volatile solids	%	94.1	96.2	86.93	96.6	32.9
Ash content	%	5.9	3.8	13.07	3.4	67.1
Dry solids	%	21	5.5	90.8	62.2	36.4
Carbon	%	54.6	55.8	50.8	56	19.1

4.3 Temperature Variations in Different Experiment

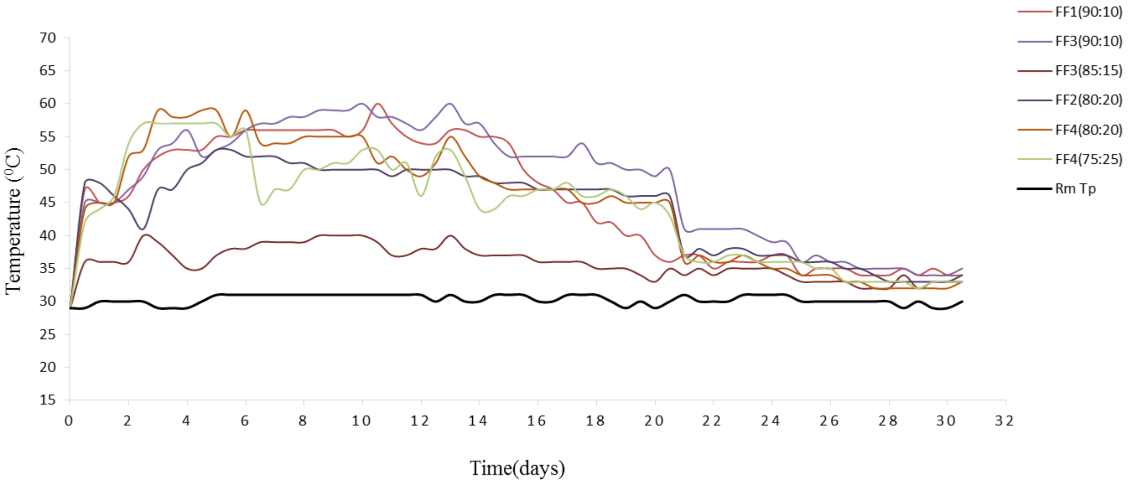
4.3.1 Temperature Variation in Wet Season

All the reactors with different mix ratio for first stage were run for 30 days. In passively aerated reactor temperature was raised to maximum from 55 ºC to 65 ºC within 6 days and decreased to minimum 31ºC. In PF4 (75:25) reactor maximum temperature was raised 65 ^{0}C within 5 days. In forced aerated reactor temperature was raised maximum from 55 ºC to 63 ºC within 8 days and decreased minimum 31 ^{0}C. Temperature variation during first stage Co-composting process are presented in Figure 4.1 and Figure 4.2.



(a)

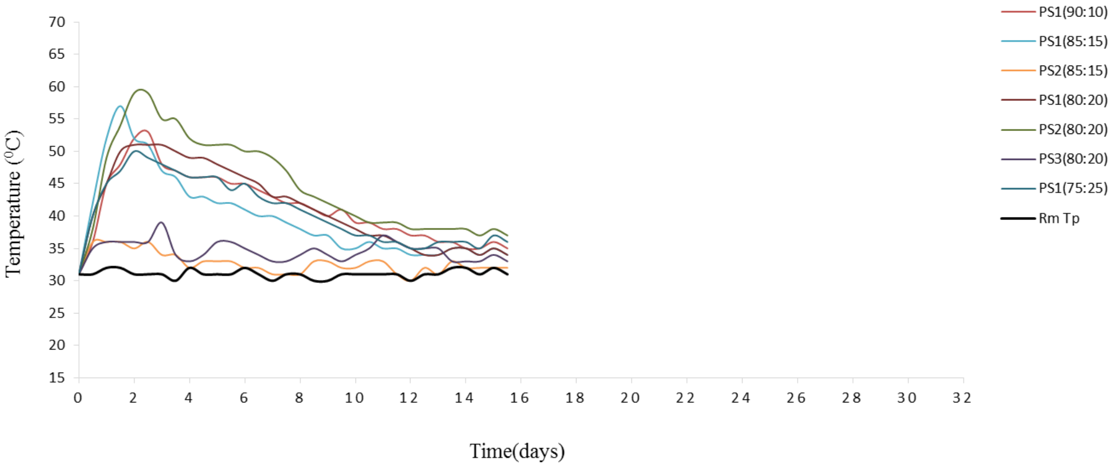
Figure 4.1. Temperature variation in wet season (a) passively aeration (1st Stage)



(b)

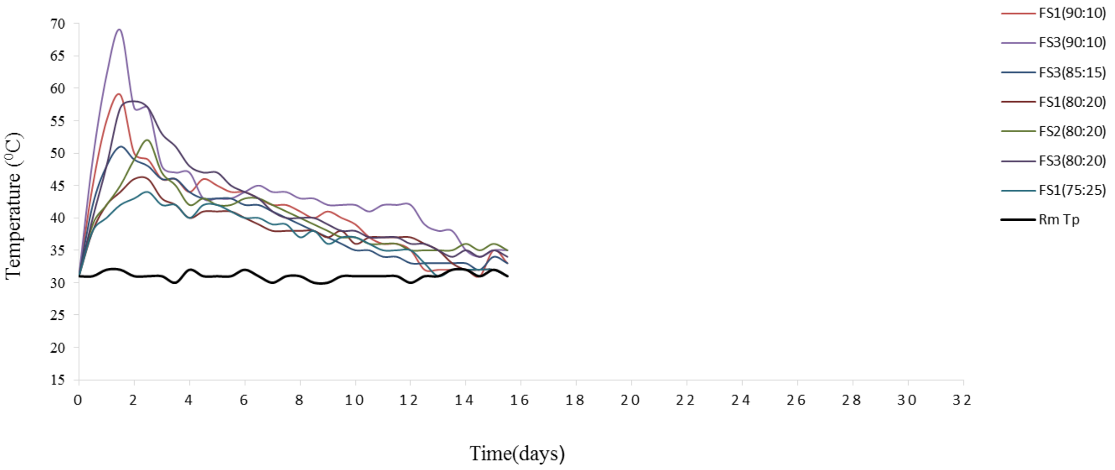
Figure 4.2. Temperature variation in wet season (b) forced aeration (1st Stage)

Compost released from the first stage reactor was mixed properly and used as feedstock in second stage composting. In second stage all reactors were run for 16 days as the temperatures came close to room temperature at the end. In passively aeration process, the temperature was raised maximum from 54 ºC to 60 ºC within 5 days. In forced aeration process, the temperature was raised maximum from 57 ºC to 67 ºC within 5 days. After 12 days all reactors temperature were almost same, which are very close to ambient temperature. Temperature variation during second stage composting are presented in Figure 4.3 and Figure 4.4.



(c)

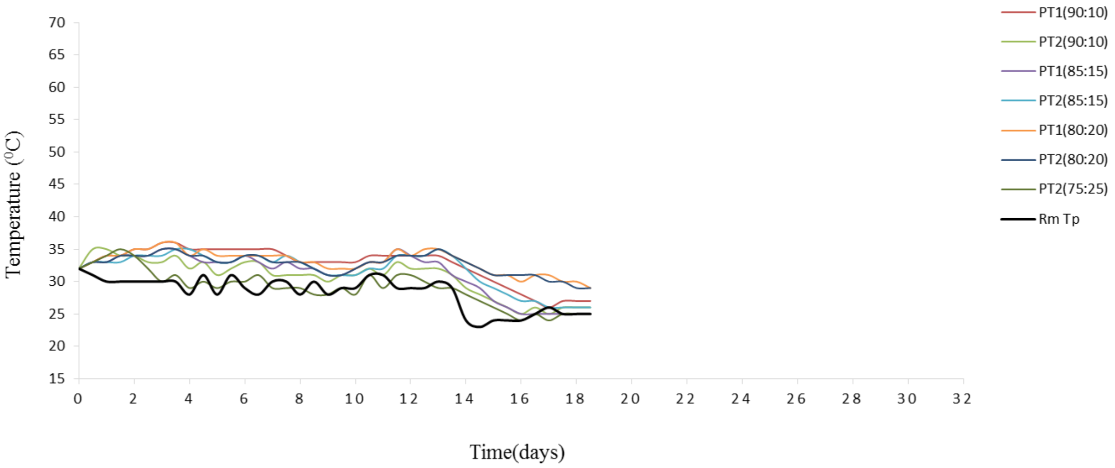
Figure 4.3: Temperature variation in wet season (c) passively aeration (2nd Stage)



(d)

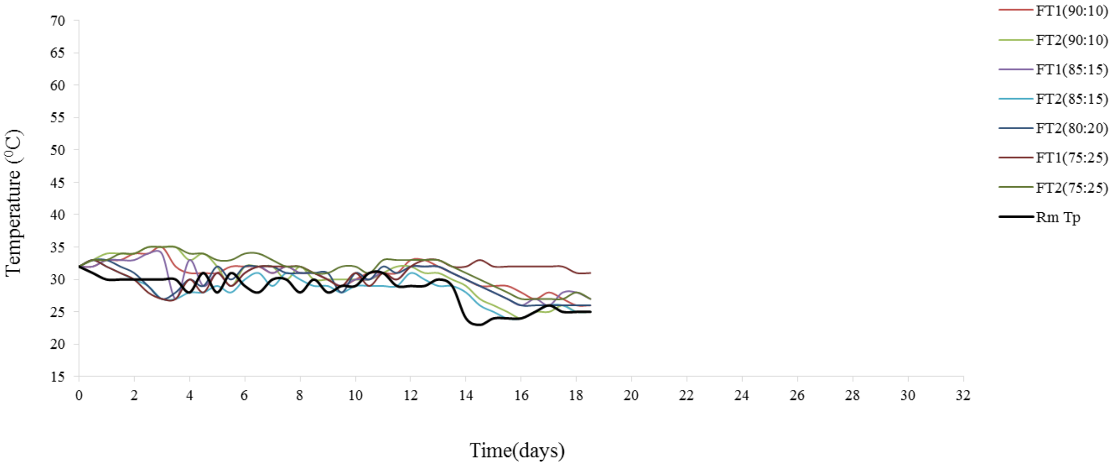
Figure 4.4. Temperature variation in wet season (d) forced aeration (2nd Stage)

Compost released from the second stage reactor was mixed properly and used as feedstock for third stage composting. In third stage all reactors were run for 19 days due to temperature fully toward ambient during that period. In passively and forced aerated reactor temperature was raised maximum from 35 ºC to 37 ºC within 7days and 33 ºC to 35 ºC within 3 days respectively. All reactors temperature were same which is very close to ambient temperature after 7 days. Temperature variation in third stage are shown in Figure 4.5 and Figure 4.6. In first stage and second stage the temperature was increased to high within one week but the third stage the temperature do not increase because in this stage the compost achieve stability.



(e)

Figure 4.5. Temperature variation in wet season (e) passively aeration (3rd Stage)



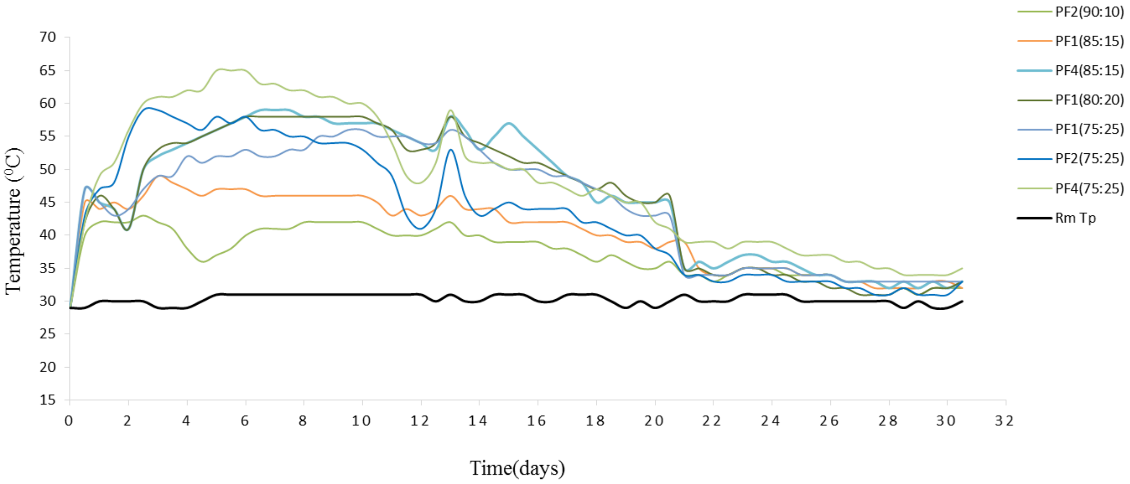
(f)

Figure 4.6. Temperature variation in wet season (f) forced aeration (3rd Stage)

It can be concluded that in wet season, the mean maximum temperature of the first stage, the second stage and third stage passively aerated composting process were 65 °C, 60 °C and 36 °C respectively. The mean maximum temperature of the first stage, the second stage and third stage forced aerated composting process were 63 °C, 67 °C and 34 °C respectively.

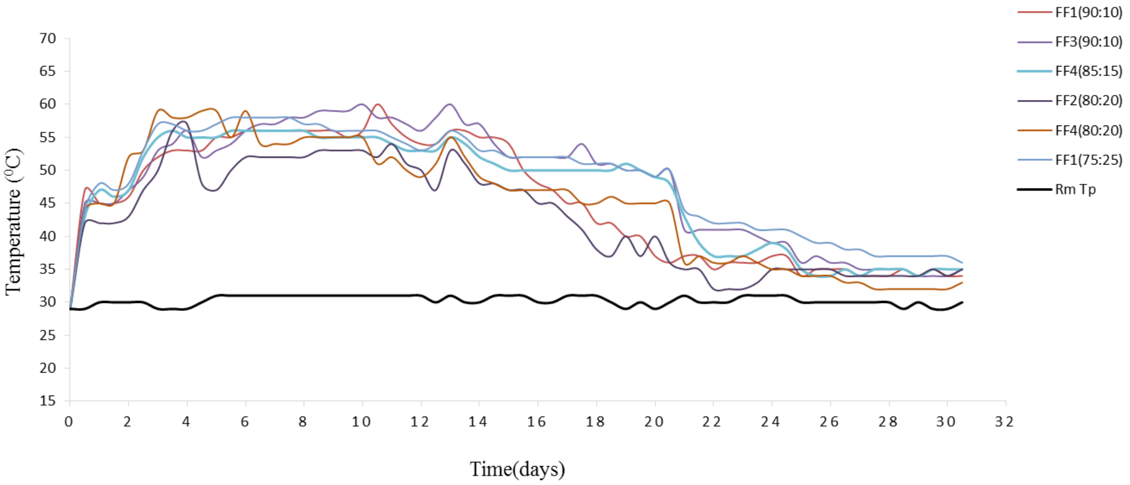
4.3.2 Temperature Variation in Dry Season

All the reactors with different mix ratio for first stage were run for 31 days. In passively and forced temperature was raised maximum from 57 °C to 67 °C within 5 days and 52 °C to 61 °C within 3 days. All reactors temperature were same which is very close to ambient temperature after 24 days. Temperature variation in dry season passively aeration and forced aeration first stage are present in Figure 4.7 and Figure 4.8



(g)

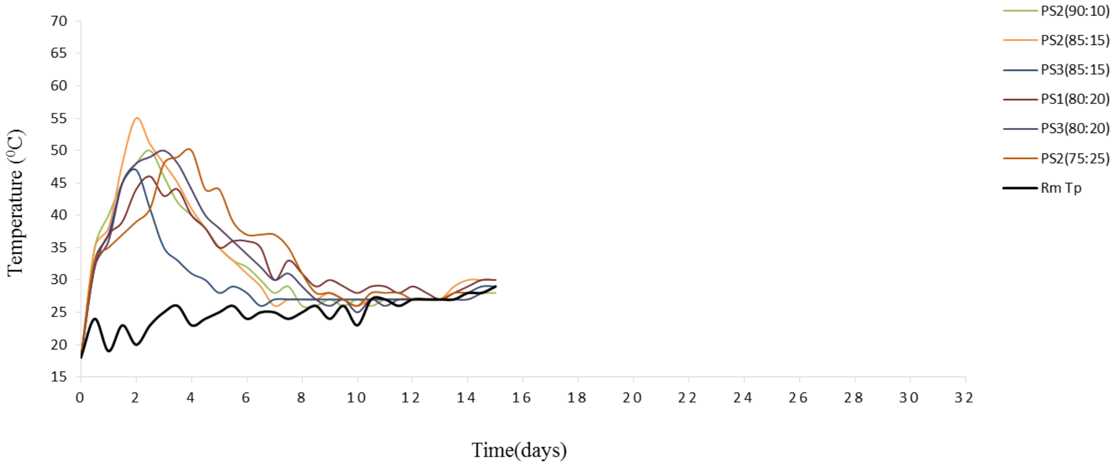
Figure 4.7. Temperature variation in dry season (g) passively aeration (1st Stage)



(h)

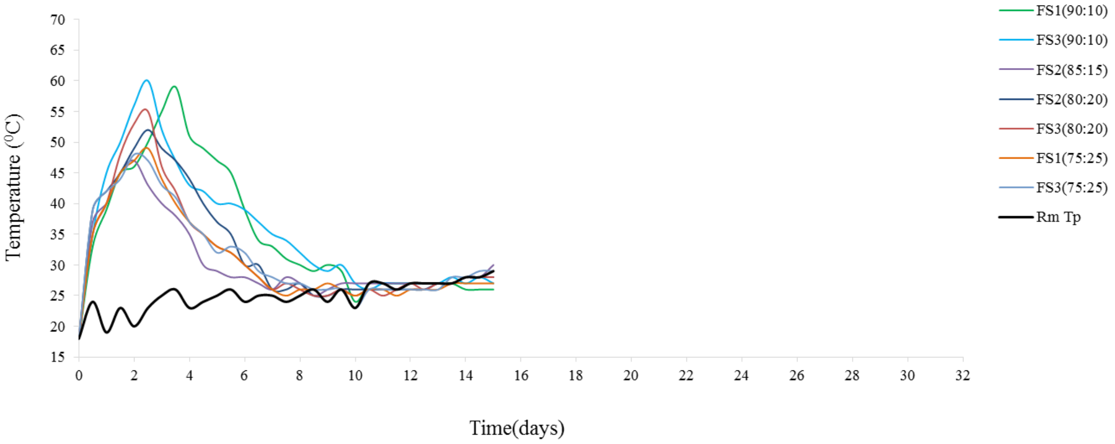
Figure 4.8. Temperature variation in dry season (h) forced aeration (1st Stage)

Compost released from the first stage reactor was mixed properly and used as feedstock in second stage composting. In second stage all reactors were run for 15 days as the temperatures came close to room temperature at the end. In passively aeration process, the temperature was raised maximum from 45 ºC to 56 ºC within 3 days. In forced aeration process, the temperature was raised maximum from 54 ºC to 60 ºC within 2 days respectively. After 10 days all reactor temperature were almost same, which are very closed to ambient temperature. Temperature variation in dry season passively aeration and forced aeration second stage are present in Figure 4.9 and Figure 4.10.



