İSTANBUL TECHNICAL UNIVERSITY ★ INSTITUTE OF SCIENCE AND TECHNOLOGY

COMPERATIVE EVALUATION OF DIFFERENT COMPOSTING TECHNOLOGIES FOR MUNICIPAL SOLID WASTES IN İSTANBUL

M.Sc. Thesis by
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Department : Environmental Engineering

Programme : Environmental Biotechnology

JANUARY 2009

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

İSTANBUL'DA EVSEL KATI ATIKLAR İÇİN FARKLI KOMPOSTLAŞTIRMA TEKNOLOJİLERİNİN KARŞILAŞTIRMALI OLARAK DEĞERLENDİRİLMESİ

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FOREWORD

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TABLE OF CONTENTS

Page

ABBREVIATIONS

AFP	: Air Filled Porosity
COD	: Chemical Oxygen Demand
EC	: Electrical Conductivity
EPA	: European Pollution Agency
EU	: European Union
MOW	: Municipal Organic Waste
MRF	: Material Recovery Facility
MSW	: Municipal Solid Waste
OFMSW	: Organic Fraction of Municipal Solid Waste
OM	: Organic Matter
PVC	: Perforated Polyvinyl Chloride
SAP	: Static Aerated Pile
SPCR	: Soil Pollution Control Regulation
TAP	: Turned Aerated Pile
TEC	: Total Extractable Carbon
TKN	: Total Kjeldahl Nitrogen
TMECC	: Test Methods for the Examination of Composting and Compost
TP	: Turned Pile
USA	: United States of America
VS	: Volatile Solids
WEC	: Water Extractable Carbon

LIST OF TABLES

Page

LIST OF FIGURES

Page

COMPERATIVE EVALUATION OF DIFFERENT COMPOSTING TECHNOLOGIES FOR MUNICIPAL SOLID WASTES IN İSTANBUL

SUMMARY

Composting is a widespread method used for biological treatment of municipal solid wastes. In the present study, composting process for municipal solid wastes in İstanbul was investigated. The main goal of this investigation was to evaluate and compare three different composting methods; in-vessel, turned windrow and aerated static pile. According to this aim, Kısırmandıra Compost and Recovery Facility was selected to investigate the in-vessel composting technology. Additionally, two compost piles were constructed at the facility, in open area, for evaluating turned windrow and aerated static pile methods. In all three systems, municipal solid waste with the same characteristic was used. This study was performed during the summer 2008 and composting process lasted for eight weeks at all systems. The composite samples were taken during the mixing operation in turned windrow and in-vessel system, and at the same time from aerated static pile for necesarry experiments. During this study, physical and chemical analyses were conducted to determine the characterization of the composting material each week. Finally, it has been proven in this study that composting of the municipal solid wastes can be achieved by simple and economical turned windrow method instead of composting in the reactor with high capasity equipments and appropriate space requirements.

İSTANBUL'DA EVSEL KATI ATIKLAR İÇİN FARKLI KOMPOSTLAŞTIRMA TEKNOLOJİLERİNİN KARŞILAŞTIRMALI OLARAK DEĞERLENDİRİLMESİ

ÖZET

Kompostlaştırma teknolojileri evsel katı atıkların biyolojik arıtımında yaygın olarak kullanılan bir metoddur. Bu çalışmada, İstanbul kenti evsel katı atıklarının kompostlaştırılabilirliği araştırılmıştır. Çalışmanın esas hedefi, üç farklı kompostlaştırma metodu olan; kapalı sistem, aktarmalı yığın ve havalandırmalı statik yığın sistemlerinin değerlendirilmesi ve birbirleri ile karşılaştırılmasıdır. Bu amaçla, Kısırmandıra Kompost ve Geri Kazanım Tesisi bir kapalı kompostlaştırma metodu olarak incelenmiştir. Bunun yanı sıra, tesiste açık alanda oluşturulan yığınlarda aktarmalı ve havalandırmalı statik yığın sistemleri değerlendirilmiştir. Her üç sistemde de aynı özellikteki evsel katı atık kullanılmıştır. Bu çalışma 2008 yaz döneminde yapılmıştır ve kompostlaştırma prosesi tüm sistemlerde sekiz hafta sürmüştür. Gerekli deneysel çalışmaların yürütülmesi amacı ile havalandırmalı statik yığın sistemi ile eş zamanlı olarak aktarmalı yığın ve kapalı kompostlaştırma sistemlerinden karıştırma esnasında kompozit numuneler alınmıştır. Çalışma esnasında, kompostlaştırılan evsel katı atığın karakterizasyonun belirlenmesi amacıyla haftalık olarak fiziksel ve kimyasal analizler yapılmıştır. Sonuç olarak, uygun yer seçimi ve yüksek kapasiteli aktarma ekipmanları kullanılarak reaktörde kompostlaştırma yerine çok daha basit ve ekonomik olan aktarmalı yığın yöntemiyle kompostlaştırmanın uygulanabileceği gösterilmiştir.

1. INTRODUCTION

1.1 The Meaning and Importance of the Thesis

Waste generation is continuously increasing because of the obligate consumption of people. Nowadays, human activities have reached such a degree of development that the recycling capacity of nature has been exceed, and the accumulation of residues has become a serious environmental and economical problem.

In Turkey, the municipal solid wastes contain plenty of organic matters, and are rich in nutrients that could be treated through composting and could be used for the soil improvement. Besides these advantageous characteristics, pathogens, heavy metals and other kind of pollutants could also stand in municipal solid wastes, which are harmful to the environment, ecosystem and human health. Serious damages would occur if these wastes have been applied to soil, without any proper treatment. Among the solid waste treatment methods, composting seems to be the most promising and clean technology. The organic substrates in solid wastes can be biodegraded and stabilized by composting, the final compost products may be applied to land as a fertilizer or soil conditioner. Additionally, municipal solid waste (MSW) composting is the decomposition of MSW with a variety of microorganisms, which utilize the organic matter as a carbon source, to make an earthy, dark, crumbly substance that is excellent for adding to plants or enriching the soil.

Selection of the suitable composting method is an important task in order to shorten the process time and thus reduce the composting area and production costs. In addition, this selection will also affect the quality of compost. In-vessel, turned windrow and aerated static pile systems are the most common technologies used for composting of municipal solid wastes. Therefore, these three methods were evaluated with in the context of the thesis. Characteristics of feedstock, desired compost quality and the performance of each system should be investigated carefully to make a decision about the composting system.

1.2 The Objective and the Scope of the Thesis

The purpose of this study was to investigate three different methods for composting of municipal solid wastes. In this study, in-vessel, turned windrow and aerated static pile systems were used to compost pre-treated municipal solid wastes. According to this objective, turned windrow and aerated static piles were prepared at Kısırmandıra Compost and Recovery Facility as an alternative for the current in-vessel (tunnel type) system.

The municipal solid waste with the same characteristic was used both at the pilot scale pile systems and at the facility itself. Additionally, the composting process started at the same time and lasted for 8 weeks in all methods. The samples were taken during the mixing operation at turned windrow and in-vessel system, in parallel with aerated static pile. Certain control parameters of composting process and the characteristics of final products were compared in order to determine the best composting technology.

2. LITERATURE REVIEW

2.1 Definition of Composting

Mixed municipal solid waste includes various discards from residential, commercial, and institutional sources. The largest components of mixed municipal solid waste are typically paper and paper products, leaves, brush and yard trimmings, wood, food scraps, glass, plastics, and metals. The composition of mixed MSW varies depending on the characteristics of the waste generators in the service area, but usually from about 50% to 65% is compostable when recovered by separation at a central facility. Mixed municipal solid waste will contain relatively fewer recyclables and a relatively higher fraction of compostable material when an aggressive source-separated recycling collection program operates in conjunction with mixed municipal solid waste collection [1].

