Microbial Quality of Compost of Municipal Solid Waste

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ABSTRACT

Dhaka is one of the fastest growing mega cities of the world. Generation of large volume of solid waste in urban areas is creating environmental problem in Dhaka city. Dhaka City Corporation (DCC), responsible for management of solid waste of Dhaka, is inefficient and its services are unsatisfactory. Presently, improper dumping of huge amount of urban solid waste causes serious environmental and health hazards.

This research is aimed at investigating the generation pattern and characteristic of domestic solid waste and microbial quality of the compost samples collected from the Box-composting pilot plant located at Green Road Staff Quarter and Barrel type composting system in Mirpur slum. The assessment was carried out on microbiological and physico-chemical characteristic of compost at different stages of maturation.

The research finding indicates that daily solid waste generation rate per households in Green Road area is higher (about 2.68 kg/household) than solid waste generated from slum household (0.59 kg/household). The physical composition of domestic solid waste reveals that organic part (i.e., food waste) generation is higher for slum people in Mirpur (93%) than that of Green Road dwellers (80%). Laboratory analysis reveals that highest number of total coliform $6.0\text{x}10^2$ cfu/g is found in raw solid waste sample and their population decreases during maturity process. The number of faecal streptococci shows a district decrease from $2.0\text{x}10^2$ cfu/g to nil during the thermophilic phase (60 to 65°C). Experimental results also indicate that highest Faecal Coliform count in the raw solid waste sample and nil in the finished compost samples. The physico-chemical parameters such as temperature, moisture content, pH, C/N ratio during composting are found similar for both composting systems. Field survey also reveals that there is renewed public interest in composting for safe and easy disposal of waste and attainment of favorable economics by selling the produced compost. Therefore, composting of solid waste brings in environmental and financial benefits and offset the costs of collection and processing and management of solid waste.

DECLARATION

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

(Md. Harunur Rashid)
Name of the Candidate

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ABBREVIATIONS

BARC	:	Bangladesh Agricultural Research Center
C	:	Carbon
CBO	:	Community Based Organization
GO	:	Government Organization
MC	:	Moisture Content
MSW	:	Municipal Solid Waste
N	:	Nitrogen
NGO	:	Non-Government Organization
O_2	:	Oxygen
RECP	:	Rayer Bazer Environment Cleanup Project
SEMP	:	Sustainable Environmental Management Program
SWM	:	Solid Waste Management
SW	:	Solid Waste
UNCED	:	United Nations Conference of Environment and Development
USEPA	:	United State Environmental Protection Agency
W C	:	Waste Concern (Name of an NGO)

CHAPTER 1: INTRODUCTION

1.1 Background

Generation of large volume of solid waste in urban areas is a budding environmental problem in Bangladesh. Most of the solid waste is dumped in the low-laying lands without proper sanitation. Improper dumping of large garbage from the huge dwellers of the Dhaka, the capital city of Bangladesh is causing serious environmental and health hazards. Because this is not only occupy valuable space in landfills, but they also decompose, which can result in the production of methane gas and surface water pollution by wash out of dump sites and groundwater pollution by toxic leach ate from the dumped wastes. Other harms associated with improper management of solid wastes include diseases transmission by dogs, birds, insects and rats, odor nuisances, and aesthetic nuisance and economic losses. Therefore, recycling this solid waste as composts benefits the environment and financial returns from the sale of municipal composts can help offset the costs of collection and processing. Recycling the composts back on residential gardens, nursery, city parks, on farms, or for re-vegetation of disturbed lands, also can make such entities more sustainable.

Solid waste in Dhaka city is mixed wastes from residential, institutional, commercial, hospitals and industrial sources. Urban solid waste comprises food waste, plants debris, metals, textile wood plastic, papers, re-useable goods, soils, chemicals etc., and amongst them organic materials making about 50-70 % of all municipal solid waste. Therefore, municipal waste has a compostable potential of 60-70% (Mamo et al, 2002). Solid waste compost reduces waste volume and disease-causing organisms and to cycle nutrients. Nowadays, composting is emerging to be a popular solid waste management alternative both in developed and developing countries. Although several studies are available concerning the composting and dynamics of the micro flora during the compositing of these wastes, a little is known about the microbial diversity during the compositing of the organic faction of sources separated household waste (McKinley and Vestal 1984, Kutzner and Jager 1994, Herrmann and Shann 1997, Beffa et al, 1996; Atkinson et al, 1996.)

Studies conducted by Rahman and Al-Muyeed 2006; Al-Muyeed 2005; Rahman 2004 and Moqsud 2003 reveal that major portion (80-90%) of domestic solid waste in and around Dhaka city is mainly organic. Very high fraction of organic matter in the solid waste in urban areas suggests that composting could be a viable option for disposal of solid waste.

In Bangladesh, some NGO's have been working on composting for the last few years. Most of the implementing authorities are promoting this technology without proper attention to research and development. While municipal solid waste is converted into compost, the question arises about the microbial quality of the compost once it is produced.

This research aimed at investigating the microbial quality in compost of municipal solid waste as well as the prevailing physico-chemical conditions of the presently existing composting plants in Dhaka city.

1.2 Objectives of the Study

The most important goal of the composting are to decompose organic fraction of the solid wastes to reduce its volume, weight and moisture content, minimize potential odor, decrease pathogens so that the finished product can be used as potential nutrients for agricultural lands. This process may minimize spread of diseases because of the destruction of some pathogens and parasites at elevated (composting) temperature. Aim of this study is to identify the microbial quality of compost of solid waste. The specific objectives of the study are as follows:

- To review the generation pattern and characteristic of solid waste in

Dhaka city.

- Assessment of microbial quality of the compost at different stages of maturation based on laboratory analysis

1.3 Methods and Materials

The research study is carried out based on the literature reviews of the relevant studies in Bangladesh and journal publications as well as primary and secondary data collection of the study area. Study area includes two locations of the Dhaka municipality areas. The project locations map is presented in Figure 1.1. Field survey is conducted through questionnaires survey and observation of the solid waste management system of two different composting systems of Waste Concern", Laboratory analysis of solid waste samples collected from the municipal solid waste composting pilot plant and barrel type composting system. Microbiological testing of the aerobic waste samples at different time period from initial raw solid waste sample to finished product during composting process are carried out. Measurement of different physico-chemical environmental conditions (e.g. moisture content, temperature) and other parameters also conducted during aerobic composting process. Finally chemical and biological analysis of various staged aerobic product and its findings quantifying the microorganism's presence in the staged product are carried out based on the laboratory analysis.

1.4 Organization of the Thesis

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

Chapter 1: comprise general introduction, objectives, method and materials of the study.

Chapter 2: comprises literature review on the solid waste generation, its characteristic, composting process, etc.

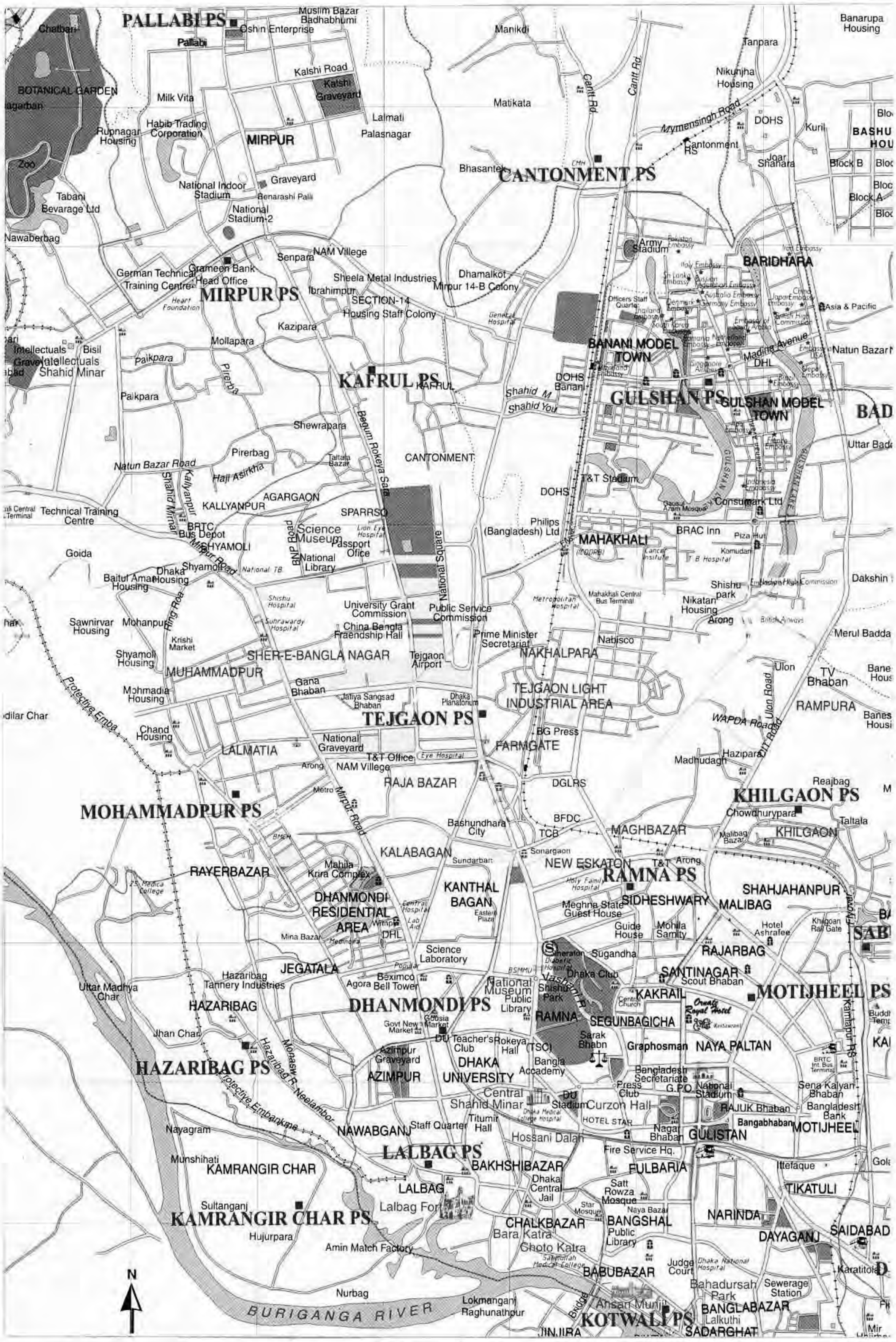

Figure 1.1: Location Map of the Study Areas

Chapter 3: includes experimental works, which are carried out in this study.

Chapter 4: comprises result of the experiment and a general discussion on the findings of the study based on the laboratory test results and secondary data.

Chapter 5: includes conclusion and recommendation for future study

CHAPTER 2: LITERATURE REVIEW

2.1 Municipal Solid Waste in Dhaka

The municipal solid waste in the urban centers of Bangladesh generates mainly from domestic, commercial, institutional, hospital and industrial sources. Approximate quantities of solid wastes collected by different city corporations and municipalities in Bangladesh are shown in Table 2.1 (Rahman 1993). Large amount of municipal solid waste generated in Dhaka about 3,000 tons/per day from 5.38 million residents (Sutradhar 2002). About 1000-14400 ton/day total solid waste collection are taking place in the Dhaka city. Dhaka City Corporation (DCC) is responsible for management of solid waste of Dhaka, which has inadequate and insufficient managing capacity to control the city's vast solid wastes.

Table 2.1: Quantities of Solid Waste Collected at different Cities in Bangladesh

City	Area (xl03ha)	Total Collection (ton/day).	Collection Rate (kg/capita/day)
Dhaka	44.29	1000 - 14400	0.18 - 0.25
Chittagong	54.91	400 - 600	0.22 - 0.34
Rajshahi	10.36	40 - 60	0.12-0.15
Khulna	7.16	70 - 80	. 0.09 - 0.10
Mymensingh	5.44	40 - 50	0.11-0.14
Pabna	3.37	5.5 - 6.5	0.04 - 0.05
Kurigram	2.07	2.5 - 3.0	0.04 - 0.05
Natore	0.26	2.0 - 3.0	0.25 - 0.08

(Source: Rahman, 1993).