(i)

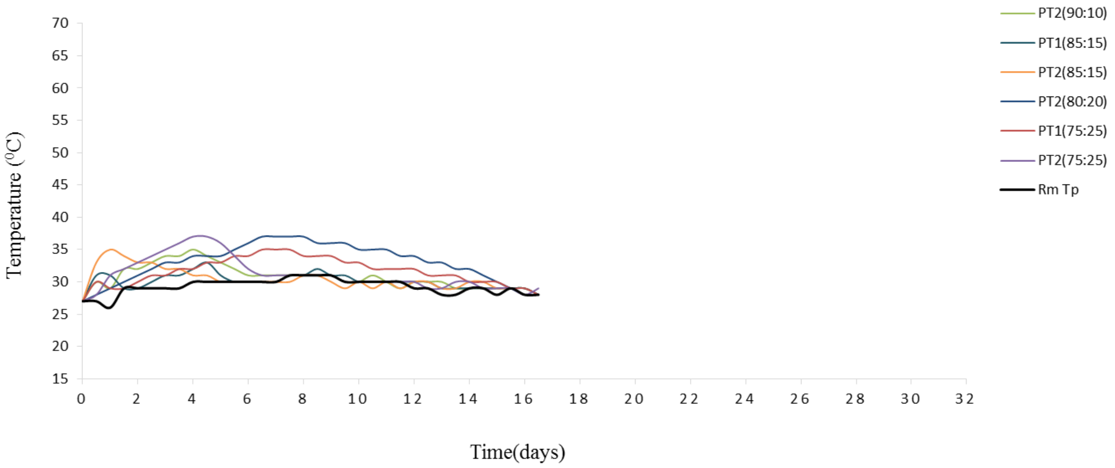
Figure 4.9. Temperature variation in dry season (i) passively aeration (2nd Stage)



(j)

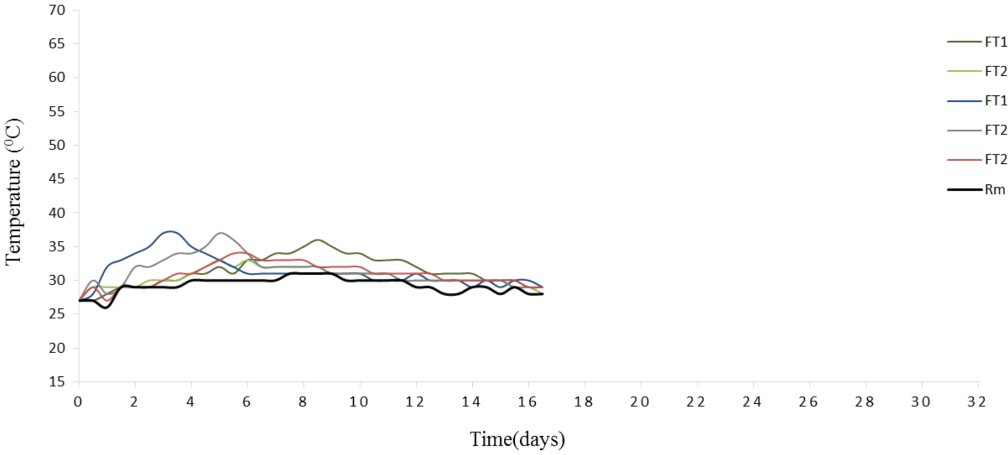
Figure 4.10. Temperature variation in dry season (j) forced aeration (2nd Stage)

Compost released from the second stage reactor was mixed properly and used as feedstock for third stage composting. In third stage all reactor were run for 17 days due to temperature fully toward ambient during that period. In passively and forced aerated reactor temperature were raised maximum from 33 ºC to 36 ºC within 3 day and 33 ºC to 38 ºC within 4 day. Temperature variation in dry season passively aeration and forced aeration third stage are present in Figure 4.11 and Figure 4.12. In first stage and second stage the temperature was increased to high within one week but the third stage the temperature do not increase because in this stage the compost achieve stability.



(k)

Figure 4.11. Temperature variation in dry season (k) passively aeration (3rd Stage)



(j)

Figure 4.12. Temperature variation in dry season (j) forced aeration (3rd Stage)

In dry season, the mean maximum temperature of the first stage, the second stage and third stage passive aerated composting process were 67 °C, 56 °C and 35 °C respectively. The mean maximum temperature of the first stage, the second stage and third stage forced aerated composting process were 61 °C, 60 °C and 36 °C respectively.

4.4 Mass Balances for Different Experiment

4.4.1 Mass Balances in Wet Season

The change in total mass (TM), moisture content (MC) and volatile solids (VS), fixed solids during bench scale Co-composting tests of first stage , second stage and third stage are shown in Table 4.2, Table 4.3, and Table 4.4 respectively. The moisture content (MC) reported on a wet basis and volatile solids (VS), fixed solids on a dry basis. Initial moisture content of the waste mixtures varied between 60 to 70%. In wet season, passively aerated Co-composting process, the average percent reduction of total mass, moisture content, volatile solids and fixed solids of first stage were 37.7%, 44.8%, 25.9% and 19.68% respectively. In second stage average percent reduction of total mass, moisture content, volatile solids and fixed solids were 17.1%, 18.4%, 17.3% and 11.9% respectively. In third stage percent reduction of total mass, moisture content volatile solids and fixed solids were 7.1%, 19.6% 11.4% and 5.7% respectively. In forced aerated Co-composting process, the average percent reduction of total mass, moisture content, volatile solids and fixed solids of first stage were 39.2%, 46.2%, 27.6% and 21.3% respectively. In second stage average percent reduction of total mass, moisture content, volatile solids and fixed solids were 23.4%, 27.8%, 19.4% and 14.3% respectively. In third satge percent reduction of total mass, moisture content volatile solids and fixed solids were 7.9%, 26.5% 13% and 4.9% respectively.

Table 4.2. Change in total mass, moisture content, volatile solid and fixed solid of first stage passively and forced aeration composting for wet season.

Reactor	Total mass initial (gm)	Total mass final (gm)	Reduction %	MC initial (gm)	MC final (gm)	Reduction %	VS initial (gm)	VS final (gm)	Reduction %	Fixed solid initial (gm)	Fixed solid final (gm)	Reduction %
PF1(90:10)	740	490	33.78	490.9	276.8	43.63	215.8	182.6	15.38	33.3	30.6	7.97
PF2(90:10)	720	465	35.42	477.6	262.6	45.02	210.0	173.3	17.46	32.4	29.0	10.24
PF3(90:10)	680	392	42.35	451.1	221.4	50.92	198.3	146.1	26.33	30.6	24.5	19.88
PF4(90:10)	640	372	41.88	424.6	210.1	50.51	186.7	138.7	25.72	28.8	23.2	19.22
PF1(85:15)	580	362	37.59	371.8	210.6	43.37	180.4	129.7	28.10	27.8	21.7	21.81
PF2(85:15)	580	332	42.76	371.8	193.1	48.06	180.4	118.9	34.05	27.8	19.9	28.29
PF3(85:15)	660	478	27.58	423.1	278.1	34.29	205.3	171.3	16.56	31.6	28.7	9.27
PF4(85:15)	520	290	44.23	333.4	168.7	49.40	161.7	103.9	35.75	24.9	17.4	30.13
PF1(80:20)	540	264	51.11	344.6	150.2	56.41	169.3	97.5	42.43	26.1	16.3	37.40
PF2(80:20)	740	488	34.05	472.3	277.7	41.20	232.0	180.1	22.35	35.7	30.2	15.56
PF3(80:20)	720	504	30.00	459.5	286.8	37.59	225.7	186.1	17.57	34.8	31.2	10.37
PF4(80:20)	640	390	39.06	408.4	221.9	45.67	200.6	144.0	28.25	30.9	24.1	21.97

PF1(75:25)	600	368	38.67	362.6	198.6	45.23	205.7	145.1	29.46	31.7	24.3	23.29
PF2(75:25)	500	284	43.20	302.2	153.3	49.28	171.4	112.0	34.67	26.4	18.8	28.96
PF3(75:25)	480	378	21.25	290.1	204.0	29.68	164.5	149.0	9.43	25.4	25.0	1.51
PF4(75:25)	540	324	40.00	326.4	174.9	46.42	185.1	127.7	30.99	28.5	21.4	24.96
FF1(90:10)	520	294	43.46	345.0	166.1	51.86	151.7	109.6	27.74	23.4	18.4	21.42
FF2(90:10)	480	310	35.42	318.4	175.1	45.02	140.0	115.6	17.46	21.6	19.4	10.24
FF3(90:10)	560	334	40.36	371.5	188.6	49.22	163.3	124.5	23.78	25.2	20.9	17.11
FF4(90:10)	500	348	30.40	331.7	196.6	40.74	145.8	129.7	11.05	22.5	21.7	3.27
FF1(85:15)	500	214	57.20	320.6	124.5	61.17	155.5	76.7	50.69	24.0	12.8	46.38
FF2(85:15)	640	352	45.00	410.3	204.8	50.10	199.0	126.1	36.64	30.7	21.1	31.10
FF3(85:15)	600	443	26.17	384.7	257.7	33.01	186.6	158.7	14.94	28.7	26.6	7.50
FF4(85:15)	620	354	42.90	397.5	205.9	48.19	192.8	126.8	34.22	29.7	21.2	28.47
FF1(80:20)	660	340	48.48	421.2	193.5	54.07	206.9	125.5	39.34	31.9	21.0	34.03
FF2(80:20)	680	414	39.12	434.0	235.6	45.72	213.2	152.8	28.31	32.8	25.6	22.04
FF3(80:20)	700	492	29.71	446.7	279.9	37.34	219.4	181.6	17.24	33.8	30.4	10.00
FF4(80:20)	620	336	45.81	395.7	191.2	51.68	194.4	124.0	36.19	29.9	20.8	30.61
FF1(75:25)	520	316	39.23	314.3	170.5	45.74	178.2	124.6	30.11	27.5	20.9	24.00
FF2(75:25)	520	382	26.54	314.3	206.2	34.40	178.2	150.6	15.51	27.5	25.2	8.12
FF3(75:25)	620	412	33.55	374.7	222.4	40.66	212.5	162.4	23.57	32.7	27.2	16.89
FF4(75:25)	540	304	43.70	326.4	164.1	49.73	185.1	119.9	35.25	28.5	20.1	29.59

Table 4.3. Change in total mass, moisture content, volatile solid and fixed solid of second stage passively and forced aeration composting for wet season.

Reactor	Total mass initial (gm)	Total mass final (gm)	Reduction %	MC initial (gm)	MC final (gm)	Reduction %	VS initial (gm)	VS final (gm)	Reduction %	Fixed solid initial (gm)	Fixed solid final (gm)	Reduction %
PS1(90:10)	374	318	15.0	233.3	197.4	15.4	95.8	81.1	15.3	44.9	39.4	12.3
PS2(90:10)	402	326	18.9	250.8	206.5	17.6	102.9	77.3	24.9	48.3	42.2	12.7
PS3(90:10)	384	272	29.2	239.5	167.7	30.0	98.3	68.3	30.5	46.1	36.0	21.9
PS1(85:15)	344	282	18.0	204.3	171.6	16.0	83.2	64.5	22.4	56.6	45.9	18.9
PS2(85:15)	384	344	10.4	228.0	198.0	13.1	92.8	86.3	7.0	63.2	59.7	5.5
PS3(85:15)	352	278	21.0	209.0	161.7	22.7	85.1	67.7	20.4	57.9	48.6	16.0
PS1(80:20)	388	348	10.3	230.0	207.1	9.9	94.8	82.2	13.4	63.2	58.7	7.1
PS2(80:20)	382	326	14.7	226.4	186.9	17.4	93.4	81.3	12.9	62.2	57.8	7.2
PS3(80:20)	408	362	11.3	241.8	205.8	14.9	99.7	92.4	7.4	66.5	63.8	4.0
PS1(75:25)	398	308	22.6	222.2	170.4	23.3	94.8	72.0	24.0	81.1	65.6	19.1
PS2(75:25)	394	338	14.2	219.9	181.3	17.5	93.8	80.0	14.8	80.2	76.7	4.4
PS3(75:25)	424	342	19.3	236.7	182.8	22.8	101.0	84.2	16.7	86.4	75.0	13.1
FS1(90:10)	376	226	39.9	222.0	117.6	47.0	104.9	73.0	30.4	49.1	35.4	27.8
FS2(90:10)	328	264	19.5	193.7	145.1	25.1	91.5	78.2	14.5	42.8	40.7	4.9
FS3(90:10)	390	234	40.0	230.3	124.1	46.1	108.8	72.9	33.0	50.9	37.0	27.3

FS1(85:15)	320	224	30.0	188.4	127.9	32.1	77.9	55.8	28.3	53.8	40.2	25.1
FS2(85:15)	302	226	25.2	177.8	129.6	27.1	73.5	56.4	23.3	50.7	40.1	21.0
FS3(85:15)	298	262	12.1	175.4	150.0	14.5	72.5	66.9	7.8	50.1	45.1	9.9
FS1(80:20)	386	294	23.8	225.2	157.5	30.1	96.0	78.3	18.5	64.8	58.2	10.1
FS2(80:20)	392	334	14.8	228.7	187.2	18.1	97.5	85.3	12.5	65.8	61.4	6.6
FS3(80:20)	356	280	21.3	207.7	145.7	29.8	88.6	78.8	11.0	59.7	55.5	7.1
FS1(75:25)	344	258	25.0	188.2	134.0	28.8	82.1	62.5	23.8	73.7	61.4	16.6
FS2(75:25)	434	380	12.4	237.4	194.6	18.0	103.6	95.0	8.3	93.0	90.4	2.8
FS3(75:25)	390	326	16.4	213.4	179.1	16.1	93.1	73.6	20.9	83.5	73.3	12.3

Table 4.4. Change in total mass, moisture content, volatile solid and fixed solid of third stage passively and forced aeration composting for wet season.