In general, composting is an attractive treatment method for food wastes, which results with less environmental pollution and beneficial use of the final product [2]. Composting is a natural biological degradation process that is controlled and accelerated at a composting facility. Composting is the transformation of biologically decomposable material through a controlled process of biooxidation that results in the release of carbon dioxide, water, and minerals, and in the production of stabilized organic matter (compost or humus) that is biologically active [1]. Another definition is that, composting is the process of rapidly decomposition of organic matter using aerobic microorganisms at high temperatures (the active phase) followed by a more gradual decomposition of any remaining by-products at more moderate temperatures (the curing phase) [3].

2.2 The Process Steps at Composting Plants

Certain sequential steps must exist in any composting system regardless of its type. These are named as, the preparation of compost mixture, the composting, the screening and the storage. If mixed municipal solid waste is used as the feedstock, non-biodegradable components must be separated at the pre-treatment step. In addition, if necessary, bulking agent could be mixed with feedstock at this step. Composting phase is the actual operational phase of bacterial decomposition, during which organic matter is decomposed into humic substances and harmless material. This step is very significant for the whole process because the conditions within this step (temperature, moisture content, oxygen concentration, etc.) directly affect the system. After composting phase finishes, the mixture is screened to obtain final product, compost. In addition, size diversification of compost is provided at this step. At the final stage, composted material is let to get mature before marketing, and that is called curing stage. Since the area, that is needed for letting composted material to get mature needs to be considered, because this stage directly affects the area which is required for the whole process. Compost is stored at the composting area before marketing.

2.3 Environmental Factors

Since the nature of the reactions within the composting process is biochemical, the environmental conditions should be suitable for the microorganisms which are responsible for biodegradation. The duration of the composting can be reduced, hence the capital cost can be minimized; further a good product can be obtained after creating suitable environmental conditions for the bacteria. There are certain factors, which should be considered as important for the efficiency of a composting process, which are;

2.3.1 Temperature

Temperature is one of the important factors affecting microbial activity in composting. Composting is an exothermic process and produces relatively large quantity of energy. The rising temperature increases the efficiency of the thermophylic phase to a limit. In addition, the high temperature is necessary for the sanitation of the compost. However, above a limit, high temperature values will inhibit the process by collapsing the microbial community [4]. The temperature distribution in a compost pile is affected by moisture content, aeration rate, atmospheric conditions and nutrients. For instance, one turning causes about 5^{o}C drop at the temperature of composting material [4].

It was indicated that maximum CO_2 production occurred at 60-65^oC for MSW (mixed garbage and refuse). In addition, it was reported that maximum decomposition of MSW occurred at temperatures 65-70^oC. Other researchers found that maximum oxygen uptake rates occurred between 45-66^oC [5].

High temperatures inhibit microbial growth through slowing down the biodegradation of organic matter. Only few species of thermophilic bacteria show metabolic activity above 70ºC. For the most efficient operation, the temperature in the compost should range between 55 and 65^oC, but not above 80^oC. The time-temperature relationship affects the rate of decomposition of the organic matter and therefore it is important for the production of a stable and mature product for consumer use. For sanitation purposes, temperatures above 55^oC for 15 days and five turnings or two turning with temperatures above 65^oC must be maintained during the composting period [6].

2.3.2 Moisture content

Moisture content is a measure of the amount of moisture present in a compost sample and is expressed as a percentage of fresh weight. Moisture is required for the growth and multiplication of the microorganisms within the compost unit. Depending on the components of the mixture, the initial moisture content can range from 55-70%. If moisture content is below 20%, the rate of decomposition decreases rapidly; if it is higher than 70%, undesirable anaerobic conditions develop because the pores are not open for oxygen diffusion (penetration) to reach microorganisms [7]. In another source, minimum value is given as 20% and maximum value as 40% [5]. Under these conditions, microbes become less efficient, the compost loses heat energy, and chemical pathways are altered, leading to the production of odors. Therefore, moisture should be added often during composting to support an active process [3].

Also, moisture in the composting process can affect microbial activity and thus influence temperature and the rate of decomposition. In addition, moisture can affect the composition of the microbial population. Moisture is produced as a result of microbial activity and the biological oxidation of organic matter. On the other hand, water is lost through evaporation. Based on a work which involves using a laboratory composter, it was reported that water released through microbial activity was greater than water lost through evaporation [5].

Moisture content also affects the temperature values. The highest temperature was achieved at the moisture content of 55-69%. Higher moisture values results with lower temperatures and lower ones cause intermediate temperature values [5].

2.3.3 Carbon/Nitrogen ratio

The Carbon/Nitrogen (C/N) ratio is not a test within itself; it is rather a test for organically bound carbon and for total nitrogen. The C/N ratios during composting affect the process and the product. Bacteria, actinomycetes, and fungi use available carbon for energy which they require to grow and reproduce, and nitrogen to build protein and genetic material [8].

As the microbes consume carbon, they convert it to carbon dioxide gas, which is eventually vanished. This causes the C/N ratio to fall as the compost process progresses. By the time the compost becomes ready to use, its C/N ratio will have decreased considerably, typically to between 10:1 and 20:1 [3].

Higher C/N ratios slow down the microbial degradation and lower C/N ratios result in the release of nitrogen as ammonia. At high C/N ratios (approximately 30:1 or greater) nitrogen may be temporarily tied up (immobilized) by microbes during the decomposition process. Because this deprives the amount of nitrogen which is required for plants to nourish, additional fertilizer is required. Products with C/N ratios below 15:1 are likely to supply at least some soil nitrogen. It is important to understand that immobilization is a temporary phenomenon, and that immobilized nitrogen will eventually be released in plant-available forms [3].

2.3.4 pH

The literature indicates no pH control problem during composting process as long as the system is kept under aerobic conditions. However, pH is an important process evaluation (control) parameter during the decomposition. To achieve an optimum aerobic decomposition, pH should remain around 7 and 7.5. To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above 8.5 [9]. When compost is used as a soil amendment, it is generally desirable to have the final soil/compost mixture fall between pH 6.5-7.5 [3]. The pH value of compost is important, since applying compost to soil may alter the soil pH and therefore have an effect on the availability of nutrients to plants [10].

2.3.5 Conductivity

Conductivity is the measure of a solution's ability to carry electrical charge, that is, a measure of the soluble salt content of compost. The salt content of compost is due to the presence of sodium, chloride, potassium, nitrate, sulphate and ammonia salts. Some soluble salts may be detrimental to plants whereas, other plant nutrients supplied to plants exist in salt form and are essential for plant growth. Usually compost does not contain quantities of soluble salts which cause concern in landscape applications. Though excessive amounts of soluble salts in compost used in growing media or applied to the land may inhibit crop growth and affect crop yield. It is reported that the recommended range for conductivity in compost is between 2.000-6.000 µS/cm [10].

2.3.6 Microorganism

In the beginning phases of the composting process, mesophilic bacteria are the most prevalent (30-45^{o}C). After the temperatures in the compost mixture rise, thermophilic bacteria become predominate (45-90^{o}C), leading to thermophilic fungi, which appear after 5 to 10 days. In the final stage or curing period, actinomycetes and molds appear. The death of pathogens is a function of time and temperature [8].

During the aerobic composting process, a succession of facultative and obligate aerobic microorganisms is active. As a biological process, composting involves a myriad of microorganisms. These organisms decompose organic matter and organic compounds. Several important factors affect the microbiological population. These parameters include oxygen, moisture, temperature, nutrients and pH. Because of complex nature of organic matter and many organic compounds, both natural and xenobiotic, many microbes and other organisms are involved in the decomposition process [5].