It is also noted that in spite of uncontrolled recycling, mostly by scavengers, DCC can handle only 42% of the generated solid wastes and only 30% of the population use roadside bins and the rest throw away their waste on the drains, low-lying areas, streets and open spaces. Approximate 9% of the slums in DCC area have any form of solid waste collection service and rest remaining 91% of slums dump their waste on open land, roadside drains and khals. Transportation of solid waste through open truck (43%) results public nuisances due to irregular cleaning of open bin and removal of demountable containers. As a result, all these uncollected and untreated wastes in open spaces are left to rot, which pose a threat to the public health, environment as well as the ecology.

Dhaka City Corporation collected solid wastes from the city dwellers and disposes into community garbage bins located different parts of the city, but still all parts of the city yet to be furnished with these fixed and movable bins. According the study report (Sutradhar 2002) about 130 Community Based Voluntary Organizations (CVO) are working in Dhaka city. They are collecting waste from door to door of the city dwellers and dispose off collected waste into nearest DCC communal solid waste collection bins.

Usually DCC dispose off theses solid into the low land without thinking more about recycling. Study stated that DCC had disposal sites at Mirpur with an area of 25 acres, on the low lying depression lands alongside of the Dhaka-Chittagong road at Jatrabari, and about 50 acres land at South-East of Dhaka at Matuil (Bhide 1990, MMI 1991). It was also reported that all of these sites are now already filled up (Enayetullah 1995, Yousuf 1996). Therefore, the availability of land is limited in and or around the city and in the near future it will not be possible to provide more land area for dumping the daily generated solid waste from the city. Furthermore, dumping of garbage without proper sanitation land filling is causing serious surface water pollution from the dumpsites and river pollution from rain water passing through garbage and flowing into the rivers as well as groundwater contamination by lecheate from the dumped wastes, which cause various environmental hazards.

Compositing of municipal solid waste is an alternative to landfills and incineration and presently composting is emerging to be a popular solid waste management alternative both in developed and developing countries.

Vegetables, fruits, dairy products, grains, bread, unbleached paper napkins, tee and coffee filters, eggshells, meats and newspaper can be composted. It is noted that if it can be eaten or grown in a field or garden, it can be composted. Items that cannot be composted include plastics, grease, glass, and metals - including plastic utensils, plastic wrap, foil, silverware, condiment packages, plastic bags, drinking straws, bottles, polystyrene or chemicals. Items such as red meat, bones and small amounts of paper are acceptable, but they take longer to decompose.

Municipal solid waste is composted to reduce waste volume and disease-causing organisms, and to cycle nutrients (Mamo et al. 2002). Many studies (Rahman and Al-Muyeed 2006, Al-Muyeed 2005, Rahman 2004 and Moqsud 2003) reported that 80-90% of domestic solid waste in and around Dhaka city is mainly organic. Presence of high organic matter in the waste suggests that composting could be a viable option for disposal of solid waste in Bangladesh.

Most of the agricultural cropping systems cause depletion of organic matter of the lands. The application of municipal solid waste compost to agricultural soil can be a means to return the organic matter to agricultural soil and in many cases reduce the cost of municipal solid waste disposal. It was also reported that the physical benefits of organic matter on soil include improved soil structure, increased aeration, reduced bulk density, increased water holding capacity, enhanced soil aggregation, and reduced soil erosion. Therefore, agricultural lands are excellent sites for beneficially using municipal solid waste compost as an organic soil amendment (Mamo et al. 2002).

It was also reported that the microbial abundance, composition and activity changed substantially during compositing and compost maturity was correlated with high microbial diversity and low activity (Ryckeboer et al, 2003). A verity of methods has been used so far to investigate the microorganism during compositing. These include the use of traditional plating and identification of culturable microorganisms for determining microbial diversity during composting.

2.2 Composting

Composting is the biological decomposition of the organic constituents of wastes under controlled conditions. Generally composting systems are distinguished on the basis of three criteria: oxygen usage (aerobic vs. anaerobic); temperature; and technological approach. Aerobic composting uses aerobic microorganisms which require the presence of oxygen to support the decomposition process. In anaerobic composting, microorganisms accomplish decomposition in the virtual absence of oxygen (air). The main advantage of anaerobic decomposition is that it may be conducted with minimal operator attention and accordingly, the operation may be sealed from the environment. It is noted that aerobic decomposition, in compare to anaerobic types, is quicker, progresses at higher temperatures, and does not produce foul odors (Roger 1991). Therefore, nowadays, most composting operations attempt to maintain an aerobic environment.

Composting process depends on biological processes to decompose organic components of solid waste, the efficiency and performance of the compost system depends upon maintaining conditions that favor the growth of the inherent microorganism populations (Roger et al, 2000). Types and numbers of microbial populations are important in the composting process. There are five influential factors of the physical, chemical, and biological characteristics of the compost pile as follows:

- appropriate microbial population(s)
- sufficient aeration
- temperature
- moisture content and
- carbon availability.

There are some infrequent situations during composting process where the microbial population would become a limiting factor, such as

- limited variety of microbial species,
- feedstock waste had been sterilized before entering the composting process; and
- microorganisms had been exposed to toxic or antibiotic effects due to the chemical nature of the residues.

Composting is a general treatment method for municipal solid waste management. A typical flow diagram of a compositing process is given in Figure 2.1. In this process the bacterial conversion of organic solid and semi-solid to stable solid transported occurs without any environmental adverse effect and can be used as organic manure for improvement of soil quality and fertility (Enayetullah and Sinha 2000 and Moqsud 2003).

Composting process involves decomposition of organic fraction of solid waste to: reduce its volume, weight and moisture content; minimize potential odors, decrease pathogens and increase potential nutrients for agricultural application.
General solid waste characteristic analysis showed that the major portions of solid waste of developing countries are organic waste (Moqsud 2003). Organic solid wastes are those that are generally cooked and uncooked vegetables, fruits peels and seeds, leaves, egg shells, flowers, cooked paste and rice, other food grains etc.

It is noted that the criteria for "stabilized" compost vary somewhat, but in general, compost is considered stable when the temperature in a static pile remains at or near ambient air temperatures for several days. Moisture content is about 50 percent; and oxygen content is more than 5 percent.

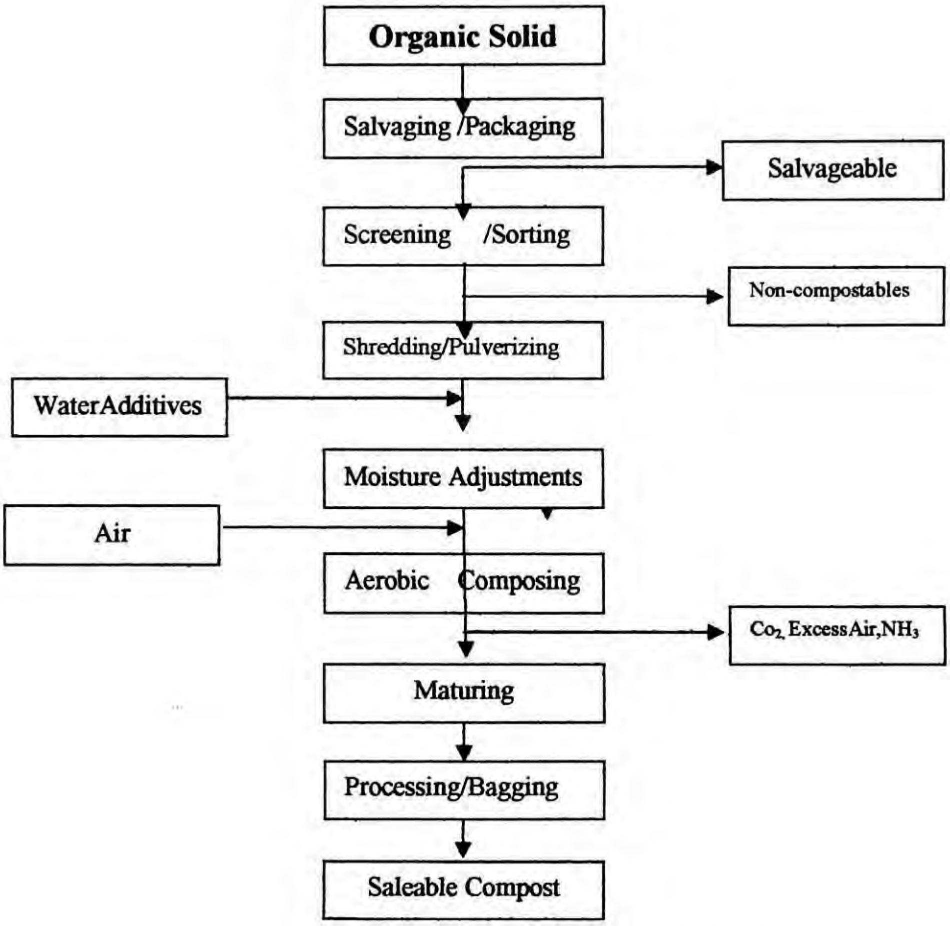

Figure 2.1: Typical Composting Processes

Aerobic composting: Composting is the microbial decomposition of biodegradable solid waste, under aerobic condition, where micro-organisms convert waste into stable end product i.e. compost. This is the most commonly used biological process (Sinha 1993), which needs yard waste, separated MSW, and commingled MSW. Aerobic digestion is done in the presence of air or oxygen. A typical Design Considerations for Aerobic Composting Process is presented in Table 2.2.

Table 2.2: Important Design Considerations for Aerobic Composting Process

Item	Comment
Particle size	For optimum results the size of solid wastes should be between 25 and 75mm (1 and 3in).
Carbon-to-nitrogen (C/N) ratio	Initial carbon to nitrogen ratios (by mass) between 25 and 50 are optimum for aerobic composting. At lower ratios, ammonia is given off. Biological activity is also impeded at lower ratios. At higher ratios, nitrogen may be a limiting nutrient.
Blending and seeding	Composting time can be reduced by seeding with partially decomposed solid wastes to the extent of about 1 to 5 percent by weight. Sewage sludge can also be added to prepared solid wastes. Where sludge is added, the final moisture content is the controlling variable.
Moisture content	Moisture content should be in the range between 50 and 60 percent during the composting process. The optimum value appears to be about 55 percent.
Mixing/turning	To prevent drying, caking, and air channeling, material in the process of being composted be mixed o: turned on a regular schedule or as required. Frequency of mixing or turning will depend on the type of composting operation.
Temperature	For best results, temperature should be maintained between 122 and 131°F (50 and 55°C) for the first few days and between 13land 140°F (55 and 60°C) for the remainder of the active composting period. If temperature goes beyond 15 1°F (66°C), biological activity is reduced significantly.
Control of pathogens	If properly conducted, it is possible to kill all the pathogens, weeds, and seeds during the composting process. To do this, the temperature must be maintained between I 40and I 58°F (60 and 70°C) for 24h.
Air requirements	The theoretical quantity of oxygen required can be estimated using Air with at least 50 percent of the initial oxygen concentration remaining should reach all parts of the composting material for optimum results, especially in mechanical systems.
PH control	To achieve an optimum aerobic decomposition, PH should remain at 7 to 7.5 ranges. To minimize the loss of nitrogen in the form of ammonia gas, PH should not rise above about 8.5.
Degree of decomposition	The degree of decomposition can be estimated by measuring the final drop in temperature, degree of self heating capacity, amount of decomposable and resistant organic matter in the composted material, rise in the redox potential, oxygen uptake, growth of the fungus Chaetomium gracilis, and the starch-iodine test.
Land requirement	The land requirements for a plant with a capacity of 50 ton/d will be 1.5 to 2.0 acres. The land area required for a larger plant will be less on a ton/d basis.

(Source: Tchobanoglous 1993).