Reactor	Total mass initial (gm)	Total mass final (gm)	Reduction %	MC initial (gm)	MC final (gm)	Reduction %	VS initial (gm)	VS final (gm)	Reduction %	Fixed solid initial (gm)	Fixed solid final (gm)	Reduction %
PT1(90:10)	370	312	7.8	230.7	183.7	20.4	91.7	81.4	11.2	47.6	47.0	1.4
PT2(90:10)	382	327	7.2	238.2	193.0	19.0	94.6	85.7	9.5	49.1	48.3	1.7
PT1(85:15)	366	322	5.8	215.4	182.9	15.1	88.2	79.4	10.0	62.3	59.7	4.3
PT2(85:15)	338	280	8.2	198.9	155.8	21.7	81.5	71.3	12.5	57.6	52.9	8.0
PT1(80:20)	318	244	10.6	184.1	128.3	30.3	78.5	65.2	16.9	55.4	50.5	8.9
PT2(80:20)	324	284	5.6	187.6	156.9	16.4	80.0	71.4	10.7	56.4	55.6	1.4
PT1(75:25)	396	350	6.1	214.4	179.5	16.3	94.6	85.0	10.2	87.0	85.5	1.7
PT2(75:25)	330	290	5.4	178.7	147.6	17.4	78.8	71.2	9.6	72.5	71.2	1.9
FT1(90:10)	260	212	7.5	138.7	104.4	24.7	80.7	68.0	15.7	40.7	39.6	2.6
FT2(90:10)	266	212	8.5	141.9	103.3	27.2	82.5	70.4	14.8	41.6	38.3	7.9
FT1(85:15)	264	208	8.9	151.1	105.1	30.4	66.3	59.4	10.5	46.6	43.5	6.5
FT2(85:15)	260	216	6.7	148.8	109.0	26.8	65.3	61.7	5.6	45.9	45.3	1.2
FT1(80:20)	332	280	7.1	178.9	143.4	19.8	88.9	77.7	12.5	64.2	58.8	8.4
FT2(80:20)	326	280	6.4	175.6	134.9	23.2	87.3	83.1	4.8	63.1	61.9	1.8
FT1(75:25)	234	184	7.8	123.3	87.9	28.7	56.0	44.8	20.0	54.7	51.3	6.2
FT2(75:25)	336	262	10.3	177.1	121.3	31.5	80.4	64.3	20.1	78.5	76.4	2.6

4.4.2 Mass Balances in Dry Season

The change in total mass (TM), moisture content (MC) and volatile solids (VS),fixed solids during bench scale Co-composting tests of first stage, second stage and third stage are shown in Table 4.5, Table 4.6 and Table 4.7 respectively. The MC reported on a wet basis and VS, fixed solids on a dry basis. Initial moisture content of the waste mixtures varied between 55 to 70%. In dry season, passively aerated Co-composting process average percent reduction of total mass, moisture content, volatile solids and fixed solids of first stage were 33.1%, 35.95%, 29.2% and 16.7% respectively. In second stage average percent reduction of total mass, moisture content, volatile solids and fixed solids were 15.7%, 25.6%, 7.4% and 4.7% respectively. In third stage percent reduction of total mass, moisture content volatile solids and fixed solids were 8%, 29.2% 5% and 3.5% respectively. In forced aerated Co-composting process, the average percent reduction of total mass, moisture content, volatile solids and fixed solids of first stage were 34.2%, 38.3%, 34% and 21.2% respectively. In second stage average percent reduction of total mass, moisture content, volatile solids and fixed solids were 18.4%, 29.3%, 7.72% and 5.6% respectively. In third stage percent reduction of total mass, moisture content volatile solids and fixed solids were 9.2%, 41.8% 5.4% and 2.7% respectively.

Table 4.5. Change in total mass, moisture content, volatile solid and fixed solid of first stage passively and forced aeration composting for dry season.

Reactor	Total mass initial (gm)	Total mass final (gm)	Reduction %	MC initial (gm)	MC final (gm)	Reduction %	VS initial (gm)	VS final (gm)	Reduction %	Fixed solid initial (gm)	Fixed solid final (gm)	Reduction %
PF1(90:10)	722	474	34.35	414.8	297.8	28.20	141.8	76.1	46.33	165.4	100.1	39.50
PF2(90:10)	574	334	41.81	329.8	202.8	38.51	112.7	56.4	49.96	131.5	74.8	43.11
PF3(90:10)	612	386	36.93	351.6	225.1	35.97	120.2	73.1	39.15	140.2	87.7	37.41
PF4(90:10)	636	392	38.36	365.4	245.8	32.73	124.9	63.0	49.53	145.7	83.2	42.92
PF1(85:15)	574	414	27.87	328.6	233.5	28.93	120.2	80.4	33.14	125.2	100.1	20.04
PF2(85:15)	544	344	36.76	311.4	191.4	38.54	113.9	63.5	44.30	118.7	89.2	24.87
PF3(85:15)	550	382	30.55	314.8	202.3	35.73	115.2	74.9	34.99	120.0	104.8	12.68
PF4(85:15)	560	346	38.21	320.5	190.6	40.54	117.3	66.9	42.92	122.2	88.4	27.60
PF1(80:20)	550	362	34.18	304.4	176.8	41.91	114.4	81.0	29.17	131.2	104.2	20.62
PF2(80:20)	531	360	32.20	293.9	156.1	46.88	110.5	89.6	18.87	126.7	114.3	9.78
PF3(80:20)	522	330	36.78	288.9	161.5	44.08	108.6	70.1	35.43	124.5	98.3	21.03
PF4(80:20)	596	398	33.22	329.8	196.9	40.30	124.0	88.9	28.30	142.2	112.2	21.08
PF1(75:25)	568	394	30.63	299.4	178.6	40.36	125.7	91.3	27.37	142.8	124.1	13.13
PF2(75:25)	548	406	25.91	288.9	167.4	42.06	121.3	110.4	8.95	137.8	128.2	6.99
PF3(75:25)	568	434	23.59	299.4	210.0	29.87	125.7	98.1	21.96	142.8	125.9	11.87
PF4(75:25)	562	400	28.83	296.3	177.7	40.03	124.4	93.6	24.79	141.3	128.8	8.89
FF1(90:10)	508	304	40.16	291.8	162.3	44.40	99.8	63.1	36.73	116.4	78.6	32.46
FF2(90:10)	541	314	41.96	310.8	166.6	46.38	106.3	67.1	36.82	123.9	80.2	35.27
FF3(90:10)	576	314	45.49	330.9	172.4	47.92	113.1	63.9	43.52	132.0	77.7	41.08
FF4(90:10)	660	464	29.70	379.2	263.9	30.41	129.6	90.4	30.27	151.2	109.7	27.43
FF1(85:15)	480	338	29.58	274.8	171.8	37.47	100.5	69.1	31.31	104.7	97.1	7.24
FF2(85:15)	512	340	33.59	293.1	170.4	41.84	107.2	76.6	28.61	111.7	93.0	16.74
FF3(85:15)	522	290	44.44	298.8	151.4	49.33	109.3	63.5	41.90	113.9	75.1	34.08

FF4(85:15)	506	338	33.20	289.6	183.4	36.68	106.0	66.7	37.05	110.4	87.9	20.38
FF1(80:20)	564	412	26.95	312.1	234.4	24.89	117.3	75.7	35.48	134.6	101.9	24.29
FF2(80:20)	524	322	38.55	290.0	161.7	44.25	109.0	71.2	34.73	125.0	89.2	28.67
FF3(80:20)	556	384	30.94	307.7	190.3	38.14	115.7	79.5	31.30	132.6	114.2	13.91
FF4(80:20)	534	344	35.58	295.5	169.3	42.70	111.1	76.9	30.73	127.4	97.7	23.28
FF1(75:25)	581	412	29.09	306.3	213.7	30.24	128.6	81.4	36.73	146.1	117.0	19.94
FF2(75:25)	554	350	36.82	292.1	170.8	41.52	122.6	81.8	33.30	139.3	97.4	30.08
FF3(75:25)	575	452	21.39	303.1	238.3	21.39	127.3	98.5	22.60	144.6	115.2	20.33
FF4(75:25)	528	368	30.30	278.4	178.6	35.86	116.9	77.9	33.30	132.8	111.5	16.02

Table 4.6. Change in total mass, moisture content, volatile solid and fixed solid of second stage passively and forced aeration composting for dry season.

Reactor	Total mass initial (gm)	Total mass final (gm)	Reduction %	MC initial (gm)	MC final (gm)	Reduction %	VS initial (gm)	VS final (gm)	Reduction %	Fixed solid initial (gm)	Fixed solid final (gm)	Reduction %
PS1(90:10)	436	367	15.83	266.6	208.0	21.97	74.0	67.6	8.69	95.4	91.4	4.20
PS2(90:10)	412	341	17.23	251.9	190.4	24.39	69.9	65.0	7.08	90.2	85.6	5.10
PS3(90:10)	264	208	21.21	161.4	113.9	29.46	44.8	40.1	10.51	57.8	54.0	6.47
PS1(85:15)	474	404	14.77	260.8	197.5	24.27	91.1	87.0	4.44	122.1	119.5	2.18
PS2(85:15)	368	315	14.40	202.5	154.0	23.92	70.7	67.8	4.06	94.8	93.1	1.78
PS3(85:15)	430	376	12.56	236.6	186.5	21.17	82.6	80.4	2.75	110.8	109.1	1.48
PS1(80:20)	390	328	15.90	185.9	135.1	27.33	88.5	81.2	8.30	115.6	111.7	3.34
PS2(80:20)	440	380	13.64	209.7	162.3	22.62	99.9	93.8	6.13	130.4	124.0	4.93
PS3(80:20)	370	308	16.76	176.3	126.4	28.34	84.0	77.8	7.40	109.6	103.8	5.30
PS1(75:25)	468	399	14.74	209.9	150.7	28.17	111.7	105.9	5.19	146.5	142.4	2.80
PS2(75:25)	474	400	15.61	212.5	154.2	27.43	113.1	105.4	6.81	148.4	140.4	5.39
PS3(75:25)	486	412	15.23	217.9	157.6	27.67	116.0	108.8	6.17	152.1	145.5	4.31
FS1(90:10)	300	238	20.67	163.7	109.6	33.04	61.5	56.9	7.40	74.9	71.5	4.51
FS2(90:10)	386	318	17.62	210.6	155.7	26.04	79.1	72.7	8.16	96.3	89.6	6.96
FS3(90:10)	454	378	16.74	247.7	180.4	27.15	93.1	88.3	5.16	113.3	109.3	3.50
FS1(85:15)	262	191	27.10	135.9	75.0	44.83	55.4	50.0	9.68	70.7	66.0	6.69
FS2(85:15)	334	268	19.76	173.2	120.7	30.33	70.6	63.5	10.13	90.2	83.9	7.00
FS3(85:15)	430	354	17.67	223.0	161.4	27.61	90.9	83.0	8.71	116.1	109.6	5.61
FS1(80:20)	444	370	16.67	228.6	169.6	25.80	92.7	85.9	7.35	122.8	114.5	6.70
FS2(80:20)	406	327	19.46	209.0	154.4	26.12	84.7	73.8	12.88	112.2	98.8	12.02
FS3(80:20)	454	393	13.44	233.7	183.9	21.31	94.8	89.5	5.53	125.5	119.5	4.75
FS1(75:25)	474	392	17.30	239.3	166.4	30.45	102.0	96.2	5.75	132.7	129.4	2.46
FS2(75:25)	426	357	16.20	215.0	155.2	27.83	91.7	86.1	6.09	119.3	115.7	2.98
FS3(75:25)	446	366	17.94	225.1	155.4	30.99	96.0	90.4	5.81	124.9	120.2	3.72

Table 4.7. Change in total mass, moisture content, volatile solid and fixed solid of third stage passively and forced aeration composting for dry season.

Reactor	Total mass initial (gm)	Total mass final (gm)	Reduction %	MC initial (gm)	MC final (gm)	Reduction %	VS initial (gm)	VS final (gm)	Reduction %	Fixed solid initial (gm)	Fixed solid final (gm)	Reduction %
PT1(90:10)	370	312	7.82	206.1	150.3	27.06	68.9	67.5	2.09	95.0	94.2	0.82
PT2(90:10)	382	317	8.63	212.8	148.4	30.24	71.2	70.6	0.87	98.0	98.0	0.03
PT1(85:15)	366	304	8.38	179.8	126.1	29.86	78.2	73.3	6.32	108.0	104.6	3.11
PT2(85:15)	338	280	8.17	166.1	115.0	30.75	72.2	68.9	4.62	99.7	96.1	3.60
PT1(80:20)	318	244	10.57	132.4	63.0	52.40	75.4	72.1	4.37	110.2	108.9	1.20
PT2(80:20)	324	271	7.60	134.9	86.0	36.25	76.8	72.9	5.06	112.3	112.1	0.19
PT1(75:25)	396	350	6.10	150.4	108.9	27.59	73.8	71.8	2.75	171.8	169.3	1.44
PT2(75:25)	330	280	6.87	125.3	88.0	29.76	61.5	57.2	6.95	143.1	134.7	5.88
FT1(90:10)	260	202	9.24	125.2	70.9	43.39	56.2	52.7	6.33	78.5	78.4	0.13
FT2(90:10)	266	205	9.73	128.1	74.2	42.13	57.5	52.9	7.99	80.3	77.9	3.02
FT1(85:15)	264	208	8.92	114.3	65.1	43.02	61.5	58.5	4.87	88.2	84.4	4.34
FT2(85:15)	260	209	7.91	112.6	64.6	42.65	60.5	58.2	3.80	86.9	86.2	0.79
FT1(80:20)	332	270	8.56	156.0	97.3	37.60	64.2	61.0	4.91	111.9	111.7	0.18
FT2(80:20)	326	260	9.38	153.1	89.3	41.70	63.0	61.5	2.43	109.8	109.2	0.56
FT1(75:25)	234	174	9.55	100.1	48.8	51.26	50.5	45.7	9.47	83.3	79.4	4.66
FT2(75:25)	336	262	10.34	143.8	74.0	48.52	72.6	69.8	3.83	119.7	118.2	1.21

It can be concluded that in passively aerated Co-composting process, the average percent reduction of total mass, moisture content, volatile solids and fixed solids of first stage were 35.4%, 40.38%, 27.55% and 18.19% respectively. In second stage average percent reduction of total mass, moisture content, volatile solids and fixed solids were 16.4%, 22%, 12.35% and 8.3% respectively. In third stage percent reduction of total mass, moisture content volatile solids and fixed solids were 7.55%, 24.4%, 8.2% and 4.6% respectively. In forced aerated Co-composting process, the average percent reduction of total mass, moisture content, volatile solids and fixed solids of first stage were 36.7%, 42.25%, 30.8% and 21.25% respectively. In second stage average percent reduction of total mass, moisture content, volatile solids and fixed solids were 20.9%, 28.55%, 13.56% and 9.95% respectively. In third stage percent reduction of total mass, moisture content volatile solids and fixed solids were 8.55%, 34.15%, 9.2% and 3.8% respectively.

4.5 Initial and Final Physico-chemical Characteristics of Waste and Compost

Initial and final physico-chemical parameters of waste and compost for bench-scale tests of passive and forced aeration composting process are present in Table 4.8. At the initial condition the pH of four mixing ratios in passive and forced aeration composting process of OSW and FS such as 90:10, 85:15, 80:20, 75:25 was observed to be 7.07, 6.86, 7.03 and 7.27 respectively. This indicates the alkaline character of the sample. But after maturation slight decrease in pH may be observed. In passive and forced aeration composting process, at final condition the pH value of finished compost is ranged in between 7.70 to 7.93. It indicate that when faecal sludge volume increased then the P^H values is increased. The conductivity of the initial waste samples varied between 2.05 to 3.42 mS/cm with an average of 2.60 mS/cm, as indicated in Table 4.8. The range of conductivity of the final samples after completion of all the stages was 1.9 to 4.6 mS/cm with an average of 3.05 mS/cm. The conductivity value of the final compost after completion of every stage of each run always increased from its starting value probably due to accumulation of mineral salt in the remaining compost through VS reduction. At the initial condition the COD (mg/g dry sample) of four mixing ratios in passive and forced aeration composting process varied between 28.8, 40.0, 26.4 and 24.0 respectively. In passive aeration composting process, at final condition the COD as mg/g dry sample value of finished compost is ranged in between 9.8 to 22.5. In forced aeration co-composting process COD as mg/g dry sample value of finished compost is ranged in between 8.8 to 22.4. The average initial and final percentage of TKN is presented in Table 4.8. The TKN of initial of four mixing ratios in passive and forced aeration composting process was observed to be 1.78%, 1.72%, 2.56% and 2.81% of dry solids respectively. Due to the loss of volatile solids, the percentage of TKN in the final samples was always found 0.12 to 0.24% higher than that in the initial samples. In passive aeration composting process, at final condition TKN value of finished compost is ranged in between 1.9 to 3.1% of dry sample. In forced aeration co-composting process TKN value of finished compost is ranged in between 1.8 to 3.1% of dry sample. From Table 4.8 it can also be seen that all ratio of OSW and FS mixer in passive and forced aeration process the range of initial C/N ratios was 11to 22. In passive and forced aeration composting process in final stage all ratio of organic solid waste and faecal sludge Co-composting process carbon-nitrogen ratio range were varied from 10 to 15. Therefore, C/N ratios decreased as composting proceeded.

Table 4.8: Initial and final physico-chemical parameters of waste and compost in bench-scale tests of passive and forced aeration composting.