2.3.7 Aeration

During aerobic metabolism, sufficient supply of oxygen is essential. According to different sources aerobic microbial activity can be maintained with oxygen concentration between 5 to 15% [4]. Proper aeration is needed to control the environment required for biological processes to thrive with optimum efficiency. A number of controllable factors are involved. If compost particle sizes are too fine, air will not be able to enter and diffuse within the pile, a condition leading to odors and to the development of phytotoxic contaminants.

Some compost operations, called turned windrow systems, physically turn the compost to promote aeration. Turning the pile restores the pore spaces in the material so that cooler fresh air can enter the inside of the pile to replace the hot carbon dioxide and water vapor escaping from the top. In another common approach, called static pile systems, air is physically forced into or drawn out of the pile. In such a process which the particles remain stationary, the layer of air surrounding the particles is constantly replaced by air forced through the composting mass. While static pile systems do not need to be turned, it is important to note that the energy required to supply the compost with air is greater than the energy required to operate turned windrow systems [3].

2.3.8 Heavy metals

Depending on the feedstock, heavy metals (copper, zinc, lead, cadmium, mercury, nickel, chromium) and toxic elements (selenium, arsenic, molybdenum) may be found at elevated levels in compost and thus create an environmental concern essentially related to crop quality and human health. As the composting process proceeds organic matter content decreases while the concentration of heavy metals remains the same thus increasing their concentration in compost. There is no consensus regarding the exact uptake of heavy metals by plants, the accumulation of heavy metals in soils and the consequences once they enter the food chain. However, it would appear that metal uptake depends on the soil type, the plant species and the quality of the compost applied to the soil. The European Union (EU) Biowaste Directive stipulates that heavy metal concentrations must be reported in mg/kg normalized to an organic matter of 30% because approximately 30% of organic matter in the feedstock is lost during the composting process concentrating the amount of heavy metals in the compost [10].

2.3.9 Available nitrogen as NH_4 - N

Highest concentrations of NH_4-N are produced in the first few weeks of composting. In fact, the ratio of organic and inorganic forms of nitrogen has been used as a maturity index. At the end of the process a concentration of NO_3-N greater than the concentration of NH_4-N would indicate that the process took place under adequate conditions of aeration and that mature compost was produced.

Levels of NH_4-N over 200 mg/L in compost are very high for use in growing media as high concentrations of NH_4-N in compost may impede seed germination and damage seedlings and soil fauna [10].

2.3.10 Phosphorus

Phosphorus is also an important nutrient for plant growth. Total phosphorous is usually expressed in terms of percentage concentration per dry weight. Available phosphorus is usually expressed as PO_4-P in mg/L on a fresh weight basis. Phosphorus content generally increases during the composting process as a result of the concentration effect due to higher losing rate of carbon. The range of total phosphorus is usually between 0.4 - 1.1 %, dry wt for biowaste and green waste compost and the typical range of PO_4-P is between 50-120 mg/L, fresh weight [10].

2.3.11 Potassium

Potassium is a very abundant nutrient in plants. Potassium in its available form in compost exists as K_2O. The amount of potassium in compost depends on the feedstock but also on the composting process. Compost usually does not contain a great concentration of potassium because due to its high water solubility it can be easily leached from the feedstock during the composting process. This may occur especially in uncovered windrows. Potassium content generally increases during the composting process as a result of the concentration effect due to higher losing rate of carbon. The typical range of total potassium in biowaste and green waste compost is between 0.6-1.7%, dry wt and that the typical range of available potassium in this compost is between 620-2280 mg/L, fresh weight [10].

2.3.12 Calcium and magnesium

Calcium and magnesium act as bases when they exist as oxides, hydroxides and carbonates. Compost containing these bases, when applied to soil, may counteract soil acidification and vary pH levels making soil nutrients more available to plants. Compost can also be used to replace peat and be of much benefit in container production of crops, as peat does not contain adequate calcium. The typical range of calcium in compost is between 1.0-4.0%, dry wt and the typical range of magnesium is 0.2-0.4%, dry weight [10].

2.3.13 Physical properties

Bulk density, free air space, pore space and water holding capacity are important parameters for both compost mixture and final compost product. Bulk density is defined as weight per unit volume of compost, calculated and reported on an oven dry weight basis (70±5°C), with $w\ v^{-3}$ unit. Free air space is the air-filled pore volume of an as received compost material, expressed by unit $\%\ v\ v^{-1}$. Pore space is the sum of water-filled pore volume plus air-filled pore volume relative to the overall volume of the compost ($\%\ v\ v^{3}$). Finally, water holding capacity is the percentage of water filled pore volume relative to the total volume of water saturated compost, with the unit of $\%\ w\ w^{-1}$. Free airspace for composting should be greater than 60% at the beginning of the process, and at least 35% during curing. Free airspace less than 60% initially and 35% during curing inhibits air flow through the pile and will result in accumulation of carbon dioxide and consequent formation of anaerobic conditions; the latter lead to odors from volatile organic acids, sulfides, and amines formation [1].

2.3.14 Maturity and stability

Maturity refers to how free the compost is of organic phytotoxic substances that can adversely affect seed germination and plant growth. Physical characteristics that reflect mature compost are a dark brown or black color and a soil-like, pleasant smell. Products with putrid odors are likely immature and should be avoided.

Compost stability refers to the resistance of organic matter to further degradation. Stability describes the amount of decomposition activity in compost. Stable compost is well decomposed, consumes little oxygen and generates little carbon dioxide or heat. Unstable compost heats up significantly if rewetted and stirred. Different methods for measuring stability, based on physical (temperature, aeration demand, odor and color, optical density of water extracts), chemical (volatile solids, C/N ratio, COD, polysaccharides, humic substances, etc.) and biological (respiration measured either as O_2 consumption, CO_2 production or heat generation, enzyme activities, ATP content, seed germination and plant growth, etc.) characteristics of composts have been proposed, but none has found universal acceptance.

2.4 Usage of Compost

High quality compost enhances the physical, chemical, and biological properties of a soil. It can successfully be used as a soil amendment, turf topdressing, mulch, erosion control agent, and water quality enhancer. Compost increases the water and nutrient-holding capacity of coarse-textured (sand-based) soils and improves the soil structure, infiltration, and drainage of heavy textured (clay-based) soils. It can also significantly increase the organic material content of a soil as well as its biological activity. Recent research indicates that some composts help suppress certain fungal diseases, as well.

When applied in adequate concentrations, compost can significantly improve the texture of sand and clay-based soils as well as the overall structure of highly compacted and poorly aerated and drained soils. Improvements in soil structure occur in two ways. First, the compost itself contains particles that improve soil tilth and porosity. To result in immediate improvements, approximately 30% of the final soil volume should be amended with high quality compost. A clay-based soil amended in this way will lead to more productive and healthy plant growth for less cost than amending the same soil with the necessary 45% sand. Second, composts may also be effective at lower application rates, although changes will be gradual, rather than immediate, and repeated applications may be necessary before observable differences are noted. As compost decomposes in soil, it encourages the formation of soil aggregates. These resulting aggregates are composed of parent soil particles and are not merely decomposed compost. Because composts encourage the formation of soil aggregates, they can be particularly useful in restoring a crumb-like structure where construction activities have damaged and altered the natural structure of the soil.

Composts improve soils and promote plant health, particularly in poor quality, problem or damaged soils commonly encountered in landscapes. Within and on the soil, compost is used to:

- Improve structure of soil; water holding capacity, nutrient holding capacity, aeration of soil and drainage in heavy soils,
- Prevent or decrease erosion,

• Decrease the need for chemical fertilizers,

• Remediate damaged soils,

• Replenish trace and macronutrient stores,

• Increase the activity and diversity of soil microorganisms,

• Filter storm water runoff [11].