General equation of the aerobic transformation of solid waste by microorganism can be denoted as follows

$$\text{Organic matter} + O_2 + \text{Nutrient} \xrightarrow{\text{Microorganism}} \text{New cells} + \begin{array}{l}\text{resistant}\\ \text{organic}\\ \text{Matter}\end{array}$$

$$+ CO_2 + H_2O + NH_3 + SO_4^{2} + \ldots + \text{heat}$$

if the organic matter in solid waste is represented (on a molar basis) as $C_aH_bO_CN_d$, the production of new cells and sulfate is not considered, and the composition of the resistant material is represented (on a molar basis) as $C_WH_XO_YN_Z$, then the amount of oxygen required for the aerobic stabilization of the biodegradable organic fraction of MSW can be estimated by using of following equation

$$C_aH_bO_cN_d + 0.5\,(ny+2s+r-c)\,0_2 \rightarrow n\,C_WH_XO_YN_Z + {}_sCO_2 + {}_rH_2O + (d-nx)NH_3$$

Where $r = 0.5\,[b\,.nx\,.3(d-nx)]$

$x = a - nw$

The terms $C_aH_bO_cN_d$ and $C_WH_XO_YN_Z$ represent the empirical mole composition of the organic material initially present and at the conclusion of the process. If complete conversion is accomplished, the corresponding expression is given by

$$CaHbOcNd + \left(\frac{4a+b\ 2c-3d}{4}\right) O2 \rightarrow aCO2 + \left(\frac{b-3d}{2}\right) H2O + dNH3$$

Sometimes, NH_3 produced from the carbonaceous oxidation of organic mater is oxidized further to nitrate, (NO_3) through nitrification as follows.

$$NH_3\ \frac{3}{2}O_2 \rightarrow HNO_2 + H_20$$

$$HNO_2\ \frac{1}{2}O_2 \rightarrow HNO_3$$

$$\overline{NH_3 + 2O_2 \rightarrow H_2O + HNO_3}$$

The amount of oxygen required for the oxidation of ammonia to nitrate can be computed by the above equations.

Anaerobic digestion: Anaerobic process is done in the absence of air or oxygen. The production of methane form solid wastes by anaerobic

Table 2.4: Temperature and Time of Exposure Influences on Common Pathogens in Compositing Process.

Organism	Observations
Salmonella typhosa	No growth beyond 46^{0}C; death within 30 minutes at 55-60^{0}C and within 20 minutes at 60^{0}C; destroyed in a short time in compost environment
Salmonella sp.	Death within 1 hour at 55^{0}C and within 15-20 minutes at 60 C.
Shigella sp.	Death within 1 hour at 55^{0}C
Escherichia coli	Most die within 1 hour at 55^{0}C and within 15-20 minutes at 60^{0}C
Entamoeba histolytica cysts	Death within a few minutes at 45^{0}C and within a few seconds at 55^{0}C
Taenia saginata	Death within a few minutes at 55^{0}C
Trichinella spiralis larvae	Quickly killed at 55^{0}C; instantly killed at 60^{0}C
Brucella abortus or Br. Suis	Death within 3 minutes at 62-63~ and within 1 hour at 55^{0}C
Micrococcus pyogenes van. Aureus	Death within 10 minutes at 5O^{0}C
Streptococcus pyogenes	Death within 10 minutes at 54^{0}C
Mycobacterium tuberculosis	Death within 15-20 minutes at 66^{0}C or alter momentary
Corynebacterium diphtheriae	Death within 45 minutes at 55^{0}C
Necator americanus	Death within 50 minutes at 45^{0}C
Ascans lumbricoides eggs	Death in less than 1 hour at temperatures over 50^{0}C

(Source: Rahman et al, 2007)

The municipal solid wastes used were characterized by a large fermentable fraction (around 70%), high moisture content (55 to 65%) and a C/N ratio around 25. According to the study of Abdennaceur et al (2002) the average principal chemical characteristics of the solid waste materials W1 to W3 samples of windrows at the beginning of the compositing process to compost is summarized in Table 2.5. Usually compost processing and maturity are assumed to be related to the microorganisms present, but still proven methods to elucidate and evaluate these relationships are lacking.

Table 2.5: Chemical Characteristics of Domestic Wastes and Produced Composts

Elements	Domestic Waste	Compost		
		W1	W2	W3
C/N	24.40 ± 3.67	11.03 ± 0.47	11.03 ± 0.55	10.73 ± 0.28
TOC	28.366 ± 5.55	16.76 ± 5.25	18.40 ± 2.97	18.4 ± 2.15
Cu	128.33 ± 52.99	69.73 ± 59.31	57.03 ± 24.49	41.2 ± 25.39
Zn	615.33 ± 62.17	226.33 ± 45.12	195.46 ± 37.21	270.8 ± 49.27
Pb	214.7 ± 60.13	76.1 ± 12.15	73.00 ± 21.79	83.56 ± 31.96
Cd	2.86 ± 1.6	0.6 ± 0.14	0.18 ± 0.02	0.21 ± 0.07
Cr	59.23 ± 30.50	14.46 ± 6.61	20.90 ± 6.77	17.76 ± 3.91
Ni	59.60 ± 25.48	6.76 ± 2.8	4.86 ± 0.28	6.66 ± 3.92

Note: TOC; total organic carbon (%). Heavy metal concentrations are in mg kg^{-1} dry weight

(Source: Abdennaceur et al, 2002)

The study of the Phospholipid fatty acid (PLFA) analysis was used to follow microbial community changes during the composting of municipal solid waste from a range of different environments and the patterns of change were compared between pilot-and full-scale facilities and between varied feedstocks. Under this research, at the pilot level, actual municipal solid waste (MSW) and two synthetic MSW formulations (similar C:N, different available C) were composted and at the full-scale facilities, actual municipal solid waste was composted as was actual municipal solid waste amended with nitrogen. The experimental results showed that the PLFA profiles changed over the composting process in a consistent and predictable manner and PLFA profiles also proved to be characteristic of specific stages of composting and may, therefore, be useful in evaluating the progress of solid biomass processing and product maturity (Herrmann and Shann 1997).

Another research has been carried on seasonal varialtion of the disinfection capacity of a municipal solid waste (Déportes et al, 1998). Finding of this study stated that in ispring and summer, MSW was followed during the composting process from raw material to mature compost and long-term storage of one year and microbial quality was tested. The microbial quality was assessed, for this purpose *Ascaris* eggs, *Salmonella, Shigella,* total streptococci, faecal streptococci, total coliforms, faecal coliforms and *Escherichia coli* were studied and results showed that Faecal coliform concentrations in raw waste reached $2{\cdot}1 \times 10^8$ cfu/g dry weight in spring (CI 95% : $5{\cdot}2 \times 10^7$–$3{\cdot}4 \times 10^8$) and $7{\cdot}2 \times 10^8$ cfu/g dry weight (1×10^8–$1{\cdot}7 \times 10^9$) in summer, and fell to less than 100 cfu/g dry weight within 20 days. The concentrations of Faecal streptococci reached $8{\cdot}7 \times 10^8$ cfu/g dry weight ($3{\cdot}7 \times 10^8$–$1{\cdot}3 \times 10^9$) in spring and $2{\cdot}0 \times 10^9$ cfu/g dry weight ($5{\cdot}6 \times 10^8$–$3{\cdot}4 \times 10^9$) in summer, and fell to $8{\cdot}7 \times 10^4$ cfu/g dry weight ($6{\cdot}9 \times 10^4$–$1{\cdot}0 \times 10^5$). Disinfection was successful in terms of a decrease in faecal contamination indicators and disappearance of faecal pathogens.

The microbial abundance, composition and activity changed substantially during compositing and compost maturity was correlated width high microbial diversity and low activity (Ryckeboer et al, 2003). The U.S. Environmental Protection Agency has required specific time-temperature standards for pathogen control in composting systems. The EPA requirements for pathogen control in composting process are presented in Table 2.6.

Table 2.6: EPA Requirements for Pathogen Control in Composting Process

Requirement	Remarks
Processes to significantly reduce pathogens (PSRP)	Using the in-vessel, aerated static pile, or windrow composting methods, the solid waste is maintained at minimum operating conditions of 40^{0}C for 5 days. For four hours during this period, the temperature exceeds 55^{0}C.
Processes to further reduce pathogens (PFRP)	Using the in-vessel or aerated static pile composting methods, the solid waste is maintained at operating conditions of 55^{0}C or greater for three days. Using the window composting method, the solid waste is maintained at operating conditions of 55^{0}C or greater for at least 15 days during the composting period. Also, during the high temperature period there will be a minimum of five turnings of the windrow.

(Source: USEPA 1979)

2.3 Composting Methods

Solid waste composting can be many forms, from simple and inexpensive backyard or onsite composting methods to more expensive and high-tech methods such as in-vessel composting. Composting varies as much in its complexity as in the range of organic materials recovered. Selecting the right composting equipment at an affordable price also requires careful research. Hundreds of vendors sell composting equipment and there are many variations on each type of equipment. The most common five composting methods are listed in order of increasing costs and levels of technology required as follows:

- Backyard or Onsite Composting (including Grasscycling)
- Vermi-Culture and Vermicomposting
- Windrow composting
- Aerated static pile composting.
- In-vessel composting systems.

Backyard or Onsite Composting (including Grasscycling): This is very simple and conventional method for composting the solid waste by simple dumping.

Vermi-Culture and Vermi Composting: This system uses worms to consume the food waste and utilizes its castings as high quality compost. This is usually done in containers, bins, or greenhouses. Typically 1 pound of worms can eat 4 pounds waste per week. Worm castings bring a premium price but the investment in worm stocking may be high depending on the size of the operation. If too much waste is added anaerobic conditions may occur. In addition, worms cannot process meat products

Under this process application of earthworm, named "red worms" (Eisenia foetida) is carried out, who are inhabitant at temperatures between 10 and 20^0C. Composting with worms avoids the needless disposal of vegetative food wastes and putting of bones, seats, fish, or oily fats in the worm box as they emit odors and may attract mice and rats. The red worms are placed in a box or bin, which can be built or purchased, along with "bedding" of shredded cardboard or paper moistened to about 75% water content. The container should be wide enough so that food scraps can be buried in a different location each time. The dimensions of the container and the amount of worms required depend on quantity of organic food waste needs to be composted per week. Worms gradually reproduce or die according to the amount of food they receive. Worms can build large populations and consume 4-6 pounds of food scraps per week and 4-6 after the box has been started, the worms will have converted all of the bedding and most of the food waste into "castings" which will need to be harvested, so the process can begin again. Worm castings are an excellent fertilizer additive for garden potted plants and this compost is a co-friendly quality fertilizer (Moqsud 2003).

Windrow Composting: This is a conventional method for composting. Generally windrows are long, narrow piles that are turned when required based on temperature and oxygen requirements. This method produces a uniform product and can be remotely located. However, turning the compost can be labor intensive or require expensive equipment. Windrows are typically used for large volumes which can require a lot of space and can have odor problems, and have leachate concerns if exposed to rainfall.

This simplest compost system can be constructed by forming the organic material to be composted into windrows 8 to 10 ft high by 20 to 25 feet wide at base (Tchobanoglous 1993). A minimal system could use a front-end loader to turn the windrow once per year and it could take up to three to five years for complete degradation of the solid wastes. Due to anaerobic digestion often nuisance odors emits. Typical design of windrow composting system consists cross section 6 to 7 ft high by 14 to 16 ft wide and dimensions of the windrows depend on the type of equipment used to turn the composting wastes. Organic material is processed by shredding and screening it to approximately 1-3 in and the moisture content is adjusted to 50 to 60 percent before the windrows are formed. High-rate systems are turned up to twice per week while the temperature is maintained at or slightly above 13 1°F **(55°C).** Complete composting can be accomplished in three to four weeks. During the curing period, domestic decomposable organic materials are further digested by fungi and actinomycetes. After the turning period, the compost is allowed to cure for an additional 3-4 weeks without turning. Turning of the windrows is often emits offensive odors.

The study carried out on to detect changes of the functional abilities of the microflora during composting of manure as a result of windrow turning frequency and to detect differences between distinct zones within the windrows. Biolog GN microliter plates containing 95 different carbon sources were inoculated with diluted suspensions of compost material containing 15,000 microorganisms. Experiment results showed a dramatic shift in functional microbial community structure during the 8-week composting process. The shift was more rapid when the compost windrows were turned. The substrate use pattern in the outer, well-aerated zone of the unturned windrow was similar to that of the turned windrows. Microbial biomass and respiration decreased more rapidly in the turned than in the unturned windrows, indicating a different pace of compost maturation. The data suggested that the Biolog assay might be a suitable approach to determine compost maturity.