Item	pH initial	pH final	Ec (ms/cm) initial	Ec (ms/cm) final	COD (mg/g) dry sample intial	COD (mg/g) dry sample intial	C (%) initial	C (%) final	N (%) initial	N (%) final	TKN (%) initial	TKN (%) final	C/N initial	C/N final
PF1(90:10)	7.07	7.86	3.4	1.9	28.8	21.6	36.5	32.4	1.7	2.3	1.8	2.0	22.0	14.0
PF2(90:10)	7.07	7.65	3.4	2.2	28.8	22.0	36.5	32.5	1.7	2.3	1.8	2.0	22.0	14.0
PF3(90:10)	7.07	7.87	3.4	2.0	28.8	19.8	36.5	32.1	1.7	2.3	1.8	1.9	22.0	13.9
PF4(90:10)	7.07	7.89	3.4	2.0	28.8	22.5	36.5	33.3	1.7	2.3	1.8	1.9	22.0	14.2
PF1(85:15)	6.86	7.79	2.7	4.5	40.0	19.2	35.6	33.2	1.6	2.3	1.7	1.9	21.7	14.6
PF2(85:15)	6.86	7.81	2.7	4.3	40.0	17.3	35.6	33.1	1.6	2.3	1.7	1.9	21.7	14.6
PF3(85:15)	6.86	7.7	2.7	4.6	40.0	20.5	35.6	33.7	1.6	2.3	1.7	1.9	21.7	14.7
PF4(85:15)	6.86	7.75	2.7	4.1	40.0	18.6	35.6	34.1	1.6	2.3	1.7	1.9	21.7	15.0
PF1(80:20)	7.03	7.81	2.2	4.3	26.4	14.4	33.8	32.8	2.4	2.5	2.6	2.7	14.3	13.3
PF2(80:20)	7.03	7.83	2.2	4.3	26.4	14.8	33.8	32.7	2.4	2.5	2.6	2.7	14.3	13.3
PF3(80:20)	7.03	7.79	2.2	4.2	26.4	12.9	33.8	32.7	2.4	2.5	2.6	2.7	14.3	13.2
PF4(80:20)	7.03	7.8	2.2	4.3	26.4	15.2	33.8	32.8	2.4	3.0	2.6	2.8	14.3	11.1
PF1(75:25)	7.27	7.9	2.1	3.5	24.0	9.8	31.3	29.7	2.7	3.0	2.8	3.0	11.4	10.0
PF2(75:25)	7.27	7.89	2.1	3.4	24.0	10.2	31.3	29.0	2.7	3.0	2.8	3.0	11.4	9.8
PF3(75:25)	7.27	7.87	2.1	3.3	24.0	8.8	31.3	29.5	2.7	3.0	2.8	3.0	11.4	9.9
PF4(75:25)	7.27	7.93	2.1	3.6	24.0	11.1	31.3	29.4	2.7	3.0	2.8	3.1	11.4	9.8
FF1(90:10)	7.05	7.03	3.4	2.1	28.8	21.5	36.5	32.4	1.7	2.3	1.8	1.9	22.0	14.0
FF2(90:10)	7.05	7.01	3.4	2.2	28.8	21.6	36.5	32.5	1.7	2.3	1.8	2.0	22.0	14.0
FF3(90:10)	7.05	6.95	3.4	2.0	28.8	19.7	36.5	32.1	1.7	2.3	1.8	1.9	22.0	13.9
FF4(90:10)	7.05	6.96	3.4	1.9	28.8	22.4	36.5	33.3	1.7	2.3	1.8	1.9	22.0	14.2
FF1(85:15)	7.07	7.85	2.7	4.4	40.0	19.5	35.6	33.2	1.6	2.3	1.7	1.9	21.7	14.6
FF2(85:15)	7.07	7..86	2.7	4.4	40.0	19.2	35.6	33.1	1.6	2.3	1.7	1.9	21.7	14.6
FF3(85:15)	7.07	7.88	2.7	4.5	40.0	19.6	35.6	33.7	1.6	2.3	1.7	1.8	21.7	14.7
FF4(85:15)	7.07	7.91	2.7	4.3	40.0	21.3	35.6	34.1	1.6	2.3	1.7	1.8	21.7	15.0
FF1(80:20)	6.86	7.8	2.2	4.4	26.4	15.7	33.8	32.8	2.4	2.5	2.6	2.7	14.3	13.3
FF2(80:20)	6.86	7.81	2.2	4.3	26.4	14.7	33.8	32.7	2.4	2.5	2.6	2.7	14.3	13.3
FF3(80:20)	6.86	7.76	2.2	4.2	26.4	14.2	33.8	32.7	2.4	2.5	2.6	2.7	14.3	13.2
FF4(80:20)	6.86	7.81	2.2	4.2	26.4	16.3	33.8	32.8	2.4	3.0	2.6	2.7	14.3	11.1
FF1(75:25)	7.03	7.81	2.1	3.5	24.0	9.8	31.3	29.7	2.7	3.0	2.8	3.0	11.4	10.0
FF2(75:25)	7.03	7.83	2.1	3.4	24.0	8.9	31.3	29.0	2.7	3.0	2.8	2.9	11.4	9.8
FF3(75:25)	7.03	7.81	2.1	3.5	24.0	8.8	31.3	29.5	2.7	3.0	2.8	3.0	11.4	9.9
FF4(75:25)	7.03	7.8	2.1	3.7	24.0	10.3	31.3	29.4	2.7	3.0	2.8	3.1	11.4	9.8

4.6 Estimation of Initial Biodegradable Volatile Solids

The determination of the biodegradable fraction of VS or biodegradable volatile solids (BVS) would give a better understanding of the waste degradability and final product stability (Fernandes and Sartaj, 1997). The term biodegradable volatile solids (BVS) are generally used when referring to the degradation rates or oxygen consumption rates (Haug, 1993, Bari, 1999 Bari and koenig, 2001 and Bari, 2011). The total initial biodegradable volatile solids (BVS) for different proportion mixture solid waste bench scale tests were calculated from the sum of VS degraded in the first stage, second stage and third stage. According to Bari (1999), it was estimated that the remaining BVS in the compost, after 63 days of effective degradation in the first stage, second stage and third stage would not be more than 10%. Therefore, the sum of VS degraded is increased by 10% to have a suitable estimation of initial BVS. The calculation procedure and the estimated initial amounts of BVS are presented in wet and dry season in Table 4.9.

Table 4.9. Estimated initial biodegradable volatile solids (BVS) of bench scale tests in wet and dry season.

Season	Run	Initial DS* (gm)	Initial VS (gm)	Final VS (gm)	Duration in day				VS degraded in (gm)				Grand total after 10% increase (gm)
					ST1	ST2	ST3	Total	ST1	ST2	ST3	Total	
Wet season	P(90:10)	936	674	332	30	15	18	63	189.1	114.8	38.3	342.2	376.4
	P(85:15)	840	516	270	30	15	18	63	152.3	59.2	34.1	245.6	270.1
	P(80:20)	955	598	306	30	15	18	63	197.8	44.5	48.8	291.2	320.3
	P(75:25)	839	465	230	30	15	18	63	152.3	57.8	25.3	235.3	258.8
	F(90:10)	693	500	223	30	15	18	63	141.8	95.1	40	276.9	304.6
	F(85:15)	847	520	243	30	15	18	63	189.1	66.3	21.4	276.8	304.5
	F(80:20)	962	602	308	30	15	18	63	209.3	55.3	29.3	293.9	323.3
	F(75:25)	870	483	220	30	15	18	63	150.4	56.8	55.2	262.4	288.7
Dry season	P(90:10)	1082	500	206	30	15	16	61	231	17.1	45.9	293.9	323.3
	P(85:15)	953	467	253	30	15	16	61	181	10.4	22.2	213.5	234.9
	P(80:20)	982	457	225	30	15	16	61	127.8	29.9	75.2	232.9	256.2
	P(75:25)	1062	497	315	30	15	16	61	103.7	45.3	32.8	181.8	200
	F(90:10)	972	449	241	30	15	16	61	164.3	26.2	17.5	208	228.8
	F(85:15)	864	423	192	30	15	16	61	147.2	22.5	61.7	231.5	254.6
	F(80:20)	973	453	209	30	15	16	61	149.8	52.9	41.2	243.9	268.3
	F(75:25)	1058	495	244	30	15	16	61	155.7	50.4	45.6	251.8	277

*DS= Dry solids

4.7 Extent of Degradation

The amount of biodegradable volatile solids (BVS), which degraded in wet and dry season of each first stage, second stage, third stage are presented in Table 4.10. The total BVS percentage reduction of passive aeration composting was 83% to 89% in wet season. The

ΔBVS of waste proportion (75:25) of BVS was greater than other mix proportion and was 89%. In forced aeration composting process total BVS reduction was 78% to 92%. The waste mixture proportion (85:15) of BVS was greater than other mix proportion and was 92%. Total BVS percentage reduction of passive aeration composting process was 82% to 89% in dry season. The waste mixture proportion (85:15) of BVS was greater than other mix proportion and was 89%. Forced aeration composting process total BVS percentage reduction was 73% to 91%.

Table 4.10. Biodegradable volatile solids (BVS) degraded (Δ) in first stage, second stage and third stage with overall sum.

Season	Run	ST1 (wet season 30 days and dry season 29 days)			ST2 (15 days)			ST3 (wet season 18 days and dry season 16 days)			Days Total	Total ΔBVS (%)
		BVS_i	BVS_f	ΔBVS (%)	BVS_f	ΔBVS (%)	ΔBVS (%) of inital	BVS_f	ΔBVS (%)	ΔBVS (%) of inital		
Wet season	P(90:10)	376.4	208	44.74	126	39.3	21.71	42	66.6	22.36	63	88.8
	P(85:15)	270.1	167.5	37.98	65.1	61.2	37.93	38	42.4	10.21	63	86.1
	P(80:20)	320.3	217.6	32.05	72.4	66.7	45.33	54	25.9	5.86	63	83.2
	P(75:25)	258.8	167.5	35.29	63.5	62.1	40.17	28	56.3	13.81	63	89.3
	F(90:10)	304.6	156	48.8	105	32.9	16.86	44	57.9	19.89	63	85.5
	F(85:15)	304.5	208	31.69	73	64.9	44.35	24	67.8	16.24	63	92.3
	F(80:20)	323.3	230.2	28.79	60.9	73.6	52.38	32	47.1	8.86	63	90
	F(75:25)	288.7	165.5	42.67	62.5	62.3	35.69	61	2.76	0.6	63	79
Dry season	P(90:10)	323.3	254.1	21.42	55	78.3	61.57	50	8.3	1.41	60	84.4
	P(85:15)	234.9	199.1	15.25	26.3	86.8	73.57	24	6.99	0.78	60	89.6
	P(80:20)	256.2	140.6	45.13	62.1	55.9	30.64	48	22.6	5.47	60	81.3
	P(75:25)	200	114.1	42.97	49.9	56.3	32.09	36	27.7	6.91	60	82
	F(90:10)	228.8	180.7	21.02	28.9	84	66.37	19	33.3	4.21	60	91.6
	F(85:15)	254.6	162	36.39	72.2	55.4	35.27	68	5.9	1.67	60	73.3
	F(80:20)	268.3	164.8	38.57	58.2	64.7	39.75	45	22.1	4.79	60	83.1
	F(75:25)	277	171.3	38.15	55.5	67.6	41.83	50	9.45	1.89	60	81.9

4.8 Relationship between gm VS Reduction and Area under Temperature Curve

An attempt have been made so far to establish some relationships among the area under the temperature curves, and VS reduction according to Bari (1999) using data of more than 64 reactors which were applied for similar type waste mixture of compost.

For Passively aeration composting process, the correlation between $A_{total-ambient}$ (area under net temperature increase curve) in °C.h and gm volatile solids reduction is presented Figure 4.13. The correlation co-efficient was $R^2 = 0.7248$ which followed a linear relation. In forced aeration Co-composting process, the correlation co-efficient between $A_{total-ambient}$ (area under net temperature increase curve) in °C.h and gm volatile solids reduction was $R^2 = 0.7322$ as shown in Figure 4.14. It is clearly shown that higher $A_{total-ambient}$ indicate higher VS degradation. Therefore, the extent of degradation in a specified bench-scale test can be determined more exactly from the correlation between $A_{total-ambient}$ in °C.h and gm VS reduction as indicated in Figure 4.13 and 4.14. In forced aeration Co-composting process correlation co-efficient was greater than passive aeration composting process. It can be concluded that forced aeration process volatile solids reduction was greater than passive aeration process.

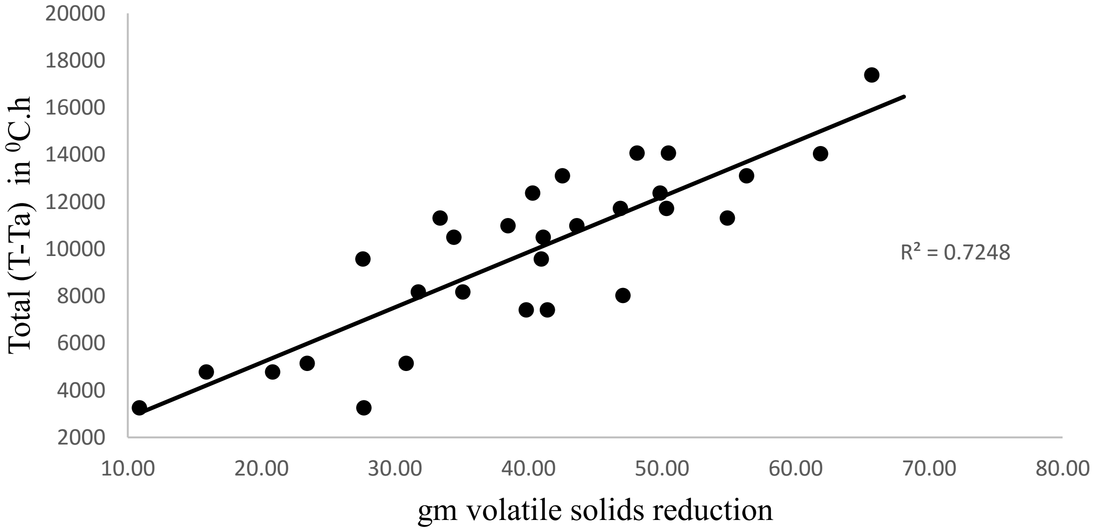


Figure 4.13. Correlation between $A_{total-ambient}$ (area under temperature curve after completion) in °C.h and gm volatile solids reduction in passively aeration process

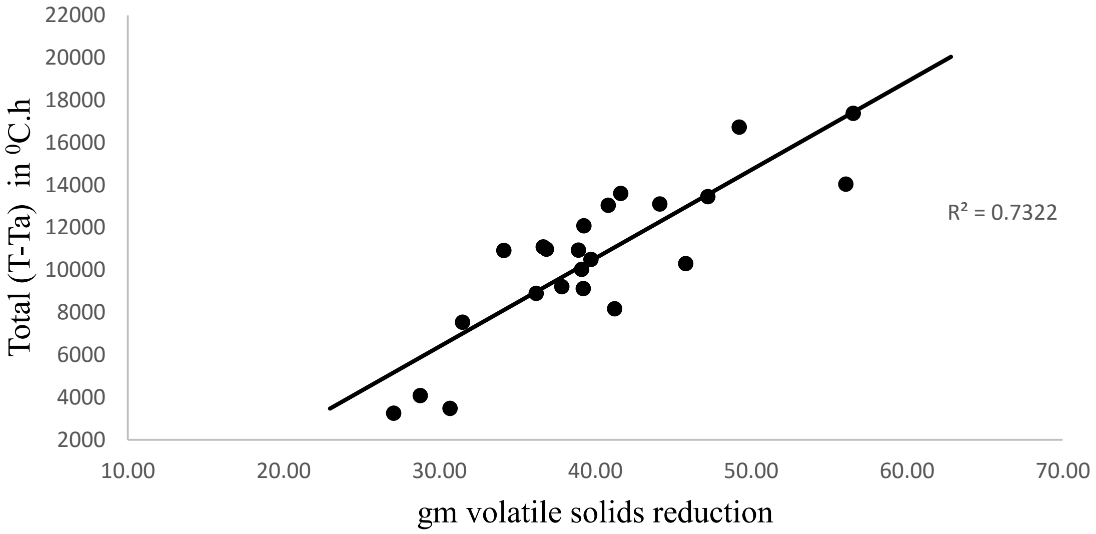


Figure 4.14. Correlation between $A_{total-ambient}$ (area under temperature curve after completion) in °C.h and gm volatile solids reduction in forced aeration process

4.9 Relationship between gm VS Reduction and Temperature

Few attempts have been made so far to establish some relationships among increase maximum temperature rate, maximum temperature and VS reduction according to Bari (1999) using data of more than 64 reactors bench scale test which were applied for similar type waste mixture in passively and forced aeration Co-composting process.

In passively aeration Co-composting process correlation co-efficient between maximum temperature increase rate (I_{max}) in ºC/h and gm volatile Solids reduction was $R^2 = 0.6323$ as shown in Figure 4.15. Another correlation co-efficient between maximum temperature in ºC and gm volatile solids reduction was $R^2 = 0.6580$ presented in Figure 4.16.

In forced aeration Co-composting process correlation co-efficient between maximum temperature increase rate (I_{max}) in ºC/h and gm volatile Solids reduction was $R^2 = 0.6781$ as shown in Figure 4.17. Another correlation co-efficient between maximum temperature in ºC and gm volatile solids reduction was $R^2 = 0.6933$ presented in Figure 4.18. It can be concluded that correlation co-efficient of forced aeration was greater that passively aeration process. Higher I_{max} indicates higher degradation and thereby a less stable end product. Therefore, it was confirmed that unstable compost has a higher I_{max}. Maximum temperature indicates that maximum volatile solids reduction in co-composting process.