2.5 Regulations In Turkey

Some properties of the finished compost should be satisfied by the regulations before applying to the land. In Turkey, Soil Pollution Control Regulation (SPCR) is in use to control the characteristics of compost [12].

According to SPCR, the compost product should provide the following criteria:

▪ If C/N ratio is higher than 35, nitrogen should be added to compost reactor in order

to provide optimum conditions for composting process.

▪ The organic matter content of compost should be at least 35% of dry solid.

▪ Moisture content of marketed compost should not exceed 50%.

▪ Inert materials in compost should not exceed 2% of total weight in the marketed compost.

▪ The heavy metal content of produced compost should be determined in every 6 months by analyzing lead, cadmium, chromium, copper, nickel, mercury and zinc concentrations.

▪ The soil and compost samples should be taken as appropriate to the sampling techniques and should represent all compost mass.

▪ In case the heavy metal contents of the soil exceed the values given in Table 2.1, compost should not be applied to this soil.

▪ If compost is added to agricultural land annually, limit values for quantities of heavy metals should not exceed the values based on a 10-year average are given in Table 2.2.

Table 2.1 : Limit values for heavy metals in soil [12].

Parameter (mg/kg in oven dry soil)	pH 5-6	pH>6
Lead	50	300
Cadmium	1	3
Chromium	100	100
Copper	50	140
Mercury	1	1.5
Nickel	30	75
Zinc	150	300

Table 2.2 : Limit values for heavy metals, based on a 10-year average [12].

Parameter (kg/da/year, in dry matter)	Limit Values
Lead	1500
Cadmium	0.15
Chromium	1500
Copper	1200
Mercury	10
Nickel	300
Zinc	3000

2.6 Composting Methods

There are some general guidelines that can be applied to maximize the potential for a composting system to be efficient, produce a product of suitable quality, and be cost effective. Firstly, the composting system has to be technically simple and applicable. Secondly, the composting system used to be readily adaptable to the labor and economic conditions [13].

Three different composting processes are typically used: turned windrow, aerated static piles and in-vessel composting. The proper approach depends on the time to complete composting, the physical and handling characteristics of the materials and volume to be decomposed, space available, the availability of resources (labour, finances, etc.) and the quality of finished product required. Each method has distinct operational characteristics such as compost pile configuration and level of management and equipment required.

2.6.1 Turned windrow

Turned windrow composting consists of placing a mixture of raw materials in long, open-air piles or windrows that are agitated or turned on a regular basis. The piles are turned frequently to introduce oxygen into the pile, ensure that adequate moisture is present throughout the pile, and ensure that all parts of the pile are subjected to high temperatures. Windrow composting is a good method for large quantities of materials, especially where machinery for building and turning is available. Composting process is aided only by watering and mechanical turning for aeration. Windrows can be placed directly on soil or paved area. The land requirement for a windrow composting facility depends on the volume of material processed. This method is simple, non-intensive, has a very low capital cost. The result can be a quick return of good quality compost.

The size of a windrow will depend on the nature of the material being composted, and the reach of the machinery, or people available for making and turning it. If the windrow is too large, anaerobic zones occur near the center of the pile. Windrows that are too small may not achieve temperatures high enough for composting. Compost is formed into long piles, which are typically 1.5 to three meters high, three to six meters wide, and up to 100 meters or more in length. The height of the pile depends on the turning equipment which will be used. The width of the pile is limited at these values to obtain sufficient oxygen amount through the pile and the length of the pile is indeterminate [14].

Windrows should be turned regularly as can be seen from Figure 2.1, at least in the early stages, to ensure that all material spends some time in the warm moist centre of the heap. Turning mixes the composting materials, rebuilds the porosity of the windrow, and releases trapped heat, water vapor, and gasses. Turning improves passive air exchange. It also exchanges the material at the windrow surface with material from the interior. Turning also breaks composting materials into smaller particles, so that increase their active biological surface area. A well-aerated and properly mixed compost pile should not produce unpleasant odors. Structural strength and moisture content of the material are important factors in determining the frequency of turning. Turning should be more frequent when the moisture content of the pile is too high so as to minimize the development of anaerobic conditions. Also, high-rate composting requires frequent turning because, rate of degradation is proportional to frequency of turning. The drier the material, the less frequent turning will be required. If the composting mass gives off objectionable odors, it shows that anaerobic conditions have occurred and therefore additional turning is required.

Figure 2.1 : Mixing operation of turned windrow.

Generally, all of the materials handling and pile building can be accomplished with a front-end loader. The windrows can be aerated mechanically by turning with a front end loader for smaller operations or using a windrow turner [15]. Following the composting period, the windrows are broken down and reconstructed into curing piles for additional aging and drying of the material. Curing compost stabilizes it to prevent odors or other nuisances from developing while the material is stored. After curing, the compost can be screened to improve the quality of the final compost product, depending on the requirements of the compost buyer or consumer.

In areas that receive heavy rainfall, it may be necessary to cover the windrows so they do not become too wet; however, the cost of this may be prohibitive for certain operations. Alternatively, maintaining a triangular or dome shaped windrow is effective for shedding excess rain or preventing excess accumulation of snow in the winter. In windrow composting, the raw material is mixed and placed in rows, either directly on the ground or on paved or concrete surfaces. During the active compost period, the size of the windrow decreases.

Advantages and disadvantages of turned windrow composting is listed as bellows [16];

Advantages

- Easy for turning, especially with machinery,
- Good for large quantities; only limitation is land,
- Easy to implement and operate,
- Handles a large volume of material,
- Low capital costs,
- Better homogeneity of the final product,

- Less equipment and maintenance is needed than other composting methods (low technology).

Disadvantages

- Covering may be needed,
- Mechanical operations in adverse weather require good ground surface,
- Requires a lot of land for composting,
- Attracts scavengers,
- Often produces odors,
- May require processing of rainwater runoff,
- High water evaporation from piles,
- Compost can become anaerobic in rainy conditions.

2.6.2 Aerated static pile

Aerated static piles are supplied with oxygen via blowers connected to perforated pipes or grates running under the piles (Figure 2.2). Forced aeration system is used in aerated static piles, by using a blower to supply air to the bottom of the pile. Aerated static piles are not turned during active composting. This system of aeration requires electricity at the site and appropriate ventilation fans, ducts and monitoring equipment. The monitoring equipment determines the timing, duration and direction of air flow. Air flow requirements change depending upon the materials composted, the size of the pile, and age of the compost [15].

In a static system, air is either forced upwards through the composting mass or is pulled downwards and through it. The forced aeration system involves an initial period of drawing air into and through the pile, followed by a period of forcing it upward through the pile. The air that leaves the system at the suction step is discharged directly into environment or is forced through the finished compost pile or biofilter.

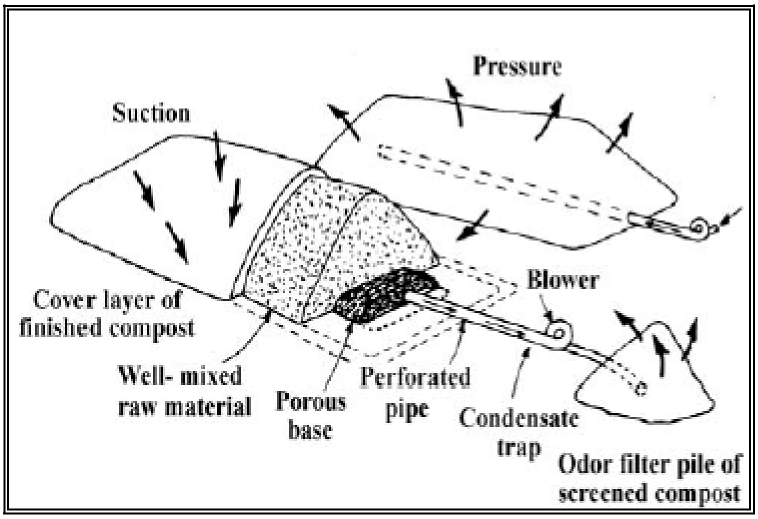

Figure 2.2 : Schematic view of an aerated static pile system.