Aerated Static Pile Composting: Air is introduced to the stacked pile via perforated pipes and blowers. This method requires no labor to turn compost but is weather sensitive, and can have unreliable pathogen reduction due to imperfect mixing.

The aerated static pile compositing system or the Beltsville or ARS process consists of a grid of aeration or exhaust piping over which the processed organic fraction of MSW is placed. This process developed by the U.S. Department of Agriculture Agricultural Research service Experimental Station at Beltsville, Maryland. This process basically developed for the aerobic composting of wastewater sludge, can be used the compost a wide variety of organic wastes including yard waste or separated municipal solid waste. Usually typical pile heights are about 7 to 8 ft (2 to 2.5m). A layer of screened compost is often placed on top of the newly formed pile for insulation and odor control. Each pile is usually provided with an individual blower for more effective aeration control. For air supply a disposable corrugated plastic drainage pipe is used and air is introduced to provide the oxygen for biological conversion and to control the temperature within the pile. Blower operation is typically controlled by a timer or in some systems by a microcomputer to match a specific temperature profile. Within 3-4 weeks waste material is composted and then cured for a period of four weeks or longer depends on the wastes. to improve the quality of the final product shredding and screening of the cured compost usually is needed to be carried out. Odor control and covered or enclosed systems may be preferable for new facilities.

In-Vessel Composting Systems: Perforated barrels, drums, or specially manufactured containers are simple to use in this system. These are easy to turn, require minimal labor, are not weather sensitive, and can be used in urban and public areas. The initial investment can be high and handling volumes are typically low.

Any suitable kind of vessel or enclosed container (Tchobanoglous 1993) can be used as a reactor in this system, including vertical towers, horizontal rectangular and circular tanks, and circular rotating tanks. Two categories of In-vessel composting systems are available; plug flow and dynamic (agitated bed). This is a dynamic system, the composting material is mixed mechanically during the processing of compositing and system runs on a first-in, first-out principle. For this process requires the detention time 1 to 2 weeks and 4- to 12 weeks curing period after the active composting period. Nowadays mechanical systems are designed to minimize odors and process time by controlling air flow, temperature, and oxygen concentration. The system is a popular due to odor controlled devices with small area requirement, low cost and faster operating system.

2.4 Control Parameters of Composting

Efficient aerobic composting at high temperatures depends on several important factors as follows:

- Moisture content
- Carbon-nitrogen ratio
- Oxygen requirement
- Temperature
- Surface area
- Volume
- P^H

Moisture Content (M.C.): Generally MC content lies in the range of 50-60% during the composting process and optimum being about 55%. Above 65% MC water begins to fill the interstices between the particles of the wastes, reducing the interstitial oxygen and causing anaerobic conditions as results offensive odors generates due to rapid fall in temperature. When the moisture contents drops much below 50%, the composting process becomes slow.

Carbon-Nitrogen Ratio (C / N ratio): Microorganism use carbon as an energy source and nitrogen for cell building. For this purpose an optimum balance between carbon (C) and nitrogen (N) content is necessary because the bacteria need a minimum supply of nutrients to survive. The initial C/N ratio is a deciding factor in the speed at which decomposition takes place (Moqsud 2003). It is noted that the ideal initial ratio should be between 30: 1 and 35: 1 and if it exceeds 50, the time required increases considerably and ammonia is given off at lower C/N ratios and biological activity is also impeded at lower ratios. Vegetables are the main source of nitrogen and paper is the main source of carbon in the MSW. Higher the ratio of paper to vegetable/ putrescible matter, the higher C/N ratio and the putrescible matter which has a C/N ratio of about 24: 1

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

Oxygen Requirement: Oxygen requirement is the key to the aerobic process of composting. But it is hard to decide the exact oxygen requirement for composting process because of its dependence on many variables such as temperature, MCt and availability of nutrients. It is reported that the presence of foul odors indicates insufficient supply of oxygen. Therefore, one technique for monitoring sufficient oxygen supply is to check foul odors of the compost.

Temperature: Temperature is one of important factor for the biological process in the composting. Typical temperatures in a well-managed compost pile range from 50 to 65° C, which easily exceeds the thermal death limits of many mesophilic microorganisms pathogenic to animals (Roger 1991). The optimum temperatures for the composting process 45-65^{0}C, which helps a large variety of microorganisms to participate in the process. Higher temperatures e.g., 60-70^{0}C for about 24 hours should be required for pathogen decaying.

Surface Area: Surface area is another influential factor for composting. Decomposition by microorganisms occurs in contact with air during the composting process. Increasing the surface area of the material to be composted can be done by chopping, shredding, mowing or breaking up the material. In increased surface area the microorganisms are able to digest more material, multiply more quickly, and generating more heat.

Volume: Optimum volume is required for the process. A large compost pile will insulate itself and hold the head of microbial activity. Its center will be warmer than its edges. Piles smaller than 3 feet cubed 27 cu-ft will have trouble holding this heat while piles larger than 5 feet cubed 125 cu. ft don't allow enough air to reach the microbes at the center. These proportions are of importance only if the goal is fast hot compost.

P^H control: "Additional destruction of pathogenic microorganisms occurs over time due to the physical and chemical changes, e.g., alteration of pH, resulting from the combined activities of microbial populations within the compost system" (Roger 1991). Organic materials with a wide range of pH values from 3 to 11 can be composted, but the more desirable pH range for composting is between 5.5 and 8.5. The pH varies with time during the composting process and is a good indicator of the extent of decomposition within the compost mass. The optimum pH range for most bacteria is between 6.0 and 7.5. During the initial period (first 2 to 3 days) pH drops to 5.0 or less and then beings to rise to about 8.5 for the remainder of the aerobic process. It is noted that if the digestion is allowed to become anaerobic, the pH will drop to about 4.5. To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above 8.5.

2.5 Microorganism in Composting

Microorganisms, i.e. bacteria, fungi and to some extent, protozoa are that active agents for composting. It is reported (Moqsud 2003) that successful outcome of the composting process depends upon the presence of the necessary microorganisms, preferably indigenous and upon the provision of conditions conducive to microbial activity and proliferation. The conditions include nutrition and physico- chemical environments of the microbes in the composting process.

The features of nutrition and microbial succession characterize the compost process. The primary effect of the succession feature is the imparting of a series pattern to microbial attack such that one group of organisms paves the way for a succeeding group. The parallel feature has been recognized and known for years in conventional microbiology as "syntrophy," which refers to the nutritional and metabolic interactions between two or more groups of bacteria when grown as a mixed culture. At times, it also is referred to as "synergy" (working together)

Through syntrophy (synergy), metabolic end products produced by one organism may be used as nutrients by another and converted into substances that neither organism alone could accumulate in the original medium if grown separately.

Thus, because of syntrophy, the combined activities of two or more different types of organisms placed together in an environment (e.g., compost substrate) may result in products that are quantitatively or qualitatively very different from the sum total of the activities of the individual organisms when grown separately in pure culture. For instance, the anaerobic methane-producing bacteria cannot use glucose as a substrate, but can grow at the expense to the fermentation products formed by most glucose fermenting bacteria. Thus, a mixed culture of methanogens and starch users makes it possible to produce methane from starch. As in nature, the collaborative (syntrophic) decomposition of organic matter is the normal course of vents in the composting of wastes. In nature, all types of organisms grow together and contribute to the "cycle of matter."

Complexity and nature of molecular structure of the waste are especially important because they determine vulnerability to microbial attack and assimilation. Obviously, if the substrate cannot be assimilated by any of the organisms present, it will not be composted. The capacity of a microbe to assimilate a given substrate depends upon its ability to synthesize the enzymes involved in breaking down complex compounds into intermediate compounds or into an element that can be utilized by the microorganisms. If the microbes collectively lack the required enzymes the substrate remains unscathed. Some molecular structures are of a kind that can be assimilated by only a few groups of microorganisms. Translated into practical application, this limitation means that substances consisting mainly of cellulose (e.g. paper), of lignin (wood), or of molecules having a ring structure (e.g. aromatics) break down more slowly than highly proteinaceous materials (meat scraps, fresh vegetable trimmings, garbage, etc.). Newspaper stock is broken down more slowly than other paper because individual cellulose fibers in newspaper stock are partially sheathed in lignin.

Biological conversion of the solid wastes depends on the following main aspects;

- Nutritional requirements of the microorganisms commonly encountered in solid waste conversion facilities,
- Types of microbial metabolism based on the need for molecular oxygen and
- Types of microorganisms of importance in the conversion of solid waste

A brief description of the important aspects for biological conversion in composting process is discussed below.

Nutritional Requirements for Microbial Growth: All microorganisms requires a source of energy; carbon for the synthesis of new cell tissue, and inorganic elements *(nutrients)* such as nitrogen, phosphorus, sulfur, potassium, calcium, and magnesium for their reproduction and function ability. Organic nutrients *(growth factors)* may also be required for cell synthesis. Carbon and energy sources usually referred to as substrates, and nutrients and growth factor requirements for various types of organisms. Microbial nutrients are the structural units and the energy sources used by microorganisms for building and maintaining their structure and organization. Almost all elements serve to some extent as microbial nutrients. Some are essential to microbial survival. A consideration of the elemental composition of living organisms makes it obvious that relatively large amount of hydrogen (H), oxygen (O), carbon (C), and nitrogen (N) must be available.

Hydrogen and oxygen constitute a large a percentage of cellular mass in the form of water and as a part of the cellular material. The major part of the molecular structure of the cell mass has the basic formulation CH_2O. Not surprisingly, C and N are termed "macronutrients". The four elements, phosphorus (P), sulfur (S), calcium (Ca), and potassium (K) are required in amounts that are intermediate between macro and micro. At the other extreme, several elements are present in only minute (trace) amounts (cobalt, magnesium, manganese, iron, copper, molybdenum, etc.) -hence they are "micronutrients."

Even though trace elements are needed in only minute amounts and even are toxic above those traces, they are essential to the survival and multiplication of the microorganisms. Some, perhaps most, trace elements constitute an important part of enzyme molecules and enzymatically triggered or promoted reactions. Finally, water is the prime requirement of all living organisms and is an essential nutrient for almost all.

Types of Microorganisms: General classification of microorganisms by sources of energy and carbon in summarized in Table 2.7. There are two of the most common sources of carbon for cell tissue is organic carbon and carbon dioxide. Organisms that use organic carbon for the formation of cell tissue are called heterotrophs. Organisms that derive carbon from carbon dioxide are called autotrophs. The conversion of carbon dioxide to organic cell tissue is a reductive process, which requires a net input of energy. The energy needed for cell synthesis may be supplied by light or by a chemical oxidation reaction. Those organisms that are able to use light as an energy source are called *photographs.* Phototrophic organisms may be either heterotrophic (certain sulfur bacteria) or autotrophic. Organisms that derive their energy from chemical reactions are known as chemotrophs. Like the phototrophs, chemotrophs may be either heterotrophic (Protozoa, fungi and most bacteria) or autotrophic (nitrifying bacteria). Autotrophic organisms must therefore spend more of their energy for synthesis than do heterotrophs, resulting in generally lower growth rates among the autotrophs. It is also reported that Chemoautotrophs obtain energy from the oxidation of reduced inorganic compounds, such as ammonia, nitrite, and sulfide. Chemoheterotrophs usually derive their energy from the oxidation of organic compounds.

Table 2.7: General Classification of Microorganisms by Sources of Energy and Carbon

Classification	Energy source	Carbon Source
Autotrophic		
Photoautotrophic	Light	Carbon di oxide
Chemoautotrophic	Inorganic oxidation-reduction reaction	Carbon di oxide
Heterotrophic		
Chemoheterotrophic	Organic oxidation-reduction reaction	Organic carbon
Photoheteroptophic	Light	Organic carbon

Types of Microbial Metabolism: Most biological conversion processes is the conversion of the organic matter to a stable end product. In accomplishing this type of treatment, the chemo heterotrophic organisms are of primary importance because of their requirement for organic compounds as both carbon and energy source. The organic fraction of MSW typically contains adequate amounts of nutrients (both inorganic and organic) to support the biological conversion of the waste. With some commercial wastes, however, nutrients may not be present m sufficient quantities. In these cases nutrient addition is necessary for the proper bacterial growth and for the subsequent degradation of the organic waste.