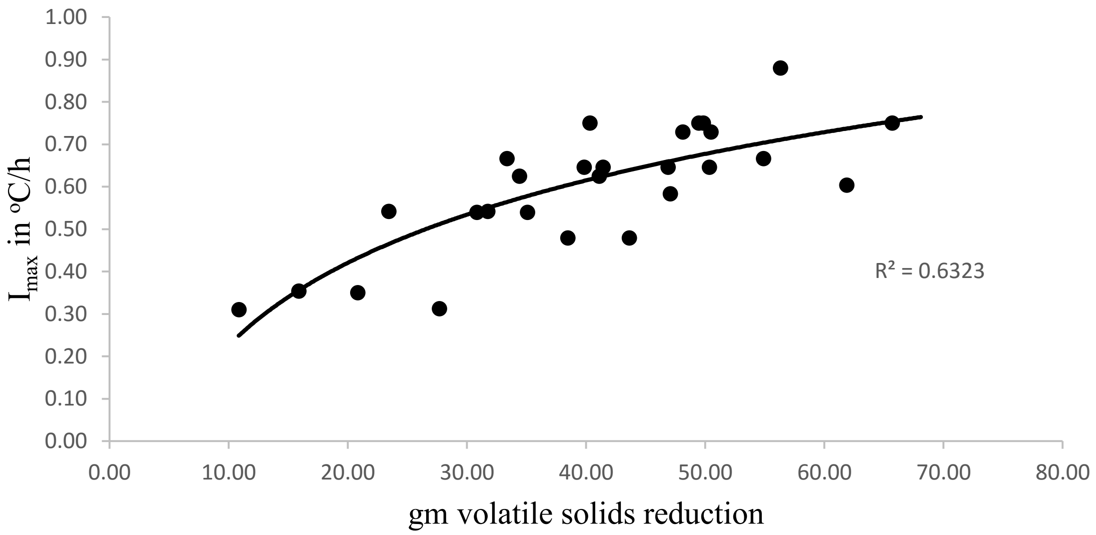


Figure 4.15. Correlation between I_{max} (maximum temperature increase) in ºC/h and gm volatile solids reduction in passively aeration Co-composting process.

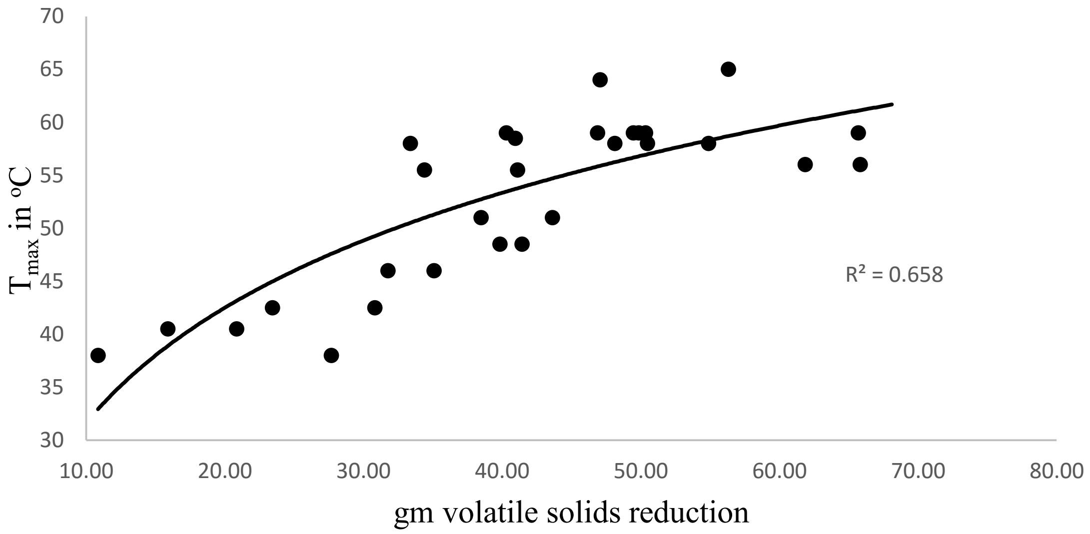


Figure 4.16. Correlation between maximum temperature °C and gm volatile solids reduction in passive aeration Co-composting process.

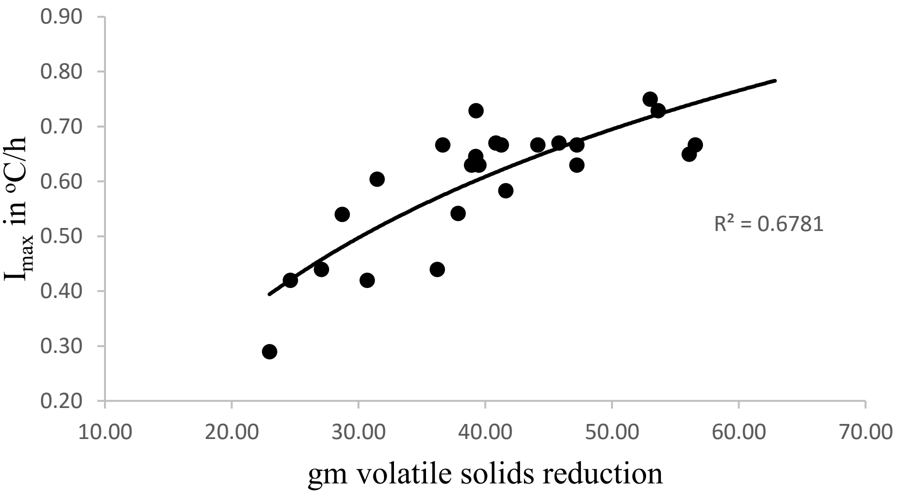


Figure 4.17. Correlation between I_{max} (maximum temperature increase) in °C/h and gm volatile solids reduction in forced aeration Co-composting process.

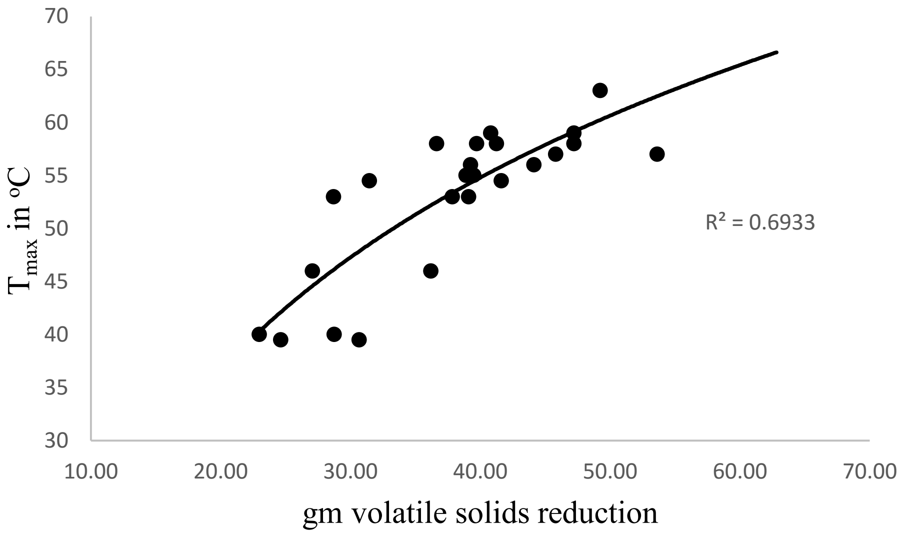


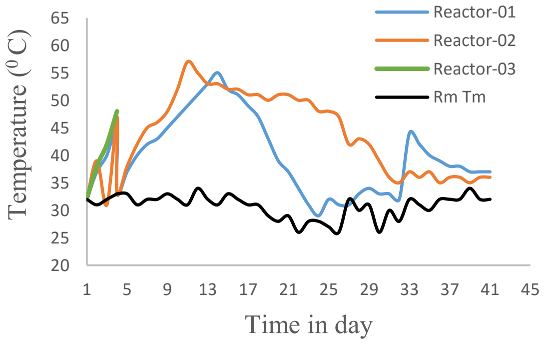
Figure 4.18. Correlation between maximum temperature °C and gm volatile solids reduction in forced aeration Co-composting process

4.10 Analysis of Degradation Rate

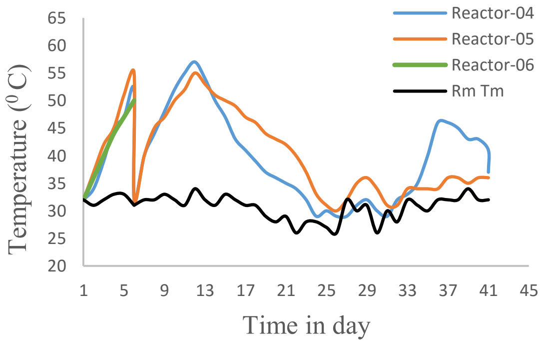
Degradation rate of Faecal Sludge with solid waste was analyzed. The temperature variations with time were measured using one hundred reactors by forced aeration composting process. In first stage sixty reactor were used (three reactor were made of one set) such as 20*3=60. During second stage forty reactor were used (two reactor were made of one set) such as 20*2=40. The variations of different data are also represented by graph

4.10.1 Temperature Variation in the Experiment of Degradation Rate of Faecal Sludge With Solid Waste

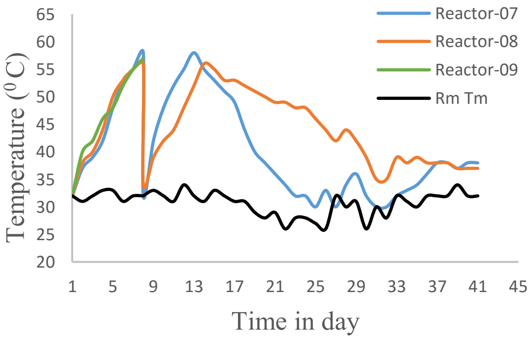
The temperature variations of first stage and second stage forced aeration composting process with time for sixty reactors (20 set) are presented in Figure 4.19. In Set-1 of Figure 4.19, the maximum temperature was 47 °C within 4 days in first stage and in second stage the maximum temperature was 57 °C within next 5 days. In Set-19 of reactor-55, the maximum temperature was 61 °C within 9 days in first stage and 64 °C within next 3 days in second stage. From 6 to 11 days during composting the temperature was above 55 °C. Within these five days many of the microorganisms that are human or plant pathogens were destroyed. Because temperatures over about 55 °C kill many form of microbes (Polprasert, 2007). In all the figures, there are a drop of three curves of first stage to ambient temperature after certain design time according to the experimental program then a rise to two curves of second stage. It means that at initial three reactors made of one set and after that the corresponding material when used to two reactors made of second stage.