Aerated static piles can produce excellent compost, by having adequate porosity for the initial material and providing adequate air flows uniformly during the active compost period to all areas of the pile. To avoid the anaerobic conditions moisture content of composting material should be in the range of 40-55% in aerated static pile.

The construction of the pile proceeds by placing perforated pipes on the compost pad. The perforated pipes are connected to a blower. Then, the composting material is replaced over a base of porous material such as wood chips. This layer is provided to facilitate the movement and uniform distribution of air during composting process. Forced aeration provides a direct control of the compost process and permits larger piles. Piles are formed typically 1.5-2.5 meters high, three to six meters wide, and 20-30 meters or more in length.

Aerated static pile method is suitable for the material that has relatively uniform particle size which do not exceed 3.5-5 cm in any dimension. Because, a mixture of particles that are too large can result in uneven distribution and movement of air through the pile, and this situation promotes short-circuiting and anaerobic conditions [13].

Advantages

- It is a space efficient method,
- They can be larger than windrows because aeration is forced rather than passive,

- Space is not needed for turning equipment,
- The increased aeration shortens the time required for composting,
- Elevated temperatures increase pathogen kill,
- Require lower capital investment than in-vessel operations that employ forced aeration.

Disadvantages

- Short-circuiting of the air in the pile can occur, which causes uneven composting and an inconsistent product.
- The pipe openings may become blocked, preventing aeration. This is difficult to correct during composting because the pipes are buried at the base of the pile.
- Installation, removal, and damage to the pipes during pile formation and cleanup can be a problem.
- Some capital investment is required to purchase the necessary equipment for blowers and pipes.
- Forced aeration tends to dry the compost pile and, at excessive amounts, it will prevent stabilization of the compost.

2.6.3 In-vessel

In general, in-vessel systems can be divided into two main types; vertical and horizontal. Horizontal systems can be further subdivided into four groups; channels, cells, containers and tunnels. Schematic view of tunnel type composting is given at Figure 2.3. In-vessel composting is the production of compost in container, building or vessel using a high-rate controlled aeration system, designed to provide optimal conditions. Aeration of the material is accomplished by continuous agitation using aerating machines which operate in concrete bays, and/or fans providing air flow from ducts built into concrete floors. In-vessel composting represents a high technology, low labour approach, high capital-intensive and producing a uniform product.

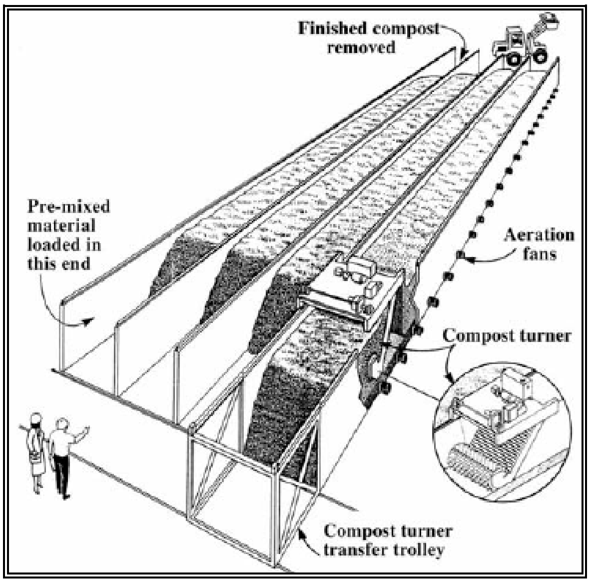

Figure 2.3 : Schematic view of tunnel type in-vessel system.

In-vessel composting method enables the odor control and treatment by biofilters. It is known that various odor control measures, such as frequent turnings, are used in conjunction with most composting operations. Frequent turnings help reduce odor producing anaerobic pockets in the composting MSW by introducing oxygen and remixing pile ingredients.

In-vessel systems require less space and provide better control than windrows for handling mixtures, and for manipulating gas emissions and polluting leachates [2]. Another advantage is higher process efficiency resulting in a decreased number of pathogenic microorganisms, and more valuable final product [17].

Advantages

- They are generally located indoors or under a protective cover, which reduces the vulnerability of the compost material to the effects of weather as well as the potential for odor problems.
- Good odor control within the composting facility is possible by diluting the inside air with air from the outside or by directing odors to a treatment system.
- They are space efficient. Rectangular agitated bed or channel composters are space efficient because they use an automated turner that is mounted on channels. Bins and silos are space efficient because their containment walls allow the material to be stacked higher than static piles or windrows

.• Except for bins, these systems require less labor than windrows because they use an automated turning process or a self-turning mechanism.

Disadvantages

- The high capital, operation and maintenance costs associated with the required automated turners.
- Breakdown can delay composting if equipment repairs cannot be made quickly.
- Bins filled too high can result in compaction and inadequate aeration.
- These systems have less flexibility than other systems, particularly concerning location and equipment.

Comparison of windrow, aerated static pile and in-vessel systems is summarized at Table 2.3.

Table 2.3 : Comparison of composting processes.

Item	Windrow	Aerated Static Pile	In-vessel
Capital costs	Generally low	Generally low in small systems, can be high in large systems	Generally high
Operating costs	Generally low	High	Generally low
Land requirements	High	High	Low
Control of odors	Depends on feedstock	Can be controlled	Good
Potential operating problems	Susceptible to adverse weather	Potential for channeling or short circuiting of air supply	Potential for short circuiting of air supply
Control of air	Limited unless forced aeration is used	Complete	Complete
Operational control	Turning frequency, Amendment	Airflow rate	Airflow rate, agitation, amendment

2.7 Recent Studies

Çekmecelioğlu et al. evaluated windrow composting using composting mixture consists of 50% food waste, 40% manure, and 10% bulking agent and then compared with the previous study done by using the same mixture but in-vessel system. Two windrow construction methods were used: conventional layering and mixing. In the layering method, the mulch hay was layered first in a farm manure spreader. The food waste was then added as the second layer, followed by manure and wood shavings on the top. The whole mixture discharged outside to form a long pile. Finally, the pile was turned and formed into a windrow. In the mixer method, each feedstock was fed into a vertical auger mixer, once the required amount was weighed and mixed, it was discharged to form the windrow pile (11m long, 2.5m wide, and 1.2m high). Two replicates were used for both methods (layering and mixing). The composting period was about three months. There was no significant difference between spreader and mixer piles as the peak temperatures and moisture losses. Moisture loss was found to be slower in windrows than the in-vessel system because of the differences in the nature of the aeration. All windrows showed a similar decrease in C/N values; 36.2 and 37.1% for spreader windrows and 26.1 and 36.5% for mixer windrows. Volatile solid loss for the spreader windrows (52.6 and 47.4%) was significantly higher than the mixer piles (32.6 and 34.5%). When compared to the results of the in-vessel data, in which C/N and volatile solids reductions were 6.2% and 15.9%, windrow composting yielded a more stable final product. It is indicated by higher reductions of C/N and volatile solids under higher temperatures and a longer period of composting. The pH increased gradually from 4.5–5.0 to 8.0–8.1 in spreader windrows and from 4.2–4.7 to 8.2 in mixer windrows. The average initial and final bulk densities for spreader windrows were 660 and 684 kg/m^3, and for mixer windrows, 599 and 648. In conclusion, the optimum compost mixture determined from in-vessel data was composted better in windrows than the in-vessel system under higher temperatures and longer retention time, which both contributed to higher reduction of C/N and volatile solids [17].