Research studies stated that Chemoheterotrophic organisms may be further grouped according to their metabolic type and their requirement for molecular oxygen. It is noted (Moqsud 2003) that organisms that generate energy by enzyme-medicated electron transport from an electron donor to an external electron acceptor (such as oxygen) are said to have a respiratory metabolism. In contrast, fermentative metabolism does not involve the participation of an external electron acceptor. Fermentation is a less efficient energy-yielding process than respiration; as a consequence, heterotrophic organisms that are strictly fermeniative are characterized by lower growth rates and cell yields than respiratory heterotrophs. When molecular oxygen is used as the electron acceptor in respiratory metabolism, the process is known as aerobic respiration. Organisms that are dependent on aerobic respiration to meet their energetic needs can exist only when there is a supply of molecular oxygen. These organisms are called obligate aerobic. Oxidized inorganic compounds such as nitrate and sulfate can function as electron acceptors for some respiratory organisms in the absence of molecular oxygen. In environmental engineering, processes that make use of these organisms are often referred to as anoxic. Organisms that generate energy by fermentation and that can exist only in an environment that is devoid of oxygen are obligating anaerobic. There is another group of microorganisms, which has the ability to grow in either the presence or the absence of molecular oxygen. These organisms are called facultative anaerobes. The facultative organisms fall into two subgroups, based on their metabolic abilities. True facultative anaerobes can shift from fermentative to aerobic respiratory metabolism, depending upon the presence or absence of molecular oxygen. Aero tolerant anaerobes have a strictly fermentative metabolism but are relatively insensitive to the presence of molecular oxygen.

Microorganisms are also classified, on the basis of cell structure and function, as eucaryotes, eubacteria, and archaebacteria, as shown in Table 2.8. The procaryotic groups (eubacteria and archaebacteria) are of primary importance in biological conversion of the organic fraction of solid wastes and are generally referred to simply bacteria. The eucaryotic group includes plants, animals, and protists. Eucaryotes important in biological conversion of organic wastes include fungi, yeasts, and actinomycetes.

Table 2.8: Classification of Microorganisms

Groups	Cell structure	Characterization	Representative members
Eucaryotes	Eucaryotic	Multicellular with extensive differentiation of cells and tissue	Plants (seed plants, ferns mosses) Animals (vertebrates, invertebrates)
		Unicellular or coenocytic or myceliar, little or no tissue differentiation	Protists (algae fungi, protozoa)
Eubacteria	Procaryotic	Cell chemistry similar to eucaryotes	Most bacteria.
Archaebacteria	Procaryotic	Distinctive Cell chemistry	Methanogens, halophiles, thermacidophilies

(Source: Moqsud 2003)

The biological conversion of an organic waste requires the biological system to be in a state of dynamic equilibrium. To establish and maintain dynamic equilibrium, the environment must be free of inhibitory concentrations, of heavy metals, ammonia, sulfides, and other toxic constituents.

However, compost is a source of plant nutrients, can be used as a much, and, in some cases, can be used as a natural fungicide The organic manure and soil conditioners produced by composting are environmentally friendly and widely used by both industrialized and developing countries. The scope and importance of conversion of municipal wastes into organic manure from both agricultural and environmental viewpoints demonstrate the need for undertaking large scale composting as well as marketing the product can be used as a much, and, in some cases.

2.6 NGOs Involvement in Solid Waste Management

There are several NGOs and CBOs are working in the urban solid waste management projects in Bangladesh. They are providing door to door services for collection the domestic waste at different areas in the different cities in Bangladesh. Besides the Community Voluntary Organization and some CBOs many NGOs are working Dhaka. Among them Waste Concern and Rayer Bazer Environment Cleanup Project (RECP) are two renowned

NGOs those area working on solid waste management in Dhaka city from collection to disposal of the domestic waste from a number of households without any kind of assistance from DCC. Waste Concern has a few pilot projects at Mirpur and Green Road Staff quarter, Bally Road Staff quarter and Dholpur near Sayedabad, for managing solid waste through composting for managing solid waste economically sustainable and environmentally safe. Waste Concern's is converting this waste into quality organic fertilizer (Sinha and Enayetullah 2001) and commercialized the finished product. This NGO initially established a pilot scale compost plant at Mirpur in Dhaka, where solid wastes are collected from selected households and aerobically processed to produce compost (Badruzzaman, 2003). Waste Concern is working under the Sustainable Environmental Management Program (SEMP), supported by UNDP implemented by Ministry of Environment and Forestry. This organization is also working on MWS management in outside of Dhaka city in Mymenshing, Jessore, Barisal, Putakhali and Rangamati as a consultant.

Another small NGO of Bangladesh has established a small scale composting plant in 2001 at KCC, only 1.33% of solid wastes (4 tons) of total estimated amount of solid wastes generated in Khulna city (300 tons), are collected by its own initiative for use in composting plant. Prodipon' another NGO has started composting project at Khulna city (Alamgir 2003). Compost stability immaturity has become a critical issue for land application of compost because immature compost can detrimental to plant growth by competing for oxygen or causing phytotoxicity to plants due to insufficient biodegradation of organic matter and the soil environment (Wu and Martinex 2000 and Brode et al, 1994). Other important issues related to the pathogenic harmfulness of compost as fertilizer to the users still not studied well. So it is required to evaluate the characteristics of compost for use as fertilizers for the plants and its microbial harms to farmer.

CHAPTER 3: EXPERIMENTAL WORKS

3.1 Introduction

The NGO "Waste Concern" has been established community based pilot scale compost plants in the five locations in the Dhaka city under the Sustainable Environmental Management Program (SEMP), supported by UNDP, implemented by Ministry of Environment and Forestry. In this research work two MSW management pilot plants located at Green Road Staff Quarter (Green Road Staff Quarter) and Mirpur slum area were studied, where solid wastes are collected from the households and are aerobically processed to produce compost. The solid waste management system in Green Road Staff Quarter is Box type pilot plant and in Mipur area is Barrel type.

The primary data was collected through interview and questionnaires survey (Annexure A and B) and laboratory analysis. Secondary data was collected through discussion with the local people of the project area and the staff of the Waste Concern NGO and review the relevant study reports.

This study investigates the microbial quality in a composting process of Green Road Staff Quarter Box type pilot plant. The microbiological community in the solid wastes includes Salmonella and Shigella as well as faecal indicator bacteria: total coliforms, and faecal streptococci, etc. The prevailing physico-chemical conditions during compositing process also are considered under this research. Laboratory analysis were conducted in compost samples collected from a semi-industrial pilot plant in Green Road Staff Quarter by Waste Concern using a moderate aeration during the composting process. Observation and information also collected on Barrel type compost system in Mirpur.

3.2 Description of Box Type Composting Pilot Plant at Green Rd

A door-to-door solid waste collection system was introduced by Waste Concern to collect the domestic waste only of the Green Road Staff Quarter

Govt. Housing area. Solid waste is collected from approximate 550 households of this area and treated in the Box Type Composting Pilot Plant, which is located at Green Road. Daily generation of wastes by person per day is about 2.5 kg. It is reported that about 7 ton solid wastes generated per day from the households of the project area, collected by modified rickshaw van (Figure 3.1). Before obtaining source separated waste from the households, 1 ton of solid waste from the restaurants and nearby vegetable markets were collected. Four vans are taking the domestic waste from the different households by the staff of the organization and dumped in the solid waste management complex, which located at one corner of the yard in Green Road Staff Quarter.

Figure 3.1: Modified Rickshaw Van for Collection of Domestic Solid Waste

After collection of the domestic solid wastes from the selected households in Green Road Staff Quarter goes successively to the following steps: manual sorting and biological fermentation, drying, sieving of compost and finished product as fertilizer. Manual systems are designed to minimize odors and process time by controlling proper environmental conditions for sufficient as air flow, temperature, and oxygen concentration. The compost fertilizer (mean granule size 3.5 com) came out from screening and transported to the main office in House 21 (B) Road 7, Block G, Banani, Dhaka and to other selling centre.

Figure 3.2: Manual Sorting the Collected Domestic Solid Waste.

Composting Plant: The composting plant consist eight chambers box type brick plant (Figure 3.2). The height and wide of the brick chamber approximately 2 meter and 1.5 meter respectively. These boxes are provided to maintain aerobic condition through providing hollow bricks and open at the top.

Figure 3.3: Setup of Eight Chambers (Box) of Composting Plant

Figure 3.4: Dried Wastes after Composting

Figure 3.5: Sieving Net of the Dried Wastes after Maturation

Figure 3.6: Sieving of Finished Product (Compost) by Women Staff

3.3 Laboratory Analysis

Under this study, detail experiments on microbial analysis of the compost samples from different stages of the composting process of Box type are carried out. Some physico-chemical parameters such as temperature variation, moisture content and C/N of the samples were also observed during composting process. Temperature variation of this plant was compared with the typical nature of curve of the temperature variation in composting. The four samples collected from the Box pilot plant of domestic solid waste for microbiological tests are as follows

- Raw solid waste, Sample No 1
- Compost after 40 days maturation, Sample No 2
- Finished product (compost), Sample No 3 and
- Finished fertilizer (compost) after one month, Sample No 4.

3.3.1 Microbial Analysis of the Samples

Four samples collected for microbial test in the laboratory and the results are expressed as colony forming unit per gram (cfu/g). During lab analysis 1 gm of compost sample is diluted in 10 ml of saline water and mixed several times. Pathogenic bacteria and fecal coliform are tested from final compost sample for public health concern. All microbial counts were performed according to recognized international standards. It isolates were identified my morphological features and biochemical properties (Capet 1970, Minor and Richard 1993). The following microbiological tests are carried out in the Microbiological Department, University of Dhaka.

Faecal coliforms: The presence of coliform bacteria is often used as an indicator of the overall sanitary quality of soil and water environments. Use of an indicator such as coliforms, as opposed to the actual disease-causing organisms, is advantageous as the indicators generally occur at higher frequencies than the pathogens and are simpler and safer to detect.

Faecal Streptococci: Faecal streptococci are commonly considered as the best indicators of faecal pollution. They are more resistant to different environmental factors than coliforms and they are essentially represented *by streptococcus faecali,. S faecium* and S *bovis*.

Staphylococci: Staphylococci are ubiquitous bacteria and *Staphylococcus aureus* is one of the main causes of collective toxic-infections of food. This species also generates cutaneous infections that represent a risk for compost handlers and agriculturists during farm compost spreading and it liberates a thermostable enterotoxin. The evolution of staphylococci during the composting cycle was similar to that of streptococci.

Salmonella and Sigella: Generally the presence of Shigella and Salmonella is considered as the major and specific problem of the hygienic quality of compost.. The United States Environmental Protection Agency (USEPA) imposes for Salmonella a rate lower than 3 bacteria in 4g of dry weight of compost and sludge (Hay et al, 1996). Salmonellae come from food wastes, essentially from meats, poultry, milk and its derivatives.

3.3.2 Chemical Analysis

Some physico-chemical parameters are tested and observed during composting process as follows.

Temperature variation during composting: The temperature is measured with a thermometer (range 0^0 to 100^0 C) regularly during composting by inserting the thermometer into the Box type and Barrel type composting plants.

Volume reduction: The waste volume starts to reduce from its initial volume during composting process. After few weeks the waste reduction rate becomes constant. It is observed that middle of the composting barrel is not sufficient with air, the rate of volume reduction becomes slow as some portion of waste is not composted properly. To overcome of this problem a perforated PVC pipe is placed at the middle of the box/barrel and it is observed that the rate of volume reduction becomes quicker as the aerobic condition is maintained at the middle portion of the composting barrel.

Moisture content: The moisture content is another important parameter for composting. The variation of moisture content has been determined by comparing the initial water in the compost to the initial total weight of the compost. To determine the moisture content the sample is placed in oven at 85 degree Celsius for 24 hrs. It is expressed as percentage. Observation of moisture content during composting process is done manually through checking by hand.

pH of compost: pH of the compost is determined by adding 10 gm of compost sample (from the plant) in a 100 ml distilled water and mix thoroughly for several minutes (Jackson,1977) .Then the digital pH meter (Model 3051, JENWAY) is used to determine the pH value of the compost directly.