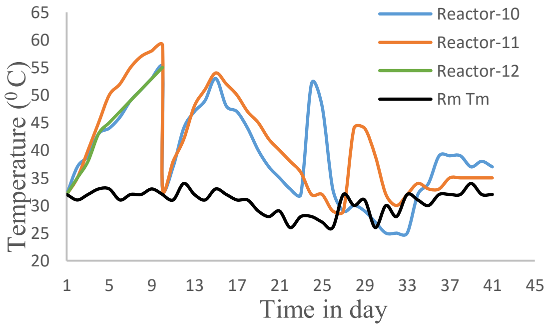
Set-1



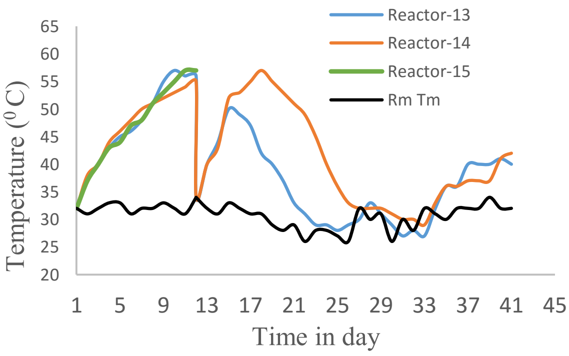
Set-2



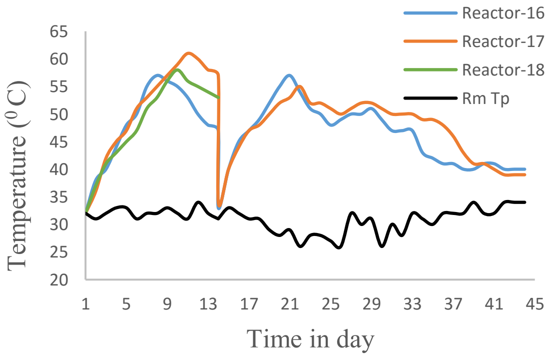
Set-3



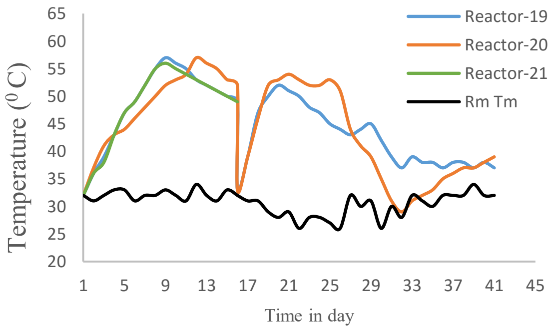
Set-4



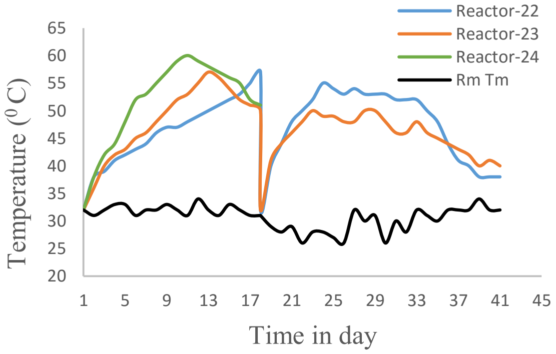
Set-5



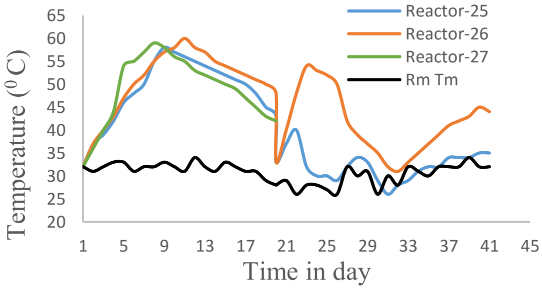
Set-6



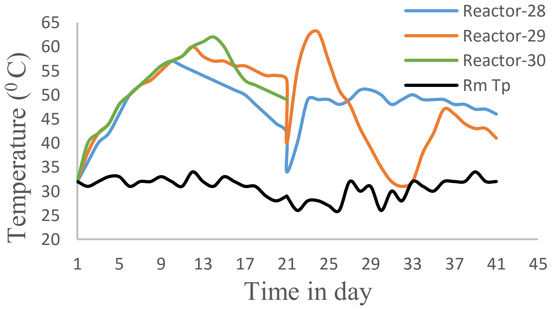
Set-7



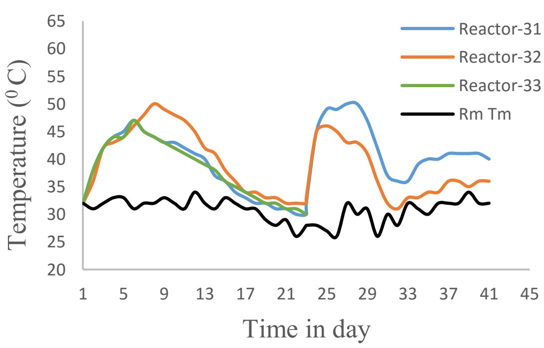
Set-8



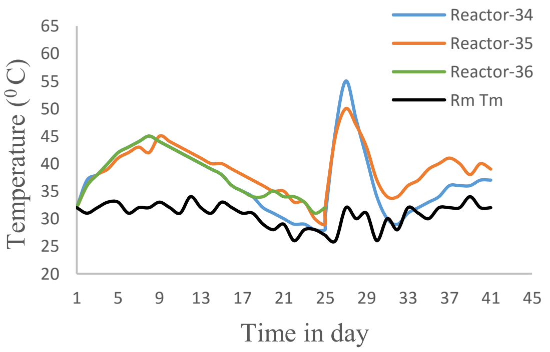
Set-9



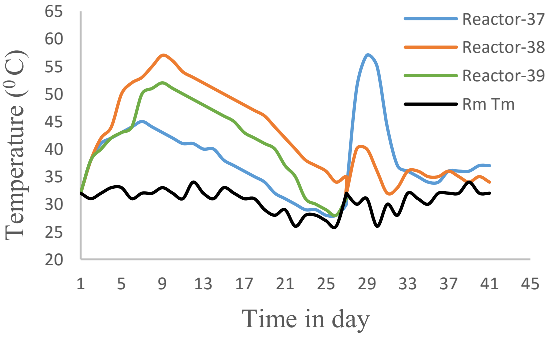
Set-10



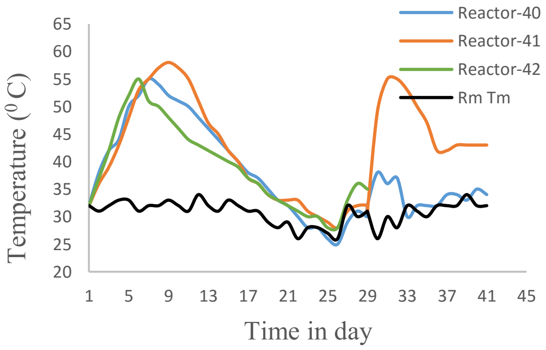
Set-11



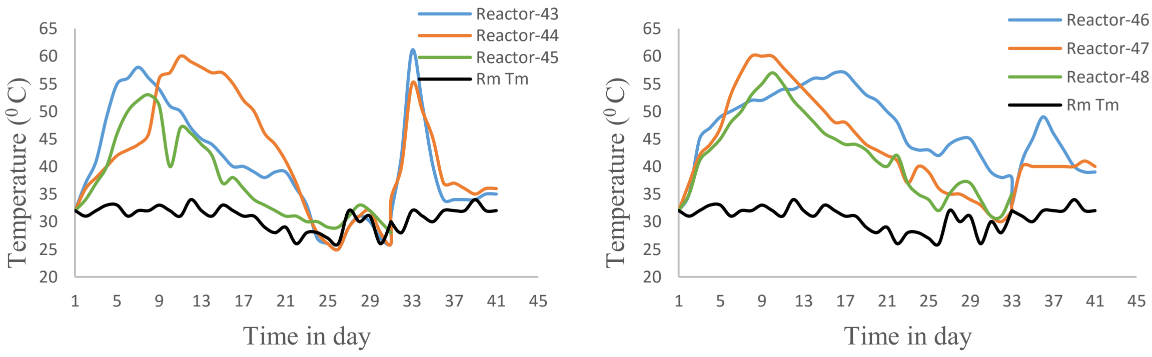
Set-12



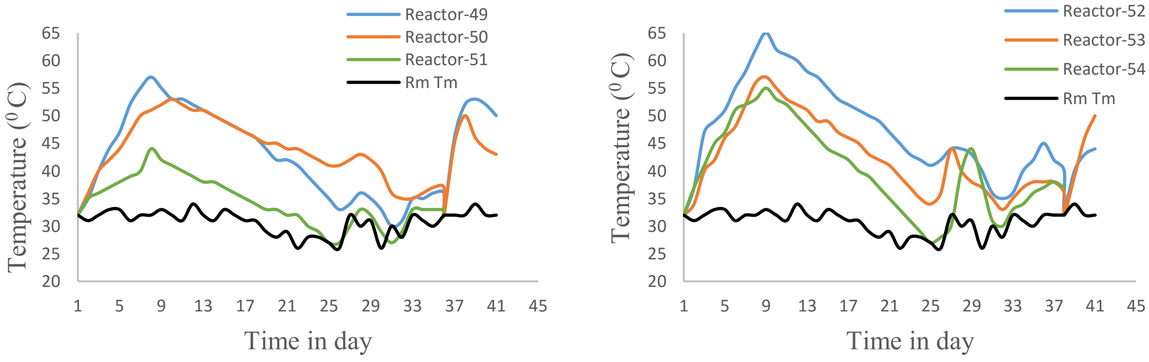
Set-13



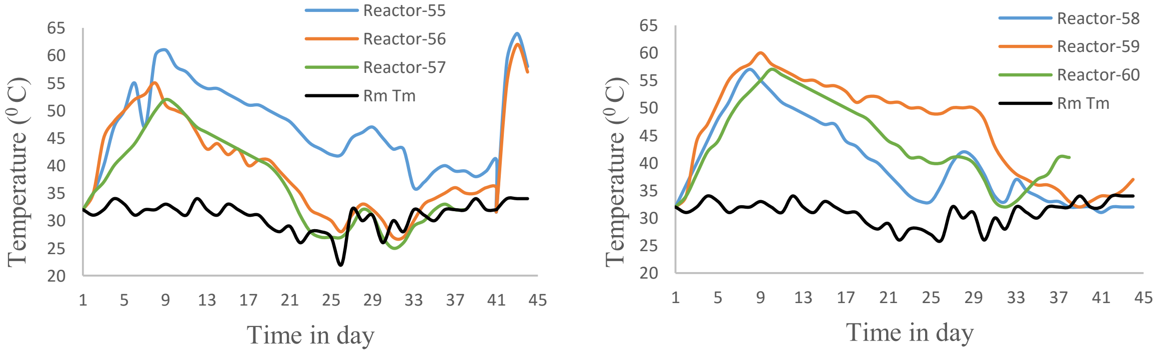
Set-14



Set-15 Set-16



Set-17 Set-18



Set-19 Set-20

Figure 4.19: Temperature variation with time during forced aeration composting for sixty reactors (twenty set).

4.10.2 Relationship between the Area under the Temperature Curves of Degradation Rate

In first stage, every reactor was calculated area under temperature ($T– T_a$). Every set was made of three reactors. In the mean area under temperature ($T– T_a$) of three reactors was estimated in every set. The relationship between the area under the temperature curve (T-Ta) in $^oC.h$ for different set (a total of fifteen set) first stage and second stage self-heating tests are presented in Figures 4.20. In first and second stage mean area under temperature (T– T_a) were 6435.5ºC.h and 5991.2ºC.h. In first and second stage mean area under temperature of all set value were shown in appendix. The self-heating tests maximum area under T-T_a of set-09 for first stage and second stage was found 9084 ºC.h and 9084 ºC.h respectively. Set-07 maximum area under T-T_a of first and second stage was found 7096 ºC.h and 9864 ºC.h. First stage area T-T_a of set-01 to 09 was increased and then decreased other set.

All set of reactor was added mean area under temperature (T– T_a) in the first stage and second stage. Every set of reactor percentage of degradation was calculated for the area under temperature multiple hundred divided by the total area under temperature. In first and second stage percentage of degradation were 51.8% and 48.91%. The Relationship between degradation percentage diagram of different sets of reactors in first stage and second stage self-heating tests were present in Figure 4.21. In Set-1, for a first stage percentage of degradation was 6.8 % and second stage percentage of degradation was 93.2%. In first stage percentage of degradation was increased, first to last set of reactor. In second stage percentage of degradation, self-heating test was decrease first to last set of reactor. It can be concluded that every set of reactor for first and second stage total percentage of degradation was almost same. Regression between area (T-Ta) with time log curve of different set of reactor of first stage self-heating tests was R^2 = 0.8589 as present in Figure in 4.22. Correlation co-efficient area (T-T_a) curve during time for second stage was R^2 = 0.7087 as shown in Figure 4.23. Regression area under temperature curve of first stage was greater than second stage in composting process.

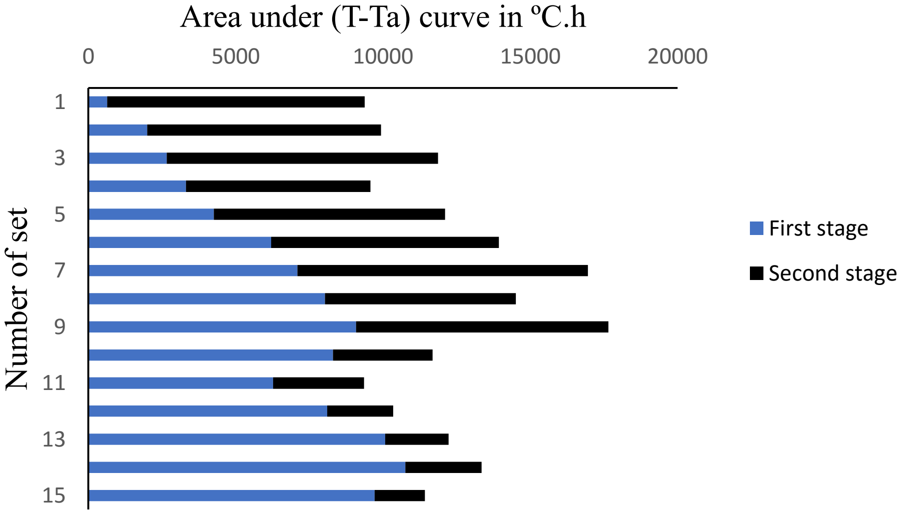


Figure 4.20: Relationship between the areas under (T-Ta) curve of different set of reactor first stage and second stage.

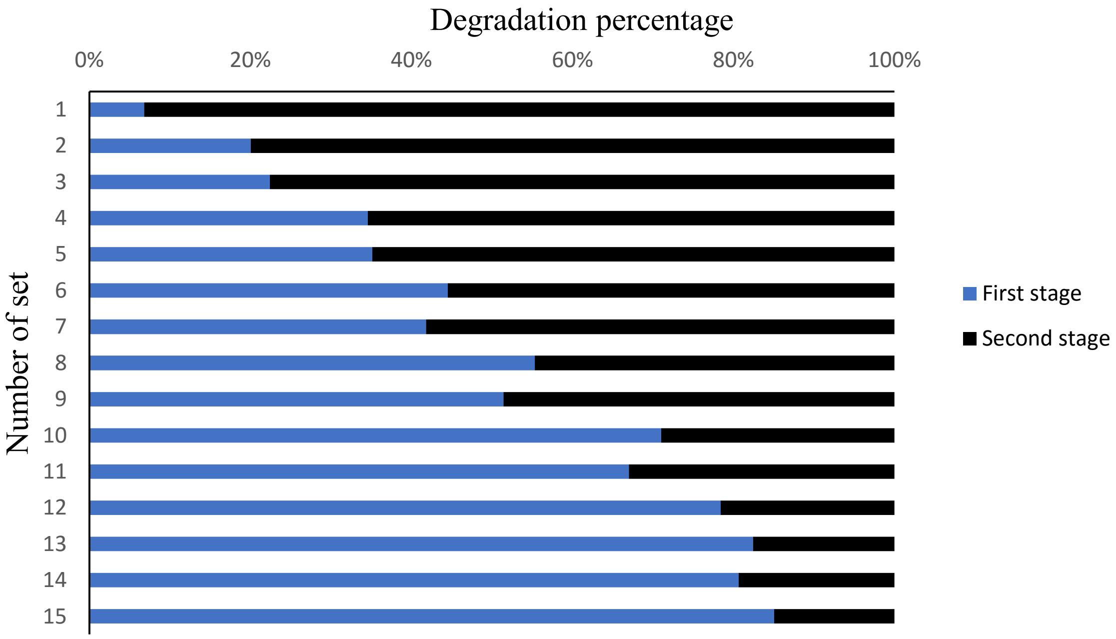


Figure 4.21: Relationship between degradation percentage diagram of different set of reactors in first stage and second stage.

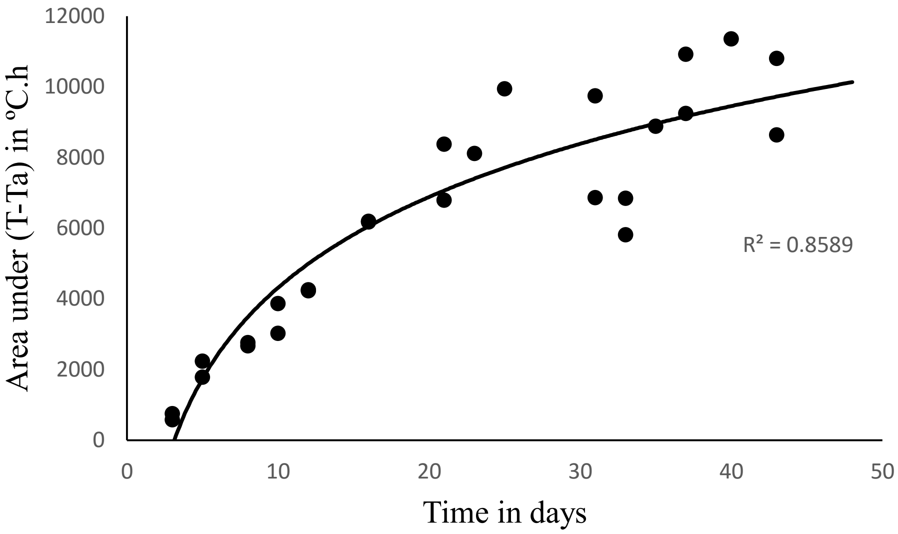


Figure 4.22: Correlation between the areas under (T-Ta) during with time log curve of different set of reactor first stage in Co-composting process.

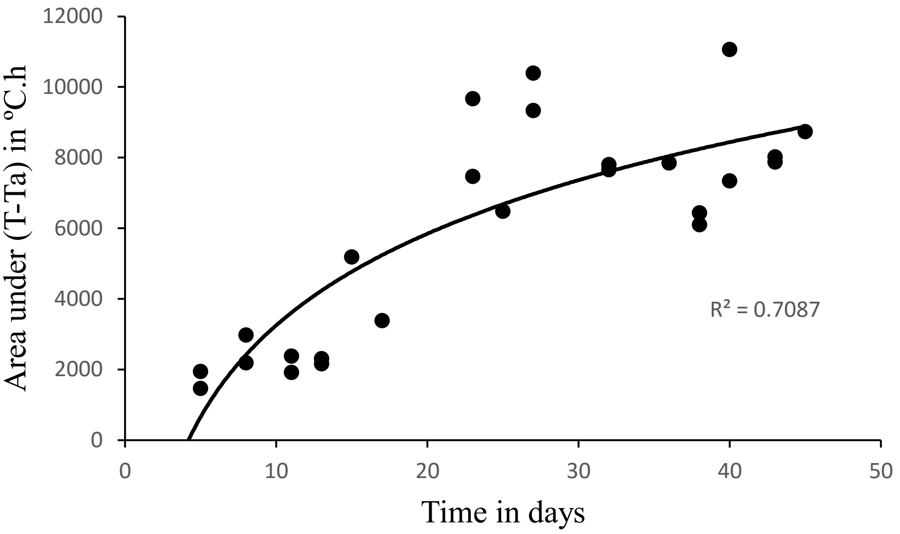


Figure 4.23: Correlation between the areas under (T-Ta) with time log curve of different set of reactor second stage in Co-composting process.

4.11 Volatile Solids Reduction with Time

The value of initial dry solids (IDS), initial volatile solids (IVS), final dry solids (FDS) and final volatile solids (FVS) were determined of every reactor. In sixty reactor were added to initial dry solids, initial volatile solids, final dry solids and final volatile solids. The percentage of initial volatile solids reduction was estimated the ratio of initial volatile solids and initial dry solids. The percentage of final volatile solids reduction was determined the ratio of final volatile solids and final dry solids. Initial volatile solids of every set of rector were determined to initial dry solids multiplied by percentage of initial volatile solids reduction. Final volatile solids of rector were determined to final dry solids multiplied by percentage of final volatile solids reduction. The difference of initial volatile solids and final volatile solids was calculated of every reactor. In percentage of volatile solids reduction of every reactor was determined to differentiate of volatile solids multiple by hundred and divided by initial volatile solids. In Percentage of volatile solids reduction with time was present in Figure 4.24. The value of Co-efficient of regression was found as $R^2 = 0.8763$. So the percentage reduction of volatile solids was nearly accurate value. The percentage reduction in volatile solids increased with time. Correlation co-efficient between gm volatile solids reduction and time is $R^2 = 0.7048$ as presented in Figure 4.25.

Difference of volatile solids with time was shown in Figure 4.25.when time is increasing then the volatile solids reduction was increased. It can be concluded that the percentage of volatile solids reduction is proportional to the duration of the composting process.

In the first stage, initial dry solids (IDS), initial volatile solids (IVS), final dry solids (FDS) and final volatile solids (FVS) were calculated of every reactor as shown in Table 4.11. In the first stage of composting process initial dry solids (IDS), correct initial volatile solids (IVS), final dry solids (FDS) and correct final volatile solids (FVS) were calculated of every reactor as shown in Table 4.12. All reactor value of IDS, IVS, FDS and FVS was added. Then the value of difference of volatile solids and % reduction of volatile solids (FVS) was calculated.

Table 4.11: In first stage initial dry solids, initial volatile solids, final dry solids and final volatile solids of forced aeration Co-composting process

Set No	Reactor No	Time (days)	Initial Dry solid (gm)	Final Dry solid (gm)	Initial Volatile solid(gm)	Final Volatile solid(gm)
1	1	3	161	158	133	129
	2		155	151	128	123
	3		147	146	121	119
2	4	5	158	148	130	120
	5		165	154	136	126
	6		168	153	138	124
3	7	8	156	144	129	117
	8		172	159	142	129
	9		165	153	136	124
4	10	10	164	150	135	121
	11		159	141	131	115
	12		146	131	120	106
5	13	12	150	134	124	107
	14		156	142	129	114
	15		149	123	122	97
7	19	16	172	157	141	126
	20		152	139	125	112
	21		174	145	144	115
8	22	21	173	148	142	118

	23		158	141	130	114
	24		163	151	134	121
9	25	23	156	143	129	115
	26		158	147	130	119
	27		153	140	126	113
10	28	25	186	169	153	137
	29		169	149	139	119
	30		165	137	136	109
13	37	31	163	124	134	96
	38		179	138	148	107
	39		181	137	149	105
14	40	33	156	111	128	83
	41		186	140	153	107
	42		171	130	141	100
15	43	35	175	130	144	99
	44		159	114	130	86
	45		163	119	134	91
16	46	37	170	122	140	92
	47		168	110	138	81
	48		177	114	145	83
17	49	40	171	114	141	85
	50		171	123	141	93
	51		192	135	158	101
18	52	43	172	129	141	99
	53		162	132	133	103
	54		174	132	143	101
Total =			**7444**	**6206**	**6123**	**4901**

Calculation:

$\sum IDS$ = 7444 $\sum IVS$ = 6122 $\sum FDS$ = 6206 $\sum FVS$ = 4901

% IVS reduction = $\frac{\sum IVS}{\sum IDS} * 100$ % FVS reduction = $\frac{\sum FVS}{\sum FDS} * 100$

= 82.24 = 78.97

	IDS	Correct IVS	FDS	Correct FVS	Diff VS	% VS
Set-01	463	IDS* % IVS	452	IDS* % FVS	IVS-FDS	$\frac{IVS - FDS}{IVS} * 100$
		= 380.77		= 356.94	= 23.83	= 6.26

Table 4.12: In first stage initial dry solids, correct initial volatile solids, final dry solids and correct final volatile solids of forced aeration Co-composting process.