Kim et al. evaluated the performance of pilot-scale in-vessel composting for food wastes treatment. Composting material was prepared by mixing food waste with bulking agent (wood chips) in the ratio of four to three on a wet weight basis.

Composting process continued for 30 days in composting bay which has a total volume of 324 m^3. Forced aeration at a rate of $0.15 m^3/m^3$ min was supplied to maintain adequate oxygen level and temperature inside the compost pile. Bulk density, moisture content, pH, temperature and off-gases were evaluated as operational indices. Bulk density of the composting materials was 750 kg/m^3 at the beginning of the process and decreased to 390 kg/m^3 until day 12. Moisture content was also decreased from 58% to 31%. It shows that bulk density decreases with increasing solids contents and decreasing water content. Initial pH was 5 and it increased to 8.6 though the process. The temperature fluctuated at around 60^{o}C. At the beginning of the composting process O_2 concentration decreased as against to the increase in CO_2 concentration. As a result of organic decomposition, NH_3 release increased with time. Organic matter and carbon-to-nitrogen ratio (C/N) were investigated as compost maturity indices in this study. Volatile solid content in the composting material was initially 82% and reduced to 73% at the end of the composting period of 30 days, implying 11% VS reduction. Initial C/N ratio of the feed mixture was 24, and it reduced to 17 in the first 12 days period and remained at this value. Electrical conductivity and heavy metal content of the final compost were analyzed to evaluate the quality of compost. Overall electrical conductivity was in the range of 2 to 3 dS/m during composting which seems to correlate with recent studies. The concentrations of heavy metals studied increased after composting. This observation might be due to the decrease in the organic matter content of the composting materials. As a result, the final compost produced in this study was suitable for its agricultural application in terms of compost quality parameters [2].

Tognetti et al. studied the effects of different municipal organic waste (MOW) management practices on organic matter stabilization and compost quality. Four static piles (8.5 m^3) were prepared with; shredded MOW (1–3 cm particle size); shredded MOW + woodshavings (1:1 v/v; MOW volume was measured before shredding); non-shredded MOW and non-shredded MOW + woodshavings (1:1 v/v). Piles were turned with a front-end loader at 30, 50, 70, and 130 days after establishment. The four composting piles achieved thermophilic temperatures (>45 ^{o}C) shortly after pile establishment and maintained for 85–95 days, and gradually descended to ambient values. High temperatures reflect the high proportion of degradable substances. pH values were alkaline, ranging between 7.8 and 8.9; the lowest values corresponded to woodshavings addition treatments and the highest to non-shredded compost. Electrical conductivity varied between 1 and 3 mS/cm, decreased in all treatments. Values of pH and EC achieved at composting process were within the range acceptable for plant growth. The highest OM values corresponded to the shredded + woodshavings treatments and in all treatments it decreased over time due to the mineralization of OM by microorganisms. Total N concentrations in composts generally showed an overall decrease throughout the process, because of the loss by ammonia volatilization, which is favored by high temperature and pH values. The highest initial concentrations of NH_4^+-N corresponded to the non-shredded + woodshaving treatments and the lowest to the shredded treatment. In all treatments, NH_4^+-N decreased during the process. Conversely, nitrate (NO_3^--N) concentrations increased throughout the process, with greatest values in the shredded compost. Decreases of NH_4^+-N concentration led to increases of NO_3^--N through nitrification, when temperatures became more adequate for this process. Production of CO_2 decreased rapidly between days 50 and 90, reaching stable values thereafter. It reflects a clear OM stabilization during the composting process. Treatments which contained woodshavings also had higher CO_2 production rates compared to the same treatment without woodshavings. Shredding MOW accelerated microbial activity, resulting in a constant decrease of respiration. Shredding led to a more stable and mature product, while non-shredded treatments exhibited slower and less continuous degradation processes. Shredding or adding woodshavings led to products richer in OM, and combining these practices resulted in the highest OM values. Although woodshavings reduced total N and available nutrients, they decreased pH and EC in the finished composts [18].

Avnimelech et al. studied the effects of temperature and oxygen profiles to the composting process in windrow systems. The municipal solid waste from a non-separated collection is first screened to remove large particles, than mixed with yard trimming and wood. The mixture is introduced into a Dano drum for 24-48 hours. The material going out is screened to remove inorganic substances. Windrows are constructed with the remaining material which has a moisture content of 40%. Windrows were 8-10 meters long, 4 meters wide and 2 meters high. Temperature and moisture content is determined at different depths. Temperature in the outer 10 cm layer was in the range of 35-45^{o}C, because it was affected by the ambient air temperature. At the depth of 30 cm, temperature was around 65°C and at 50 cm it was higher than this value because not affected from outside temperatures. The maximum temperature is measured at a depth of 50 cm because the outer layers of the pile were loosing heat and becoming cooler. Also, at deeper distances there was a decrease in temperature values. It is due to the low rate of heat production and limited oxygen supply to these layers. Oxygen concentration decreased after each mixing and lower values observed at deeper layers. When oxygen was diffusing though the inner layers, it was consumed and can not reach the core zone. The limiting factor for organic matter decomposition and heat production in the core of active windrows seems to be oxygen supply. At depths higher than 50-70 cm oxygen supply poses a serious limitation to the composting process. Changes in temperature and oxygen profiles are related to each other in windrow systems. When temperature rises too much, metabolic activity will slow down and less oxygen will be consumed. Temperature and oxygen concentration should be carefully monitored in windrow systems [4].

Day et al. investigated the chemical and physical changes in the composting material, along with the emissions of volatile compounds. The composting material was consisting of food residues, yard trimmings, agricultural wastes and wood wastes. The mixture was loaded into a concrete composting bay of 80 meters long and two meters square cross section area. Process was continued for 49 days. The initial moisture content of feed was 64%, it has a C/N ratio of 24.6 and bulk density of 0.59 g/ml. Moisture content declined from 65% to 58% after four weeks, and dropped to 30% at the end of the process. Initial bulk density was 0.59 g/ml, as the process continued it was decreased to 0.35 g/ml by the end of the composting period. Inorganic content of the feed increased through the process, because they were unaffected by the biological action and remain same after composting period. The net loss in organic matter corresponded to increase in the inorganic content of the material. The initial value of 20.5% increased to 34.45 by the 49 days of composting period. C/N ratio of the composting material fell from a value of 24.5 at the beginning to a value of 13.6 at the end. There was not a significant change of nitrogen concentration but some ammonia was released through the process. The initial composting material was slightly acidic with an initial pH of 6.2. During the first weeks there was a decrease of pH value, but after that it increased to 7.5 and it was maintained for the remainder of the composting period. The temperature was increased to 68°C, and it remained above 60°C for several days than declined until the process was stopped [19].

Rasapoor et al. studied the effects of different aeration rates and aeration patterns on the composting of municipal solid wastes. Composting piles were 3 m wide, 6 m long and 1.6 m high. For a better air distribution, perforated polyvinyl chloride (PVC) pipes of 90 mm diameter were laid along the beds of the heaps. Aeration rates of 0.4, 0.6 and 0.9 L min^{-1} kg^{-1} were used in this study. The maximum temperature values were obtained earlier at high aeration rates, besides this thermophilic phase lasted shortly. High rate of aeration cooled the pile sooner. Medium aeration rate showed higher increase in the percentage of nitrogen and higher decrease in total organic carbon. In all piles, the C/N ratio decreased due to mineralization of organic matter. Low and medium aeration rates decreased C/N values to optimum ranges that are needed for mature compost. Higher aeration rates result with higher pH and electrical conductivity values during composting. Aeration rates may cause some increases in the percentage of potassium, while they have little effect on phosphorous concentration. Lower aeration rates had a significant effect on the ammonium and nitrate formation. Low and especially medium aeration rates had better impacts on the composting process. It was concluded that starting at a rate of 0.6 L min^{-1} kg^{-1} during first 2 months of the process and continuing at a rate of 0.4 L min^{-1} kg^{-1} until the end of composting process would result in lower energy consumption [20].