Particle size distribution: This is important in designing collection vehicles, mechanical recovery system, and also to design biological treatment methods. It can be determined by a set of manually manipulated screen and presented by size distribution curves.

Nitrogen content: Nitrogen content is determined as total Nitrogen by Kjeldhal's method. Phosphorus and Potassium content are also determined from various samples following the standard chemical analysis methods. All nutrients are presented as percentage.

3.4 Description of the Barrel Type Composting System in Mirpur

Low-cost barrel type-composting system (Figure 3.7) installed for the slums households in Mirpur by the NGO, Waste Concern. About 200 litter bottomless perforated barrels with a cover at the top is designed for composting. At the beginning this project has large project area and about 120 slum families were included under the project. Presently, domestic solid waste is collecting from only 75 households in the slum area, due to space constraint and formed groups by 6 members. It was reported that each family has 5-6 family members. Amongst 75 households only 20 households are randomly selected for the study purpose, and has given to each family a 12 liter capacity plastic green bucket for storing organic waste and a red bucket for storing their domextic inorganic waste. One barrel is allocated for six households, Community mobilization and awareness by posters, video shows and leaflets took almost four months, before actual implementation of the project in the slum (Moqsud 2003).

Figure 3.7: Barrel type Composting System

All members of the slum households were provided training on how to segregate solid waste as organic waste and inorganic waste and dump to Barrel compost type plant. All kitchen garbage is disposing into the barrels and this waste decomposes aerobically into compost in within two– three months time.

It is reported that after seven to eight weeks the compost is taken out from the barrel from the opening at bottom side of the barrel which is then stored for maturing for two weeks (Moqsud 2003). After drying the matured products, sieving is taking place by manually and the final compost is packed for sale.

Figure 3.8: Compost is taken out from the Barrel after Composting

3.5 Laboratory Analysis

Microbial analysis is carried out for one sample (Sample No. 5) of the finished compost product of the Barrel type composting system. The physico-chemical parameters such as temperature variation, moisture content and C/N of the samples were also observed during Barrel type composting process.

3.6 Field Survey

Field survey is conducted through questionnaires survey, observation and discussion with the respective Concern Officials and male and female workers, solid waste van pullers, users, etc. Two set of questionnaire (Annexure A and B) are developed for Box type and Barrel type composting systems and used for data collection in the study areas.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Characteristics of Domestic Solid Waste

The Characteristics of domestic solid waste in Box type pilot plant and Barrel type composting system are studied and also compared various types of waste generated by the domestic households. Domestic solid waste from randomly selected 45 households in Green Roads staff quarter and 20 households in the Mirpur slum area were collected daily from door to door for seven days. The collected waste is stored into two different baskets for different categories of organic and inorganic type of wastes. The daily-generated domestic wastes were weighed separately and the recorded data is presented in the Table 4.1 and 4.2.

Table 4.1: Domestic Waste Generation Rates from 45 Households in the Green Road Study Area

Day	Waste (kg)		Total waste	% of waste generated	
	Organic	Inorganic		Organic	Inorganic
1	99	16.9	115.9	85.42	14.58
2	110	17.9	127.9	86.00	14.00
3	120	14	134	89.55	10.45
4	103	17	120	85.83	14.17
5	107	14	121	88.43	11.57
6	100.1	13	113.1	88.51	11.49
7	97.9	15	112.9	86.71	13.29
Total	737	107.8	844.8	610.46	89.54
Average/ Day	**105.29**	**15.40**	**120.69**	**87.21**	**12.79**
Average/ Day/ Household	**2.34**	**0.34**	**2.68**		
Kg/capita/day	**2.34/5.6 =0.41**	**0.34/5.6 =0.06**	**2.68/5.6 =0.47**		

***Considered 5.6 persons/household as average**

Table 4.2: Domestic Waste Generation Rates from 20 Households in the Green Road Study Area

Day	Waste (kg)		Total Waste	% of waste generated	
	Organic	Inorganic		Organic	Inorganic
1	10.2	0.6	10.8	94.44	5.56
2	11	0.8	11.8	93.22	6.78
3	10.05	0.5	10.55	95.26	4.74
4	9.9	0.9	10.8	90.00	8.33
5	11.5	0.8	12.3	93.50	6.50
6	12	0.9	12.9	93.02	6.98
7	13	0.7	13.7	94.89	5.11
Total	77.65	5.2	82.85	654.34	44.00
Average/ Day	**11.09**	**0.74**	**11.84**	**93.48**	**6.29**
Average/ Day/ Household	**0.55**	**0.04**	**0.59**		
Kg/capita/day	**0.55/5.6 =0.098**	**0.04/5.6 =0.007**	**0.59/5.6 =0.105**		

***Considered 5.6 persons/household as average**

The result indicates (Table 4.1 and Table 4.2) that daily solid waste generation rate per households in Green Road area is higher (about 2.68 kg/household) than solid waste generated from slum household (0.59 kg).

The survey data on the physical composition of domestic solid waste reveals that organic part of food waste generation is more for slum people in Mirpur (93%) than that of Green Road dwellers (80%).

Other studies reveal that food waste has unique properties as a raw compost agent because it has a high moisture content and low physical structure. It is noted that to mix fresh food waste with a bulking agent that will absorb some of the excess moisture as well as add structure to the mix.

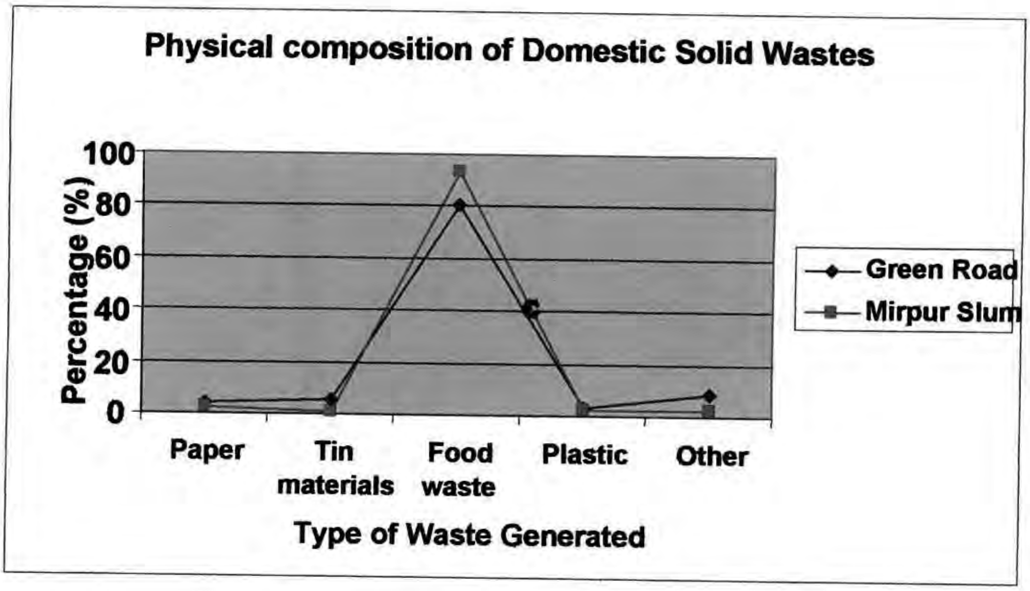

Figure 4.1: Physical Composition of Domestic Solid Waste in Two Study Areas

Bulking agents with a high C:N ratio, such as sawdust and yard waste, are good choices. But food waste is highly susceptible to odor production mainly ammonia and large quantities of leachate. To prevent the odor, a well-aerated pile that remains aerobic and free of standing water can be considered for best solution. As a result, leachate can be reduced through aeration and sufficient amounts of a high carbon bulking agent but still will have some odor and leachate production. This leachate can be captured and reapplied to the compost.

Field study indicates that the domestic waste comprises large portion of food waste in the both study areas.

4.2 Microbial Analysis of Different Composting Samples

It is reported that a different group of pathogens is present in human wastes (LeaMaster et al, 1998). In this study the experimental analysis of microbiological organisms of municipal solid waste samples from a semi industrial Box type pilot plant and Barrel type composting systems were carried out. Four samples collected different stages of the composting process. The investigated microbial community is faecal indicator bacteria such as total coliforms, feacal coliforms as well as Salmonella, Pseudomonas, Staptococci and Vibrio Cholerae.

A verity of methods has been used so far to investigate the microorganism during compositing. In this study traditional plating and identification of culturable microorganisms for determining microbial diversity during composting are carried out. The bacteriological tests are carried in the laboratory by used of different media for different microorganisms, such as Mac Conkey agar for coliform, mFc agar for Faecal coloform, Cetimide agar for Pseudomonas spp, XLD agar for Shigella/ Salmonella, TCBS agar for Vibrio Cholerae, and Mannital salt agar for Staphylococcus. Results of the microbial test of the composting samples are presented in the Table 4.3. The result of four samples; Raw solid waste (Sample No 1), Maturity waste after 40 days (Sample No 2, Finished product (sample No 3) and Finished compost after one month, (sample No 4) indicated highest number of total coliform 6.0×10^2 are found in raw solid waste material and their population became decreasing during maturity process. This decrease was presumably the result of the high temperature and of the unfavorable conditions established during the thermophilic phase. However, a phase of decreased growth appeared from the eight week in all boxes. The number of faecal streptococci showed a district decrease from 2.0×10^2 cfu/g to nil during the thermophilic phase (60 to 65° C).

Table 4.3: Result of Microbial Analysis of the Compost Samples

Sample No.	Total Colifor m cfu/g	Fecal Coliform cfu/g	Pseudomonas spp. cfu/g	Salmonella spp. cfu/g	Vibrio Cholerae cfu/g	Streptococci spp. cfu/g
No 1	$6.0x10^2$	$2.0x10^2$	$1.2x10^2$	Nil	Nil	$1.10x10^2$
No 2	$1.5.0x10^2$	$1.6x10^2$	$4.0x10^2$	Nil	Nil	$1.15x10^2$
No 3	$1.2x10^2$	$1.0x10^2$	$8.0x10^2$	Nil	Nil	$9.0x10^2$

Faecal streptococci are commonly considered as the best indicators of faecal pollution. They are more resistant to different environmental factors than coliforms and they are essentially represented by streptococcus faecalis. S faecium and S bovis. Experimental results indicated that highest of Faecal coliform count in the raw solid waste sample (No 1) and lowest in the compost sample (No 3). Absence of the *Salmonella* spp and Vibrio Cholerae microorganism are found in the tested results for all samples. The sample (No.3) of finished compost product was analyzed to determine the extent of sanitization before it is marketed and found low numbers of an indicator group allows the assumption that the associated pathogens of particular health concern are not present.

Therefore, it is noted that composting conditions are not a suitable environment for pathogens and make their survival more difficult. Managing the conditions of the composting process to eliminate pathogens involves manipulating the compost pile's contents, moisture level, and oxygen supply to favor development of decomposing microorganisms that create an environment in which it is difficult for pathogens to survive.

It was reported that the microbial abundance, composition and activity changed substantially during compositing and compost maturity was correlated with high microbial diversity and low activity (Ryckeboer et al, 2003).

The microbial quality of another two samples from the produced compost of Box type and Barrel type after one month of the composting process was tested to know the proper sanitization the compost before use by consumers. The result (Table 4.4) indicates that compost sample is almost pathogenic bacteria free. Number of total coliform, faecal coliform, *salmonella*, vibrio chelorae microorganism are found nil in the final products after one month.

Table 4.4: Result of Microbial Analysis of Compost Samples One Month after Completion of Compost Process

Sample No.	Total coliform cfu/g	Fecal coliform cfu/g	Staphlacocous spp cfu/g	Pseudomonas spp. cfu/g	Salmonella spp. cfu/g	Vibrio Cholerae cfu/g
No. 4	Nil	Nil	1.2×10^3	5.0×10^2	Nil	Nil
No. 5	Nil	Nil	1.9×10^3	6.0×10^2	Nil	Nil

It is reported (USEPA 1993 and Roger 1991) that the finished compost of 'Class A' should have less than 1000 organisms (most probable number) per gram of total dry solids for the indicator bacteria, fecal coliform. The specific characteristics of various composts depend on the organic wastes being composted and the composting process. The ultimate use and value of any compost depends not only on its physical and chemical properties, but also on its biological activity.