Set No	Time (days)	IDS	Correct IVS	FDS	Correct FVS	Diff VS	% VS
1	3	463	381	452	357	23.8	6.3
2	5	490	403	454	359	44.5	11.0
3	8	493	405	455	359	46.1	11.4
4	10	469	386	421	332	53.2	13.8
5	12	454	373	396	313	60.6	16.2
7	16	496	408	439	347	61.2	15.0
8	21	493	405	440	347	58.0	14.3
9	23	466	383	427	337	46.0	12.0
10	25	518	426	453	358	68.3	16.0
13	31	521	428	397	314	115.0	26.8
14	33	512	421	379	299	121.8	28.9
15	35	496	408	363	287	121.2	29.7
16	37	514	423	344	272	151.1	35.7
17	40	534	439	371	293	146.2	33.3
18	43	506	416	391	309	107.4	25.8

Similar calculation of second stage in co-composting process.

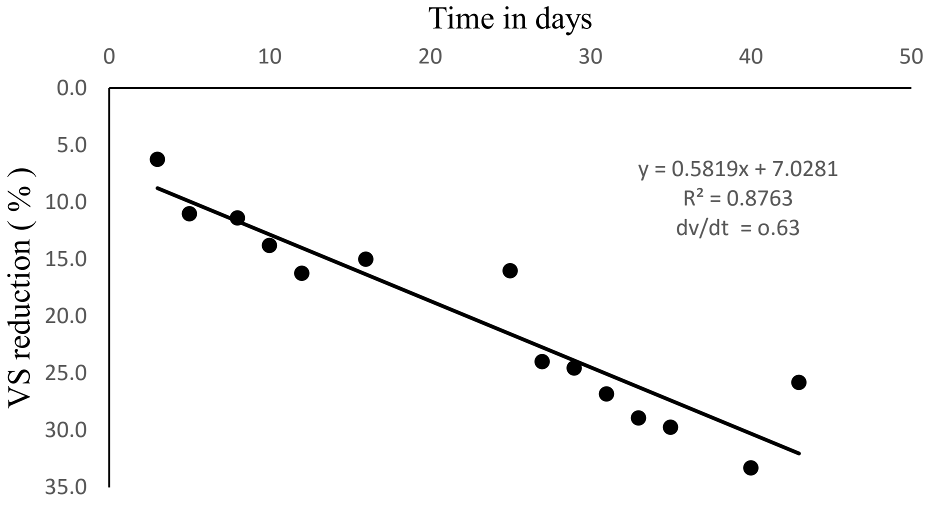


Figure 4.24: Volatile solids degradation rate with time for Co-composting process.

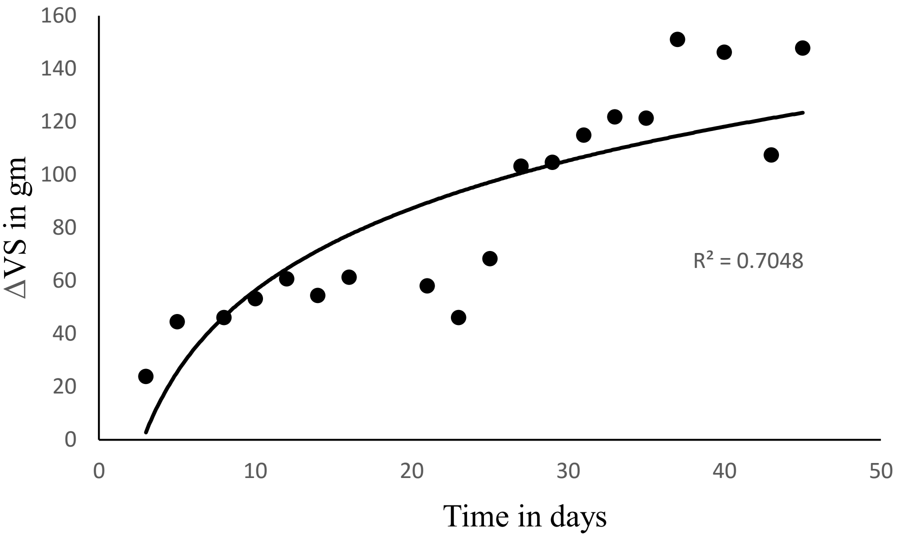


Figure 4.25: Volatile solids difference with time for Co-composting process.

4.12 Bench-scale Test: Determination of Initial Optimum Moisture Content

4.12.1 Relationship between Moisture Content and VS Degradation

Total seven initial moisture content from 20% to 80% of organic solid wastes and faecal sludge were selected to test using conduct under run 14 reactors to investigate the effect of initial moisture content on VS degradation and on temperature parameters. The %VS reduction was highest in the moisture range between 55 and 70%. VS reduction sharply decreased at an initial moisture content below 30 to 40%. Maximum volatile solids reduction percentage 19.72% of initial moisture content 60%. Relationship between % VS reduction and initial % moisture content in bench-scale test is illustrated in Figure 4.26.

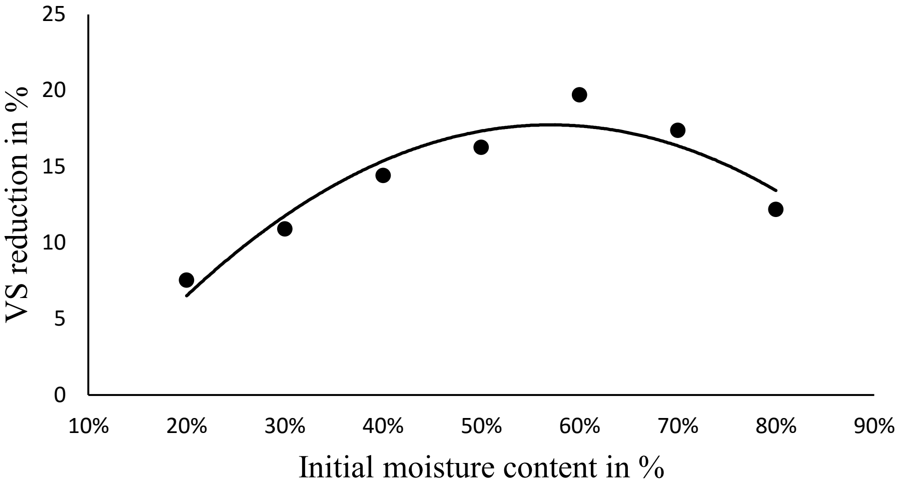


Figure 4.26: Relationship between % VS reduction and initial % moisture content in bench-scale test.

4.12.2 Relationship between Moisture Content and Temperature

Maximum temperature of composting was 55 ^{0}C to 65 ^{0}C which raised within 7 days in the moisture range between 55% and 70%. The area under the temperature curve in ^{0}C.h was highest in the initial moisture range between 55 and 70%. It should be noted that a higher value of the area under the temperature curve indicates higher heat production and thereby higher VS degradation. The relationship between the area under the temperature curve and the initial moisture content in bench-scale tests using 14 reactors is illustrated in Figure 6.27.

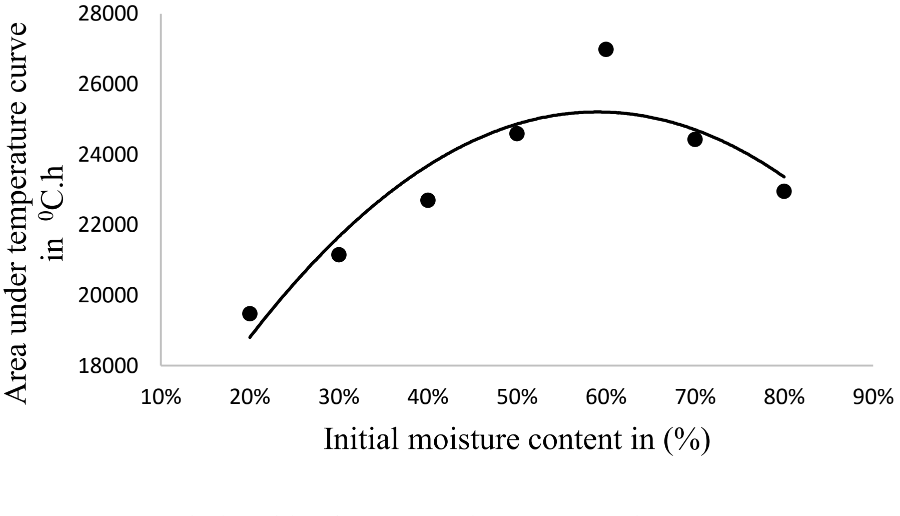


Figure 4.27: Relationship between the area under temperature curve and initial % moisture content in bench-scale test

4.13 Kinetic Analysis

4.13.1 Reaction Rates

The waste degradation rates (reaction rates) and their orders were studied for describing the kinetics of the biological composting process under two aeration modes. The reaction rate constants k1 (first order) were basically estimated from the daily O_2 consumption rates in kg/d, which are proportional to the BVS degradation using Equation 2.2 as described by Bari (1999). The relationships between different reaction rate constants k_1 and the absolute temperature T according to the Arrhenius equation (Equation 3.12) are shown in Figures 4.28 and 4.29 as ln(k) vs 1/T for tests P (80:20) and P (75:25) respectively. Although this relation was established for all tests, for the sake of simplicity, only tests P (80:20) and P (75:25) are presented. The best correlation was obtained for the first order reaction with $R^2 = 0.9995$ for test P (80:20) and $R^2 = 0.9997$ for test P (75:25).

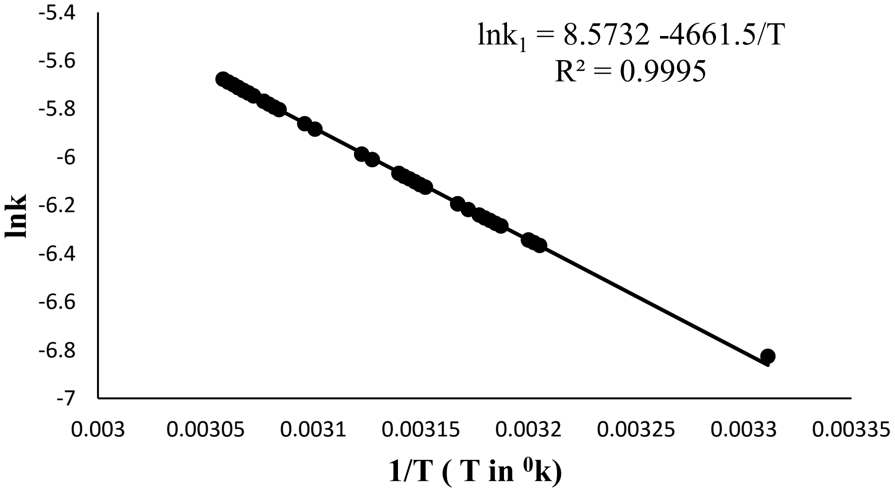


Figure 4.28. The graphical presentation of Arrhenius equation for first stage P (80:20) where k is reaction rate constant at temperature T in ^{0}K

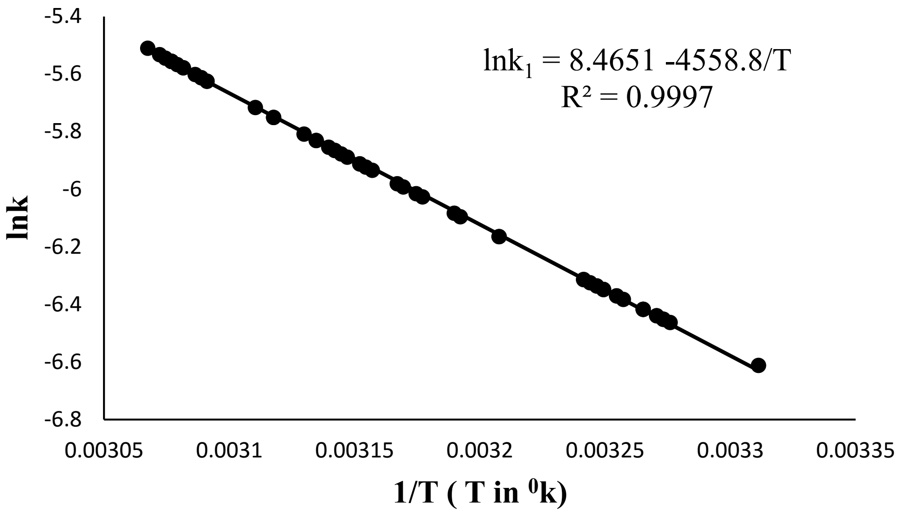


Figure 4.29. The graphical presentation of Arrhenius equation for first stage P (75:25) where k is reaction rate constant at temperature T in ^{0}K.

Table 4.13 summarizes for each test the activation energy E_a, the first order reaction rate constants at 25 and 50 ^{0}C and the temperature coefficient Q_{10} (defined as k_{T+10}/k_T) as derived from the Arrhenius plot. The activation energy E_a of 1st stage, 2nd stage and 3rd stage were varied from 37.41 to 38.76 kJ/ mole, 36.93 to 39.17 kJ/ mole and 34.88 to 35.61 kJ/ mole with mean value 37.97 kJ /mole, 37.74 kJ /mole and 35.16 kJ /mole as respectively. The activation energy Ea varied from 44 to 90 kJ/mole in different tests. Similar values of 92.05 kJ/mole at 50 to 70 °C for thermophilic bacteria (Nakasaki, 1985d) and 58 kJ/mole for Aerobacter aerogenes in continuous culture at 35 °C (McKinley and Vestal, 1984) were reported. For wastewater treatment processes, E_a values from 8.4 to 84 kJ /mole have been reported (Metcalf and Eddy., 1979). The activation energy of compost Ea varied from 44 to 90 kJ/mole in different tests (Bari et al. 2000).

Table 4.13: First order reaction rate constants at 25 ^{0}C and 50 ^{0}C temperature co-efficient and activation energy

Stage	Test	E_a (kj/mol)	Q_{10}	K_1 (d^{-1}) at 25^{0}C	K_1 (d^{-1}) at 50^{0}C
1st stage	P(90:10)	37.41	1.61	0.001	0.002
	P(85:15)	37.82	1.62	0.001	0.003
	P(80:20)	38.76	1.63	0.001	0.003
	P(75:25)	37.9	1.62	0.001	0.004
2nd stage	P(90:10)	39.17	1.64	0.001	0.004
	P(85:15)	37.29	1.6	0.002	0.005
	P(80:20)	37.57	1.61	0.001	0.004
	P(75:25)	36.93	1.59	0.001	0.005
3rd stage	P(90:10)	35.11	1.56	0.002	0.007
	P(85:15)	35.04	1.56	0.004	0.013
	P(80:20)	35.61	1.57	0.004	0.012
	P(75:25)	34.88	1.56	0.004	0.014
1st stage	F(90:10)	37.91	1.62	0.001	0.003
	F(85:15)	37.55	1.61	0.001	0.003
	F(80:20)	38.87	1.64	0.001	0.003
	F(75:25)	38.87	1.64	0.001	0.003
2nd stage	F(90:10)	38.81	1.64	0.002	0.006
	F(85:15)	36.59	1.59	0.001	0.004
	F(80:20)	37.09	1.6	0.001	0.004
	F(75:25)	37.12	1.6	0.002	0.005
3rd stage	F(90:10)	35.02	1.56	0.003	0.008
	F(85:15)	34.79	1.55	0.004	0.012
	F(80:20)	35	1.55	0.004	0.014
	F(75:25)	35.31	1.56	0.005	0.014

4.13.2 Using First Order Reaction at Different Constant Temperatures

Using the first order reaction rate constants k1 for test P (80:20) the predicted BVS degradation with time for constant temperatures of 30, 40, 50 and 60 ºC could be calculated from the following equations:

30 ºC or 303 ºK, k1 = exp (8.5732-4661.5/303)=0.0011 d^{-1}

$\frac{BVS_0-BVS}{BVS_0}$(%) = 100[1-exp (-kt)] =100[1-exp (-0.0011×t)] (7.1)

40 °C or 313 °K, k1 = exp (8.5732-4661.5/313)=0.0018 d^{-1}

$\frac{BVS_0-BVS}{BVS_0}$(%) = 100[1-exp (-0.0018×t)] (7.2)

50 °C or 323 °K, k1 = exp (8.5732-4661.5/323)=0.0028 d^{-1}

$\frac{BVS_0-BVS}{BVS_0}$(%) = 100[1-exp (-0.0028×t)] (7.3)

60 °C or 333 °K, k1 = exp (8.5732-4661.5/333)=0.0044 d^{-1}

$\frac{BVS_0-BVS}{BVS_0}$(%) = 100[1-exp (-0.0044×t)] (7.4)

Figure 4.30 shows the predicted BVS degradation with time at different constant temperatures for test P (80:20). It is clearly seen in Figure 4.30, that for the first 20 days the actual degradation curve of test P (80:20) almost followed the predicted BVS degradation of 50 °C. After 20 days the reaction rates became slower as temperature fell towards 40 ^{0}C. For test P (75:25), using similar equations, the predicted BVS degradation with time at different constant temperatures is shown in Figure 4.31. However, for test P (75:25), the actual degradation curve followed the predicted BVS degradation of 50 °C for 15 days, because the average temperature of this test was almost 50 °C for that 15 day period. After 15 days the reaction rates became slower as temperature fell towards 34 °C.