Ruggieri et al. studied the performance of turned pile (TP), static forced-aerated pile (SAP) and turned forced-aerated pile (TAP) at field-scale in the composting of source-selected organic fraction of municipal solid waste (OFMSW). Piles were built with a trapezoidal shape with 4m width, 2m height and 30–40 m length. OFMSW was mixed with wood chips at a volumetric ratio of 1.5:1 (OFMSW: bulking agent). In both turned pile systems (TP and TAP) turning was performed daily in the first two weeks, and every 2–3 days after two weeks and until the end of the process. Forced air in both aerated piles (TAP and SAP) was provided in cycles of 5 min on and 30 min off (fixed rate) during the first 50 days of process and 5 min on and 60 min off during the remaining period (total composting time was 90 days). Air flow was provided at a rate of 1 1 min^{-1} kg [volatile solids $\{VS\}]^{-1}$ to ensure aerobic conditions. A blower (positive pressure mode) was used, connected to two perforated

PVC pipes of 100mm of diameter embedded in the pile base. TP presented higher temperature values than both aerated piles. Temperature above 55 ^{o}C for a total period of two weeks and five turnings were fulfilled in TP and TAP, but not in SAP. Oxygen content of TP was lower than the recommended value of 5% unlike the aerated piles. Moisture content of TP was maintained at 40% but in SAP watering operations were not efficient since homogenisation of the material is not provided. In the case of SAP, severe drying and compaction phenomena occurred in the pile and in consequence the material formed large aggregates. AFP (air-filled porosity) was within 70–80% throughout the process for all piles. Both the turned systems presented a major OM reduction reflecting a more effective biodegradation process. On the contrary, in the SAP the decrease in OM content was very slow or negligible, thus indicating that the process was less effective. OM reduction in TP was higher than the others, in relation to the static respiration index (SRI), this reflected the evolution of the biological activity and the material stability. SRI increased at the beginning of the process at the high rate decomposition stage and then decreased through the end of the process. Decrease of SRI correlates with the increase in stability. Aerated systems showed higher SRI and low maturity grade at the end of the composting process. The most expensive system was TAP while TP and SAP accounted for 69 and 59% of TAP investment cost, respectively. TAP would also represent the highest operation cost, including labour, maintenance, energy, etc. Thus, according to the results obtained, the additional investment required for forced aeration in turned systems is not necessary. On the other hand, turning appears to be essential for pile composting of heterogeneous materials. Consequently, of the three pile systems considered, TP could be recommended for OFMSW composting [21].

Donahue et al. evaluated in-vessel system for composting of food wastes. In this study, different bulking agents were added to food wastes at different ratios and by using several mixing methods. Mulch chips, pallet chips, green chips and sawdust were bulking agents used in the experiments. Mixing methods were; hand mixing with shovels (shoveled), grinding food waste and bulking agent together (mix & grind), layering food waste and bulking agent into the in-vessel system (layered) and pregrinding food waste (food grind). 3.82 m^3 composting mixture was used in each experiment. Aeration was applied by blowers at a rate of 1.98 m^3 per hour. Food waste and green chips mixture by layering method and food waste, green chips and sawdust mixture by mix & grind method had temperatures above 55^oC for 3 days. The reason of this success depends on the easily decomposable characteristic of green chips. Also, mix & grind method provides homogenous compost mixture that promotes good aeration. In addition, this method increases the surface area of compost mixture for microbial activity and accelerates the decomposition. Total volatile solids were decreased in all experiments. Net weights were also decreased approximately 25 percent. Except using mulch chips as a bulking agent, leachate problem did not occur through the composting process. In-vessel system helps to decrease vector and odor problems before using open windrow system for compost mixture. In conclusion, mix & grind method for mixture of green chips, sawdust and food waste (1:1:1) appear to be a good combination for compost process [22].

Elango et al., investigated municipal solid waste composting in a bioreactor. The dimension of the thermophilic bioreactor dimension was 1 x 1 x 1 m. The mixing was done twice a week. Air was introduced with the help of a blower and at the amount of 13.8 kg per day of 30 minutes duration. The moisture content was between 62.3% and 53.3%. High temperatures like 65-70^oC were achieved during the process. pH decreased at the beginning of the process, then neutral values were achieved and at the end it increased because of the ammonia formation. Initially the total solids value was high, after stabilization period it decreased due to the microbial activity. C/N ratio was twenty at the end of the process which is suitable for matured compost. Initially the volatile solids values are high, during thermophilic range and aeration. After stabilization period the values of volatile solids are reduced. Phosphorous content gradually increases during the composting process. Potassium content is low on the compost (<1%), compared to the recommended 1% for composts. Total volume reduction was 78% through the process. Delgado et al. concluded that, composting of municipal solid waste in a thermophilic bioreactor results with good quality compost. Additionally, operation and maintenance of the reactor is very simple [23].

Lin tested a negative-pressure vacuum-type aeration composting reactor for composting food waste. Negative-pressure vacuum-type aeration depends on the withdrawal of air from the reactor. Using the negative-pressure aeration composting reactor will maintain adequate oxic conditions and moisture content during composting while controlling the odor problem to avoid the general public's resistance. Dimensions of the reactor were 150 cm (L) x 150 cm (W) x 170 cm (H) and aerated the rate of 1.8 L air/kg dry solid-min. Food waste was mixed with sawdust (20%, w/w) and mature compost (16%, w/w) and water was added to maintain 50-60% moisture content. The highest temperature (76 ^{o}C) was attained on the 14th day. During the entire composting period, the compost temperature exceeds 65 ^{o}C for 30 days or 50% of the total composting period. pH firstly decreased and then increased to neutral values. pH of compost product was 7.4 and this slightly alkaline neutral pH indicated that the end product was mature compost. EC values firstly increased because of the presence of mineral salts. As the composting process progresses, evaporation of ammonium ion and reduction of other basic groups cause the compost EC to drop. The initial C/N ratio of the compost mixture is 32; it drops gradually to 24 on the 30th day and further to 20 on the 60th day which indicates mature compost. Ammonia concentration was increased during the process and then decreased at the end. The tendency of initial rising and then falling of ammonia is caused by the decomposition of nitrogen-containing organic matter to convert nitrogen into ammonia leading to a higher concentration of ammonia in the reactor. The increased N, P, and K contents during the composting process may be caused by the concentration effect due to higher losing rate of carbon. In conclusion, it was suggested that negative-pressure aeration system has positive effect on odor control and good quality of compost was obtained by using this method [24].

3. MATERIAL AND METHODS

3.1 Experimental Design

In the present work, municipal solid waste composting process was examined by using three different methods including; aerated static pile, turned windrow and in-vessel. The solid waste, which has the same characteristics, was treated by these three methods. Pile systems were formed at Kısırmandıra Compost and Recovery Facility, and the study was operated from August to September 2008.

Wood shavings were used as bedding material for each pile. It had 2 m width, 30-35 cm height and had approximately 1m^3 volume. Aerated static pile was triangular in cross-section with 7.5 m length, 3.5 m width, 1.5 m height and a volume of 18 m^3. Turned windrow was triangular in cross-section with 7.5 m length, 3.5 m width, 1.2 m height and a volume of 12 m^3 (Figure 3.1).