4.3 Physico-chemical Analysis of Compositing Process

Various controlling parameters which are generally affected the composting process of solid waste are studied in this study. The change of various controlling physical parameters during composting of solid waste is observed for the Box type pilot plant and Barrel type composting. The Optimum composting conditions involve a balance of six factors are aeration/oxygen, moisture content temperature, carbon-nitrogen ratios of feedstocks, particle size, and time. The composting process involves the generation of heat, production of carbon dioxide, loss of water vapor, loss of mass (waste), and production of relatively stable humus that is free of offensive odors. Experimental data on moisture content, temperature and volume loss during the composting period of both systems are presented in Table 4.5.

Table 4.5: Variation of the Moisture content, Temperature and Volume Loss during the Composting Period

Duration of Composting Process (Days)	Box Type Composting Plant			Barrel Type Composting System		
	Moisture Content (%)	Temperature (°C)	Volume Loss (%)	Moisture Content (%)	Temperature (°C)	Volume Loss (%)
0	29	29	0		29	0
5	50	29	11	50	29	12
10	65	35	25	56	31	30
15	63	55	38	50	45	30
20	55	60	47	55	57	45
25	58	65	49	55	60	45
30	55	51	52	50	51	48
35	50	38	53	48	36	50
40	45	30		43	30	
50						

Aeration/oxygen: Aeration in all composting operations in both (Box and Barrel composting) systems is passive, such that oxygen enters the compost by natural convection. During aerobic composting, the microorganisms consume oxygen (O_2) for decomposition of organic materials under controlled condition (Figure 4.2).

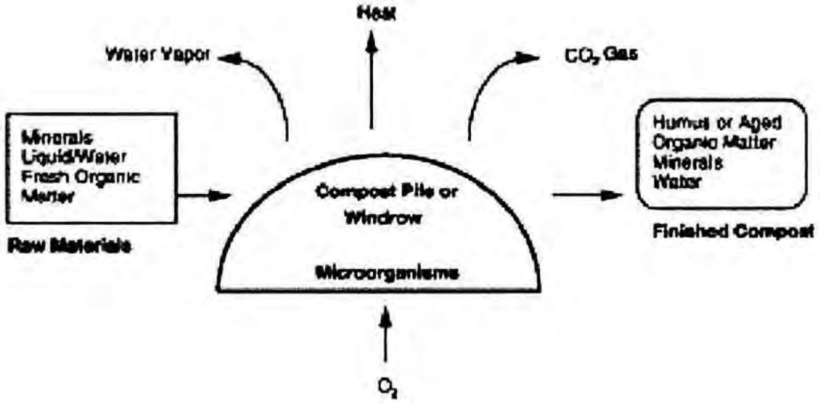

Figure 4.2: Composting Process by Microorganism in Presence of O_2

Initial stage of the composting process oxygen and easy degradable material of the raw solid waste are rapidly consumed by microorganisms and active composting generated CO and water vapor released into air and thereby reduce the volume and mass of the final product. The carbon dioxide and water losses can amount to half the weight of the initial materials thereby reducing the volume and mass of the final compost (Michael et al, 1995).

Generally compost should contain at least 5 percent or more oxygen for optimum aerobic composting (Michael et al, 1995). Good porosity is important for natural convection and diffusion of oxygen into the compost. Insufficient oxygen results in anaerobic conditions and the production of objectionable odors due to formation of some chemicals such as hydrogen sulfide, methane, and organic acids.

Moisture content variation during composting: Observation of moisture content during composting process is done manually through checking by hand. It is reported that compost with a proper moisture content will form a clump and will slightly wet the hand when squeezed. If the clump drips water, it is too wet and may require additional aeration or more bulking agent. If the compost falls through the fingers, it is too dry and may need water additions or more food waste. The moisture content of the samples are observed at five days intervals during composting process and found the changes of moisture content (Figure 4.3) of the two composting system.

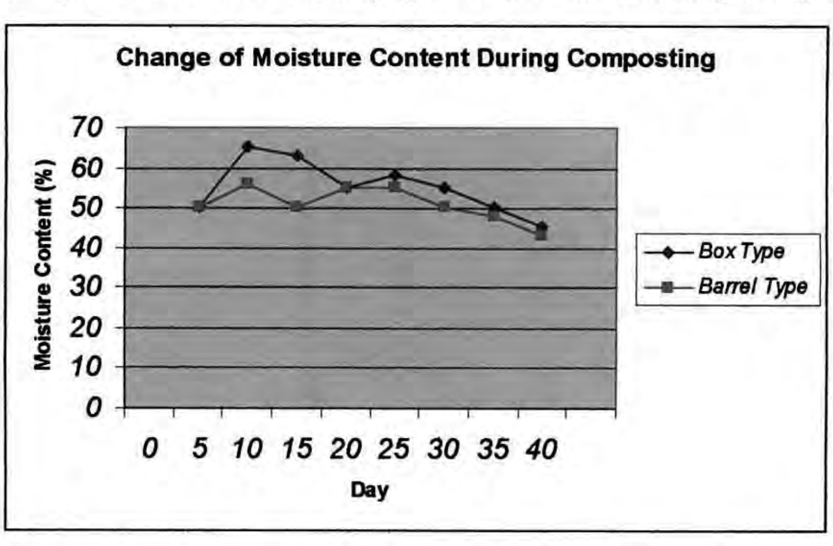

Figure 4.3: Change of Moisture Content of the Two Systems during Composting

Results show that water content in solid waste decreases continuously with increase of temperature. Many research studies stated that compost should contain 40 to 60 percent moisture to support the growth of microorganisms involved in the composting process. Microbial activity is severely inhibited below this range. Moisture levels above 60 percent result in anaerobic conditions. It is reported that about of 60 percent moisture content is optimal for microorganisms to breakdown the compost. Moisture contents above 70 percent create anaerobic conditions, slow down the process and can create foul odors. Moisture below 50 percent also slows down the decomposition process. Water is sometime added to the solid water according to the dust raising situation or mudding situation of the solid waste at fermentation chamber. Addition of water will be different at summer and winter seasons in the composting process.. The moisture content of fresh food waste is 80 to 90 percent, sawdust is 25 percent, and yard waste is 70 percent.

Temperature variation of composting process: Temperature is a good indicator for knowing what is going on during composting process. The experimental results (Figure 4.4) indicate that the temperature of the composting materials generally follows a pattern of rapid increase to 120-140oF where it is maintained for several weeks depending on the materials (Figure 2). As active composting slows, temperatures will gradually drop until the compost reaches ambient air temperatures. A curing period usually follows the active composting period. During the curing period, the materials will continue to slowly decompose. Materials continue to break down until the last easily decomposed raw materials are consumed by the remaining microorganisms. At this point, the compost becomes relatively stable and easy to handle.

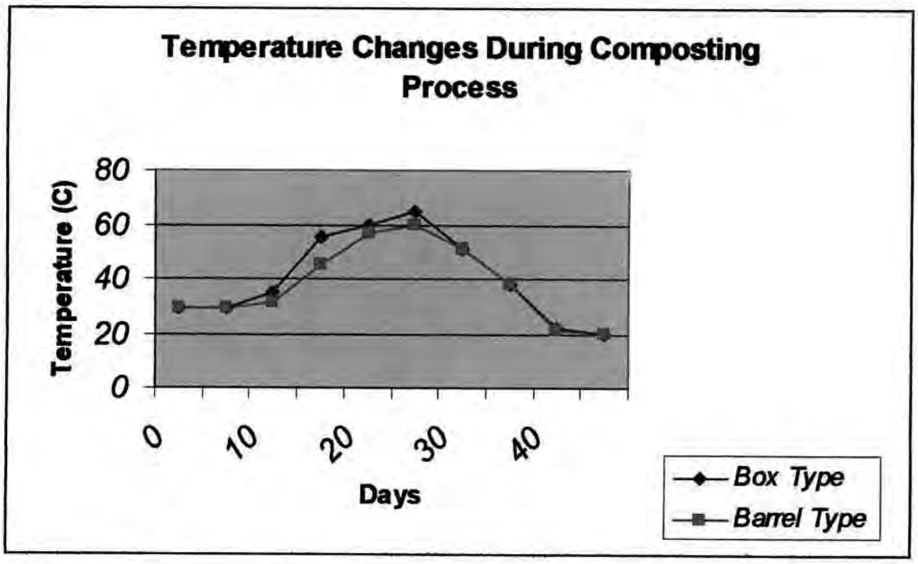

Figure 4.4: Change of Temperatures of the Two Systems during Composting

Several studies reveal that solid wastes in the composting process at fermentation plant will attempt to heat up continuously by exoteric reaction; and due to the heat and the water need at the microorganism activities that took place, the moisture in solid waste content will decrease continuously. The breakdown of wastes by microorganism in the composting rates heat. Mesophilic organisms generally are active at temperatures of 70° to 105°F. Thermophilic bacteria take over at higher temperatures (110° to 150°F). These high temperatures are what destroy weed seeds and pathogens in the compost. Some composting manures can reach temperatures of 200°F. At temperatures above 160°F, microorganism activity begins to shut down. Turning piles mechanically at this stage helps bring the temperature down. Temperatures are considered ideal between 131° and 150°F, which kill pathogens. The compost should be kept at these temperatures for as long as possible.

Change in volume during composting: Experimental results (Table 4.3) shows volume loss during the composting process. Both systems showed loss of volume more or less same manner. Active composting generated CO and water vapor released into air and thereby reduces the volume and mass of the final product (Michael et al, 1995). It is noted that the organic food supply is depleted, the compost begins to cool. Heat, water vapor, and carbon dioxide released during the composting process reduce the overall size of the compost pile by as much as 50 percent. When the compost temperature drops to 100°F or less and fails to reheat after turning, the compost is allowed to cure for one to six months or more under natural aerobic conditions. During the curing process, various fungi and actinomycetes form. Actinomycetes form filaments like fungi but are much smaller, so they are classified as higher forms of bacteria. Both fungi and actinomycetes tend to feed on more resistant materials, such as cellulose and lignins, that are left over after the composting process. Actinomycetes also convert volatile organic acids into longer chained organic acid complexes (5 carbon ringed humic acids), which make up humus. This tends to stabilize the nutrients in the compost. Curing is considered complete when the pile remains at or near ambient air temperatures and the respiration rate (rate of oxygen consumed) is less than 200 mg O_2 per kg of compost per hour. The compost can then be screened for various agronomic and horticultural uses.

Variation of Carbon-Nitrogen Ratio: All organic wastes (feedstocks) are made of carbon and nitrogen. When combining various organic wastes in a composting operation, the ideal ratio of carbon to nitrogen is 30:1 for optimum growth of bacteria, which dominate the initial composting process. Microorganisms like bacteria require carbon for energy and nitrogen for the production of amino acids and proteins in their bodies. Higher carbon:nitrogen ratios slow the composting process, while lower carbon:nitrogen ratios produce too much ammonia. Raw materials high in carbon (such as sawdust, leaves, and paper) should be combined with raw materials high in nitrogen (such as manure, grass clippings, and food waste) to obtain the appropriate 30:1 ratio for optimum composting conditions.

pH value changes during composting: During the composting process pH values are changes. The pH of compost can affect how soluble the nutrients will be in a plant's root zone.

Particle Size: The raw solid waste collected from the households is dumped into the Box type plants and Barrel type compost plants without any shredded or ground. But, it is reported that sometimes feedstock used in composting in other countries often are shredded or ground to increase the surface area of these materials. Because, particle size of these materials after processing affects the porosity of the compost, which in turn affects the flow of air in the composting process. While the particle is too small, however, airflow is inhibited and if the particles are too large, the compost dries out. Studies indicate best results are obtained when the particle ranges from 1/8 inch to 2 inches in diameter (Roger 1991). Smaller particles also produce a more homogeneous compost mixture and improve pile insulation to help maintain optimum temperatures. If the particles are too small, however, they might prevent air from flowing freely through the pile (Composting, Science/Technology US Environmental Protection Agency).