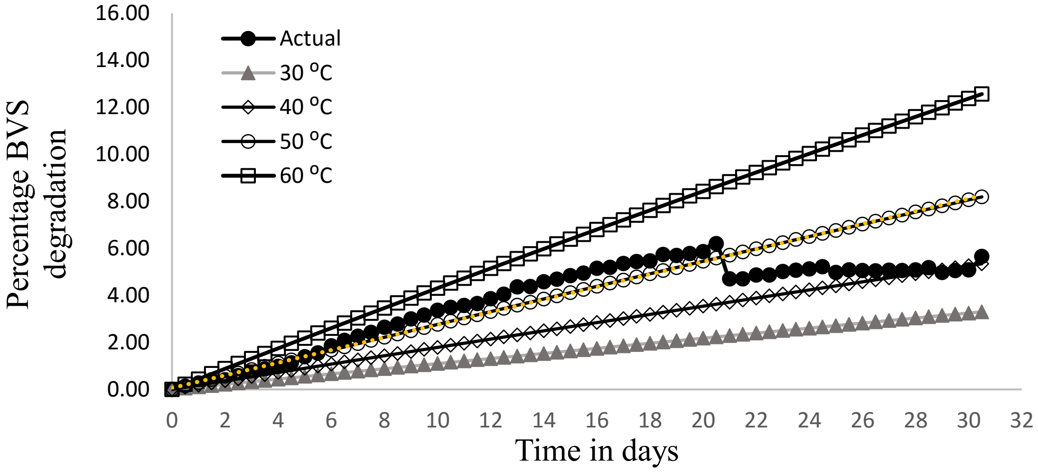


Figure 4.30: Actual and predicted % BVS degradation at different constant temperature using first order reaction model of test P (80:20)

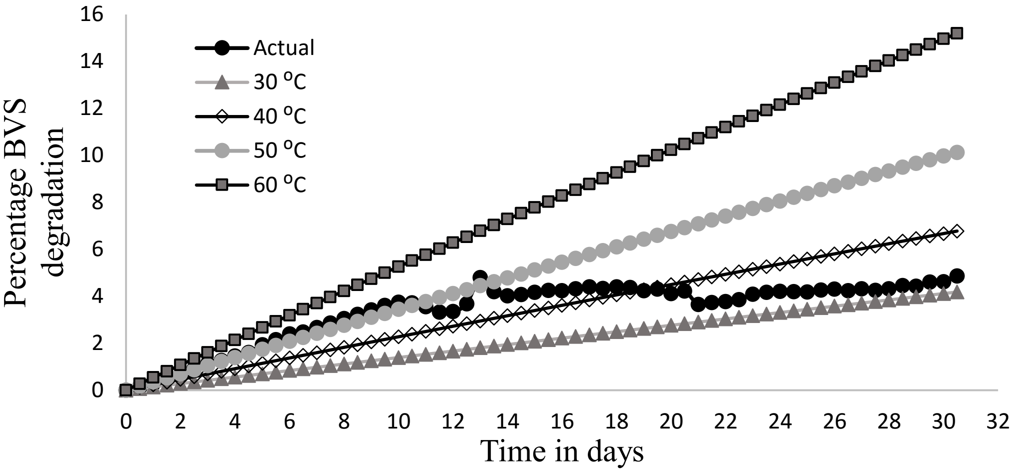


Figure 4.31: Actual and predicted % BVS degradation at different constant temperature using first order reaction model of test P (75:25)

4.14 Biological Maturity Index of Compost

In composting biological maturity or stability of compost is a significant issue. The self-heating test is widely adopted in organic solid waste and faecal sludge Co-composting process. Surface spread raw compost does not heat in the soil (even though it may release large quantities of energy). On the other hand stable compost if placed in a large –enough pile can heat up considerably (parnes, 1989). Self –heating test in finished composts can be dangerous after packing and shipping of large volume of material because of the tendency of large container or pallets to heat up during shipment. Theoretically compost could be analyzed this way but result would of course be impractical. In this study the stability index of the compost was determined using available data from self-heating test. Based on the results of the self-heating test the compost is classified according to degree of biological stability as shown in Table- 2.1 (LAGA 1985) as cited by (Koning & Bari, 2001), Where T_{max} = maximum temperature, I_{max} = maximum temperature increase, A_{72} = area under temperature curve after 72 hours. Based on the values of T_{max}, I_{max}, A_{72} of all reactor the stability index (SI) of all composts with all ratio organic solid waste and faecal sludge in first stage, second stage and third stage were presented in Table 4.14, Table 4.15 and Table 4.16 respectively. According to the all reactors self-heating test in first stage was stable with SI of II to IV. In second stage all rector stability index was II to IV. In third stage all reactor stability index were IV to V (except reactor P (90:10)), it may be mentioned that all compost are stable.

Table 4.14: Stability index and self- heating test in first stage

Reactor	A_{72} (^{0}C.h)	T_{max}	I_{max} (^{0}C/h)	SI
PF1(90:10)	2688	46	0.54	**iii**
PF2(90:10)	2724	42.5	0.54	**iii**
PF3(90:10)	2784	48	0.58	**iii**
PF4(90:10)	2844	56	0.6	**ii**
PF1(85:15)	2844	48.5	0.65	**iii**
PF2(85:15)	2928	58	0.73	**ii**
PF3(85:15)	2532	40.5	0.35	**ii**
PF4(85:15)	2856	59	0.65	**ii**
PF1(80:20)	2868	58	0.67	**ii**
PF2(80:20)	2868	59	0.75	**ii**
PF3(80:20)	2712	51	0.48	**ii**
PF4(80:20)	2880	59	0.75	**ii**
PF1(75:25)	2844	55.5	0.63	**ii**
PF2(75:25)	3204	58.5	0.77	**ii**
PF3(75:25)	2460	38	0.31	**iv**
PF4(75:25)	3288	65	0.88	**ii**
FF1(90:10)	2928	58	0.67	**ii**
FF2(90:10)	2580	39.5	0.42	**iv**
FF3(90:10)	2928	59	0.67	**ii**
FF4(90:10)	2784	53	0.54	**ii**
FF1(85:15)	2988	54.5	0.6	**ii**
FF2(85:15)	2928	55	0.65	**ii**
FF3(85:15)	2472	40	0.29	**iv**
FF4(85:15)	3000	56	0.73	**ii**
FF1(80:20)	2856	54.5	0.58	**ii**
FF2(80:20)	2844	53	0.75	**ii**
FF3(80:20)	3120	63	0.83	**ii**
FF4(80:20)	3036	58.5	0.67	**ii**
FF1(75:25)	3048	58	0.77	**ii**
FF2(75:25)	2664	46	0.44	**iii**
FF3(75:25)	2844	55	0.63	**ii**
FF4(75:25)	3108	57	0.67	**ii**

Table 4.15: Stability index and self- heating test in second stage

Reactor	A_{72} (^{0}C.h)	T_{max}	I_{max} (^{0}C/h)	SI
PS1(90:10)	3120	52.5	0.65	ii
PS2(90:10)	3468	57	1.06	ii
PS3(90:10)	3900	69	1.31	ii
PS1(85:15)	3288	54.5	0.98	ii
PS2(85:15)	2460	36	0.21	iv
PS3(85:15)	3228	52	0.85	ii
PS1(80:20)	3108	51	0.69	ii
PS2(80:20)	3396	59	0.85	ii
PS3(80:20)	2472	36.5	0.21	iv
PS1(75:25)	3036	49.5	0.63	iii
PS2(75:25)	2712	41	0.42	iv
PS3(75:25)	2808	46.5	0.35	iii
FS1(90:10)	3300	57	1.08	ii
FS2(90:10)	3480	59	1.17	ii
FS3(90:10)	3684	65.5	1.44	ii
FS1(85:15)	2544	46	0.25	iii
FS2(85:15)	3096	49.5	0.77	iii
FS3(85:15)	2484	37	0.19	iv
FS1(80:20)	2880	46	0.5	iii
FS2(80:20)	3000	50.5	0.52	ii
FS3(80:20)	2772	43.5	0.42	iii
FS1(75:25)	3384	57.5	0.9	ii
FS2(75:25)	2520	46	0.25	iii
FS3(75:25)	2532	49	0.25	iii

Table 4.16: Stability index and self- heating test in third stage

Reactor	A_{72} (^{0}C.h)	T_{max}	I_{max} (^{0}C/h)	SI
PT1(90:10)	2424	36	0.08	iv
PT2(90:10)	2400	34.5	0.08	iii
PT1(85:15)	2388	35	0.06	v
PT2(85:15)	2376	34.5	0.1	iv
PT1(80:20)	2424	36	0.1	iv
PT2(80:20)	2388	35	0.06	iv
PT1(75:25)	2460	37	0.06	iv
PT2(75:25)	2388	34.5	0.04	iv
FT1(90:10)	2376	34	0.08	iv
FT2(90:10)	2412	35	0.08	iv
FT1(85:15)	2364	33.5	0.06	v
FT2(85:15)	2244	32	0.02	iv
FT1(80:20)	2352	33.5	0.06	iv
FT2(80:20)	2268	32.5	0.02	iv
FT1(75:25)	2244	32.5	0.06	iv
FT2(75:25)	2400	35	0.06	iv

4.15 Comparison of Passive and Forced Aeration Co-composting

Temperature variation, Mass balance, Physico-chemical characteristics, Volatile solids reduction, Biodegradable volatile solids, Extent of degradation, Correlation co-efficient of area under temperature curve, Stability index of produced compost and Kinetic analysis were almost same in passive and forced aeration Co-composting process. Passive aeration composting are naturally aeration process, not addition aeration/oxygen. Forced aeration composting system are to provide addition aeration/oxygen. The use of forced aeration also requires addition calculation. The size of the blower as well as the number, length, diameter and types of pipes to use for adequate aeration must be determine. Pipes and blowers interfere with pile formation and cleanup operations. Forced aeration composting are not commonly used for large scale composting operation. Passive aeration composting system are economical in operations and maintenance easily and produce good quality final compost. It can be concluded that the passively aeration Co-composting process can be applied smoothly in Bangladesh round the year to manage faecal sludge.

CHAPTER V

Conclusions and Recommendations

5.1 Conclusions

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

- In wet season, the mean maximum temperature of the first stage, the second stage and third stage passively aerated composting process were 65°C, 60°C and 36°C respectively. The mean maximum temperature of the first stage, the second stage and third stage forced aerated composting process were 63°C, 67°C and 34°C respectively.
- In dry season, the mean maximum temperature of the first stage, the second stage and third stage passive aerated composting process were 67°C, 56°C and 35°C respectively. The mean maximum temperature of the first stage, the second stage and third stage forced aerated composting process were 61°C, 60°C and 36°C respectively.
- Maximum temperature was raised in first and second stage within first and second weeks. The temperature in third stage was not increase much because in this stage the compost become stable and contain very less BVS.
- In both seasons the peak temperature of all the passively aerated and forced aerated composting tests were almost same. It means that the Co-composting process can be applied smoothly over the year in Bangladesh to manage FS without any interruptian of seasonal effect.
- For passively aerated process, the average percent reduction of volatile solids first stage, second stage and third stage were 27.6%, 12.4% and 8.2% respectively. For forced aerated process, the average percent reduction of first stage, second stage and third stage were 30.8%, 13.6% and 9.2% respectively. Degradation rate of volatile solids of first stage was greater than second stage in composting process. In second stage volatile solids degradation rate was greater than third stage. Degradation rate of volatile solids in third stage was less because in this stage the compost become stable and contain very less BVS.

- In wet season, For passively aeration process the biodegradable volatile solids (BVS) reduction is ranged in between 83 % to 89 %. In forced aeration process, the biodegradable volatile solids (BVS) reduction is ranged in between 78% to 92%.
- In dry season, For passively aeration process the BVS percentage reduction is ranged in between 82% to 89%. In forced aeration process the BVS percentage reduction is ranged in between 73% to 91%.
- The mean total BVS reduction in both season is 86% after 63 days. All ratio of waste mixture showed almost similar total BVS reduction. Therefore, the higher OSW : FS ratio F (85:15) can be effective apply for faecal sludge management.
- The extent of degradation in Co-composting process can be determined more exactly from the correlation between area under temperature curve and gm VS reduction with different stage. The average maximum area under temperature curve ($T-T_a$) of first stage and second stage was found 10764 ºC.h and 9864 ºC.h respectively.
- Every set of reactor for first and second stage the total percentage of degradation was almost same.
- In correlation co-efficient area under temperature curve of first stage was greater than second stage.
- The percentage reductions in total weight, moisture content and volatile solids increased with time.
- For determination of optimum moisture content, the area under the temperature curve in ºC.h and %VS reduction was highest in the initial moisture content range between 55 to 70%.
- The temperature dependence of the reaction rates of different satge passive and forced aeration composting tests clearly followed the Arrhenius equation.
- The actual reaction rates provided the best fit of first order reaction rates with different stage.
- Percentage degradation of volatile solids depending on temperature could be predicted well using a first order reaction model.
- Compost produced in first and second stage were stable with stability index of II to IV. All compost of third stage were more stable than first and second stage with stability index of IV to V.

- Temperature variation, Degradation of biodegradable volatile solids and Stability index of produced compost were almost same in passive and forced aeration Co-composting process. Passive aeration composting system are economical in operations and maintenance and produce good quality final compost.
- The passively aeration Co-composting process can be applied smoothly in Bangladesh round the year to manage faecal sludge.

5.2 Recommendations for Future Studies

- Germination index are to be test during different stage of composting process
- Predictive temperature model based on air flow rates and reaction rates.
- Establishment of a relationship between estimated respirometric activity based on the heat energy balance of the self-heating test and the practical respirometric activity determined from respirometric test.
- Determination of vertical distribution of temperature and microorganisms under different stage of aeration during first, second and third stage composting.
- Heavy metal and pathogenic bacteria are to be tested initially and during different stage of composting.

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Appendix

Area under temperature twenty set (1st stage) of self-heating test for degradation rate analysis

	Set No	Time (day)	Reactor No	Area (^{O}C.h)
First stage	1	3	R-01	600
			R-02	576
			R-03	744
	2	5	R-04	1968
			R-05	2232
			R-06	1776
	3	8	R-07	2568
			R-08	2664
			R-09	2760
	4	10	R-10	3048
			R-11	3864
			R-12	3024
	5	12	R-13	4296
			R-14	4224
			R-15	4248
	6	14	R-16	5304
			R-17	6264
			R-18	5496
	7	16	R-19	6264
			R-20	6192
			R-21	6168
	8	21	R-22	6120
			R-23	6792
			R-24	8376
	9	23	R-25	7944
			R-26	8856
			R-27	8112
	10	25	R-28	8232
			R-29	9984
			R-30	9936
	11	27	R-31	3528
			R-32	4608
			R-33	3552
	12	29	R-34	3384
			R-35	4176
			R-36	3984
	13	31	R-37	3936
			R-38	9744
			R-39	6864

	Set No	Time (day)	Reactor No	Area (^{O}C.h)
First stage	14	33	R-40	6168
			R-41	6840
			R-42	5808
	15	35	R-43	7344
			R-44	8880
			R-45	5112
	16	37	R-46	13776
			R-47	10920
			R-48	9240
	17	40	R-49	10176
			R-50	11352
			R-51	3456
	18	43	R-52	15624
			R-53	10800
			R-54	8640
	19	45	R-55	15240
			R-56	7872
			R-57	6000
	20	48	R-58	9912
			R-59	16272
			R-60	12768

Area under temperature twenty set (2^{nd} stage) of self-heating test for degradation rate analysis

	Set No	Time (day)	Reactor No	Area (^{O}C.h)
Second stage	1	45	R-01	8736
			R-02	12600
	2	43	R-04	8016
			R-05	7872
	3	40	R-07	7344
			R-08	11064
	4	38	R-10	6096
			R-11	6432
	5	36	R-13	4488
			R-14	7848
	6	34	R-16	11448
			R-17	12336
	7	32	R-19	7800
			R-20	7656
	8	27	R-22	10392
			R-23	9336
	9	25	R-25	1464
			R-26	6480
	10	23	R-28	9672
			R-29	7464
	11	21	R-31	5664
			R-32	3264
	12	19	R-34	2832
			R-35	3936
	13	17	R-37	3384
			R-38	1560
	14	15	R-40	984
			R-41	5184
	15	13	R-43	2160
			R-44	2304
	16	11	R-46	2376
			R-47	1920
	17	8	R-49	2976
			R-50	2184
	18	5	R-52	1464
			R-53	1944
	19	3	R-55	1896
			R-56	1728