Finished Compost: After maturation of the waste in the Box and Barrel composting system the dried product are sieved. The particle size of the compost is observed and found about ½ to ¾ inch in diameter, which are suitable to apply to cropland. The finished compost samples from Box and Barrel composting plant are examined and found that finished compost are maintaining the ambient temperature, and there are no weed seeds or pathogens (lab analysis result). The pH value was near 7.0, and the moisture content was between 35 and 50 percent. The C:N ratio is 10:1 to 25:1 and organic matter content was between 40 and 65 percent.

Maturation and stability of the compost is the important factor for use this material as the fertilizer. Because apply of unfinished or immature compost may have phytotoxins that can kill plants. There is an inexpensive way to test for mature compost is the watercress test. It is reported that watercress seeds will not germinate or grow in immature compost because they are very sensitive to pH and nutrition (Food Waste Composting). It is reported that compost should be allowed to mature properly before use. Field survey indicated that the producer of compost sells (Waste Concern/ owner of plant) their compost product after well dried to a number houses and nurseries for gardening, at a price ranging from Tk. 4.0-5.0/ kg. Studies have shown that immature compost is generally not as effective as mature compost at suppressing disease (Quarles and Grossman 1995).

4.4 Solid Waste Collection Facilities in the Study Areas

The statistical area specific information on the collection system and disposal practices (such as number of C.I sheet bin, concrete bins, demountable container, street sweepers, van used/ person involved for each van, trucks used for disposal of solid waste etc.) in Green Road could not able to collect from DDC. Similarly, same information was not available in Mirpur slum area, but surveyed people told that there were not solid waste collection bins and other facilities nearby their slum and they had a miserable condition. It was also noted that a very low coverage of solid waste collection services (9%) provided by DCC for slum areas, for the poor dwellers of Dhaka city (Sinha 1993). The solid waste collection facilities in Green Road area before introduction of the community based composting systems was conventional methods. Presently, both areas have community based solid waste management system by Waste Concern.

4.5 Intangible Benefits of the Composting

To assess the resident's view on the intangible benefits of the SW composting some residents who are user of the Barrel type and Box type composting project were asked some questions through question survey. The result of survey reveals the following issues:

Health status: Diseases burden has decreased after introduction of Barrel type composting in the Mirpur slum area. During field survey 20 household members of the Mirpur study area are interviewed and according to their statement about 45% diarrhea and 30% dysentery incidences has decreased than previously occurrences. Also other diseases such as skin disease, dengue fever are decline after installation of the Barrel type composting in the studied slum. This study could not conducted in Green Road study area.

Cleanness of the Area: Another benefit of the composting system is cleanness of the area. It is reported that after installation of Barrel type composting the slum premises becomes cleaner than before and at the same time bad smell from the rotten organic waste are reduced. Proper way disposal of domestic solid waste improved the existing drainage system inside the slum premises and clean the small walkways inside the slum, those were dirty before introduction of the Barrel type composting due to improper throwing the wastes by slum dwellers. About 99% of the interviewee said that these composting systems are safe and easy disposal of solid waste.

Peoples Perception towards Economic Benefit of Composting: Interviewed were carried out with the staff of the Concern Waste and 35 users of the produced compost from the two type composting systems and local people of the study areas. About 80% of them reported that compost production through Barrel type composting system is an easy way to dispose off domestic waste and can be use this fertilizer in their gardening and also can generate funds by selling compost to public. Caretaker of the Barrel type composting in the Mirpur slum reported that they are selling dried compos Tk 4-5 / kg and now a days the demands are increasing for application in the residential gardening. About 90% of the Mirpur slum dwellers opted for introduction of barrel type solid waste disposal system in other slum areas in the Dhaka city.

Dwellers of the Green Road area also appreciated the operation of the Box type composting project, which improved their solid waste disposal facilities and made easy disposal by door to door waste collection services. They also opined that municipalities in Bangladesh could adopt this composting an environmentally preferred alternative of land filling. Although the exact information of the installation cost and life time of the Box type composting plant could not collected from the Waste Concern officials but it was noted that this type composting Plant can be an income generating profitable project of the governments through the direct sale of compost to the public or by reducing the purchase of chemical fertilizers and soil amendments used on gardening and croplands. Composting processes is not only avoids methane and leachate production in the landfill, it also saves valuable landfill space. The major benefit of compost is to improve the structure of a soil. It is also a source of plant nutrients.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

This research study investigates the microbial quality during composting process of municipal solid waste as well as the prevailing physico-chemical conditions of the process. Under this study two different types of composting systems of Waste Concern", a NGO, working on urban solid waste management in the Dhaka city, are studied. These are semi-industrial Box type composting pilot plant located at Green Road Staff Quarter and Barrel Type composting system located in Mirpur slum area. Experimental works included laboratory analysis of the different samples collected from the both MSW composting systems, observation and questionnaires survey. Both are moderate aeration systems during the composting process. The microbial analysis of the solid waste samples collected from different stages of the composting process is carried out. The microbiological test included *Salmonella, Shigella*, total streptococci, faecal streptococci, total coliforms, faecal coliforms and Vibrio Cholarea. Similar microbiological tests are also performed for finished compost sample after one month to observe the microbial quality of the fertilizer (compost) whether it is harmful to the users (gardeners) / farmers or not. Various physical parameters such as temperature variation during composting is observed and compared with the typical nature of curve of the temperature variation in composting.

Research Findings: The findings of this study are summarized below:

- Daily solid waste generation rate per households in Green Road area is higher (about 2.68 kg/household) than solid waste generated from slum household (0.59 kg). The physical composition of domestic solid waste reveals that organic part or food waste generation is higher for slum people in Mirpur (93%) than that of Green Road dwellers (80%).

- The microbial characteristics of a municipal solid waste (MSW) samples at different stages of maturation during composting process has been evaluated. Laboratory analysis indicates highest number of total Coliform $6.0x10^2$ cfu/g Faecal coliform $2.0x10^2$ cfu/g in raw solid waste material; their population decrease during maturation process and those values are found nil in the finished product (i.e.,compost).

- Compost samples were analyzed after one month to determine the microbial qualities before marketing. Low numbers of an indicator group indicate that there are of particular health concern.

- The physico-chemical parameters such as temperature, moisture content, pH, C/N ratio during composting are found to be similar for both composting systems and follows the same nature of the typical curves of the variation of parameters in the composting process.

- This study reveals that there is renewed public interest in composting for several important reasons:
    - safe and easy disposal of wastes (opinion of 99% of the respondents)
    - protection of public health (45% diarrhea and 30% dysentery incidences has decreased in Mirpur slum area after installation Barrel type composting)
    - reduction of environmental stress (cleanness and reduction of bed smell)
    - conservation of resources (recycling of the wastes)
    - development of useful and beneficial products (fertilizer for gardening and croplands)
    - attainment of favorable economics by selling the produced compost (Tk 4-5 / kg of compost)
    - organic manure and soil conditioners produced by composting of solid waste are environment-friendly

(compost samples are found health concerned pathogen free).

Therefore, both composting systems (Box type and Barrel type) have been found to be economically feasible and ecologically compatible and environmentally friendly methods of recycling organic wastes.

5.2 Recommendations for further Study

There is some concern that heavy metals can accumulate in the soil from heavy applications of compost. Therefore, heavy metal content of the soil waste compost can be investigated.

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Annexure A

Sample Questionnaire for Box Type Compost Pilot Plant

(Study Area —1)

A. General Information:

Study Area: ______________________

Location of the Box Type Composting Pilot Plant ______________________

Project Name: ____________

Date: ______________________

Respondent's name: ______________ Age: ______________

Family Members: ______________

No. of Households in the study area: ______________

No. of population in the study area: ______________

Size of the Box Composting Plant: ______________

Total waste generated: ______________ton/day

Starting Date of the Composting of raw solid waste: ____________

Duration of the Composting: ______________

B. Waste collection facilities of Dhaka City Corporation:

Before introduction of Box Composting Plant in the study area:

Collection system and disposal practices: ______________

No. of C.I sheet bins: ______________

No. concrete bins: ______________

No. of demountable container: ______________

No. of street sweepers/ other staff: ______________

No. of van used / person involved for each van to collect the domestic solid waste________

No. trucks used for disposal of solid waste: ______________

After introduction of Box Composting Plant in the study area : ______________

No. of C.I sheet bins: ___________

No. concrete bins: ___________

No. of demountable container: _______________

No. of street sweepers/ other staff: ___________

No. Van used for disposal of solid waste: ____________________

Total no. of Households covered by one van _____

Average waste kg/ household/day ______________

C. Solid Waste Generation Rates of Study Area

Day	Waste (kg)		Total waste	% of waste generated	
	Organic	Inorganic		Organic	Inorganic
1					
2					
3					
4					
5					
6					
7					
Total					

D. Physical Composition of domestic Solid waste of the study Area:

Solid waste	Quantity by percent
Food Waste	
Paper	
Tin materials	
Plastic	
Others	

E. Intangible Benefits of the Project

I) Benefits regarding Health status

Diseases incidences before introduction of Barrel type composting_________

Type of disease:

- Dirrhorea,
- Dysentry,
- Skin diseases,
- Malaria/ Dengue,
- Others

Diseases incidences after introduction of Barrel type composting_____________

Type of disease:

- Dirrhorea,
- Dysentry,
- Skin diseases,
- Malaria/ Dengue,
- Others

ii) Benefit regarding Cleanness of the Area:

Improved Drainage system: ________ Drainage congestion: ___________

Clean road______ Dirty Road: ______________

Fresh air: ____________________ Bad smell: ________

ii) Economical Benefits of the users:

Cost for installation of plant _________ Lifetime of the plant: ___________

Money received by dwellers for collection of solid wastes _______

Production of compost from the Plant per month: ______________________

Sale price of compost per Month: ______________

Annexure B

Sample Questionnaire for Barrel Type Compost System
(Study Area —2)

A. General Information:

Study Area: ____________________________

Project Name: ____________

Location of the Slum: ______________________

Date: ________________________________

Respondent's name: _______________ Age: _______________

No. of Households in the study area: _____________

No. of population in the study area: _____________

No. of Families used per Barrel: ___________________

Size of Barrel: __________________

Total waste generated: ____________________ton/day

Solid Waste Generation Rates of Study Areas_________

Starting Date of the Barrel System Composting _____________

Duration of Barrel System Composting: _________________

B. Waste collection facilities of Dhaka City Corporation:

Before introduction of Barrel Composting System in the study area:

Collection system and disposal practices: ________________

No. of C.I sheet bins: __________

No. concrete bins: ___________

No. of demountable container: _______________

No. of street sweepers/ other staff: ___________

No. of van used / person involved for each van to collect the domestic solid waste________

No. trucks used for disposal of solid waste: ____________________

After introduction of Barrel Composting System in the study area :

No. of C.I sheet bins: __________

No. concrete bins: __________

No. of demountable container: ______________

No. of street sweepers/ other staff: __________

Total no. of Households covered by each barrel _____

Volume of collected Waste (m^3) by each family______________--

Wt of collected waste (kg) by each family____________-

Average waste kg/ house/day _____________

C. Waste Generation Rates of Study Area

Day	Waste (kg)		Total waste	% of waste generated	
	Organic	Inorganic		Organic	Inorganic
1					
2					
3					
4					
5					
6					
7					
Total					

D. Physical Composition of domestic Solid waste of the study Area:

Solid waste	Quantity by percent
Food Waste	
Paper	
Plastic	
Tin Materials	

E. Intangible Benefits of the Project

I) Benefits regarding Health status

Diseases incidence before introduction of Barrel type composting__________

Type of disease:

- Dirrhorea,
- Dysentery,
- Skin diseases,
- Malaria/ Dengue,
- Others

Diseases occurrence after introduction of Barrel type composting______________

Type of disease:

- Dirrhorea,
- Dysentery,
- Skin diseases,
- Malaria/ Dengue,
- Others

ii) Benefit regarding Cleanness of the Area:

Improved Drainage system: _________ Drainage congestion: ____________

Clean road_______ Dirty Road: _______________

Fresh air: ______________________ Bad smell: _________

ii) Economical Benefits of the users:

Cost of Barrel::________ Lifetime of each Barrel: ___________

Money received by slum dwellers for each Barrel Tk/kg:

Sale price of compost Tk/kg _______