Figure 3.1 : Turned windrow (left)and aerated static pile (right).

Aeration was ensured by using polyethylene pipes with 110 mm diameter in aerated static pile. The pipe had 78 holes on it, with 1 cm diameter, and which were placed in 15 cm distance to each other in double line (Figure 3.2). Airflow rate was 62 m^3/hour. The blower was in progress for 15 minutes and then stopped for the next 15 minutes period. Negative-pressure suction type aeration was applied in the process.

Figure 3.2 : Aeration system used in aerated static pile.

In turned windrow system, passive aeration was used which involves turning the pile by using front-end loader once a week. By this way, particle size of the composting material decreased, homogenization of temperature and moisture, and aeration of the pile were achieved. Water was added during the turning operation. Turning and watering steps are shown in the Figure 3.3. In pile systems, two composite samples were analyzed which were taken from four different locations for eight weeks.

Figure 3.3 : Turning and watering steps.

Composting process at Kısırmandıra Compost and Recovery Facility of Istanbul Metropolitan Municipality was examined as an in-vessel composting system and was compared with pile studies. However, some technical problems occurred in the operation of the facility and the results did not reflect the actual performance of the system. Previous study which was done by Altınbaş et. al was also used to represent in-vessel composting [25]. According to this purpose, composite samples were taken during eight weeks of composting process starting from the 80 mm Trommel Screen. Samples were taken from nine different locations to characterize each stage of the composting tunnel. Each three of these samples were grouped in one sample to represent each stage by three samples.

The Kısırmandıra Compost Plant was constructed in 2001. It is one of the few sizable composting plants in Turkey. Currently, the amount of mixed MSW processed in the plant is 1000 t/day. The composting plant consists of mainly two units; material seperation facility (MSF) and fermentation facility.

Conveyor belts transfer the incoming municipal solid wastes to two rotary trommels, which have 80 mm holes. The oversize materials are directed to the MSF in order to separate recyclables such as metals, glass, aluminum and plastics manually. Approximately 250 t/day undersized materials are separated magnetically before the fermentation process. Over 70% (w/w) of the undersized materials are composed of paper, food waste and woody debris, all of which are biodegradable. The fermentation unit is designed as an in-vessel (tunnel) type with eight stages for the weekly operation. In this agitated tunnel system, the feedstock enters at one end and leaves from the other end. Height of the composting mixture is 2.5-3 m and the length of the tunnel is 31 m.

The first three stages constitute the active fermentation area where the biodegradation is at very high rate. The remaining five stages constitute the slow biodegradation. The first three stages are aerated by positive pressure, while the aeration is provided by negative pressure of the blowers for the last five stages. The air used in the active fermentation stages is fresh air mixed with the sucked air from the last five stages. The exhaust from the first three stages is collected and treated by a biofilter unit. Temperature is kept at 45-60 ^oC in the first stage, 55-70 ^oC in 2-4. stages, 45-50 ^oC in 5-6. stage and it is controlled by mixing and aeration. The transfer of the materials between the stages is performed by using the robotic engines. They add water during the transfer and mixing the mass. The amount of water added through the transfer from second to third stage was 60 m^3/week and this amount was decreased in time.

After eight stages, in other words 56 days of the fermentation process, the compost is removed from the tunnel. At the end of the process, the compost is screened by a rotary sieve with 15 mm holes. The resulting coarse (oversize) fraction is sent to landfills to use as a final coverage. The fine (undersize) fraction is used as a soil conditioner and a fertilizer at the parks of the municipality.

3.2 Analyses of Parameters

Two temperature dataloggers (WatchDog 100 data logger, Spectrum Technologies, Plainfield, IL, USA) were inserted in each pile at the depth of 50 cm to measure temperature in every 2 hours during composting.

The samples, which were collected as described in the previous section, were analyzed according to "Test Methods for the Examination of Composting and Compost (TMECC)" [1]. All samples were shredded as-received using blades in order to take homogeneous samples for the following downstream applications. Several parameters have been measured in order to monitor the system performance. These were; moisture content, organic matter, respirometry (CO_2 evolution rate), COD, pH, electrical conductivity (EC), ammonium, physical parameters such as; bulk density, free airspace, water-holding capacity and pore space. Also, carbon to nitrogen ratio (C/N), TKN and heavy metals (cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu). nickel (Ni), lead (Pb), and zinc (Zn)) were analyzed at raw MSW and compost product.

Moisture Content

The shredded samples were weighed, oven dried at 105±5ºC to steady state and reweighed. The remaining dry solids fraction represents the total solids, and the evaporated fraction represents percent moisture. Total solids and percent moisture contents of sample were calculated by using following formula [1].

$$TS = dw \div A \times 100 \quad \textbf{(3.1)}$$

$$M = 1 - (dw \div A) \times 100 \quad \textbf{(3.2)}$$

Where;

TS = percentage solid material in sample, wet basis, % g/g^{-1},

M = percentage moisture in sample, wet basis, % g/g^{-1},

dw = net dry weight, oven at 105 ± 5ºC, g, and

A = net sample weight at as-received moisture, g.

Organic Matter

An air dried (dried for 24 hours at 75ºC), milled sample was combusted at 550ºC for 2 hours to determine volatile solids content. Organic matter and ash content as percentages of total solids on an oven dry weight basis were calculated by using following formula [1].

$$Ash = (AshW \div dw) \times 100 \quad \textbf{(3.3)}$$

$$VS = [1 - (AshW \div dw)] \times 100 \quad \textbf{(3.4)}$$

Where;

Ash = percentage solids at 550ºC, % g/g^{-1},

VS = percentage of solids volatilized at 550ºC, % g/g^{-1},

AshW = sample net weight after ignition at 550ºC, g,

dw = net oven-dry weight, at 70 ± 5ºC, g, and

A = net ash weight at 550ºC, g.

Respirometry (Carbon dioxide Generation Rate)

The amount of CO_2 gas generated from the decomposition of organic matter during composting process is determined by respirometry analysis [1]. 25 g compost sample was allowed to pre-incubate at room temperature (25-28^{o}C) for 24h. Sample moisture loss was minimized by maintaining high humidity conditions in the incubator. The moisture content of the sample was determined before the respirometry test. After pre-incubation period, 20ml of 1N NaOH was transferred to biometer flask and then it was placed into the incubation vessel, which was set at 34 ^{o}C. A blank was set up by placing a 20 ml aliquot of 1N NaOH into an incubation vessel without a compost sample. Then, the date and time was recorded. The amount of CO_2 absorbed by each NaOH trap was determined daily over a four day period by back titration of the residual with normalized 0.1N HCl. 0.5ml NaOH was transferred into a beaker. 50ml distilled water and 1ml of 0.5N $BaCl_2.2H_2O$ were added. In addition, two to three drops of phenolphthalein indicator was added. The mixture was back titrated with 0.1N HCl until the solution begins to turn clear. The sample was placed back into the incubation vessel with a fresh amount of NaOH. Calculations for each of the four titrations were performed. CO_2 generation for each titration was calculated by using following formula.

$A = [(B - C) \times (D \times E)] \div (F \times G)$ **(3.5)**

Where;

A = mg CO_2-C g^{-1}(TS, OM) d^{-1},

B = volume of standardized HCl used for blank titration, mL,

C = volume of standardized HCl used for sample titration, mL,

D = normality of standardized HCl, mol L^{-1},

E = 22 = equivalent weight of CO_2 in NaOH,

F = moist weight or organic matter of sample in container, g, and

G = mass unit, fraction of total solids (TS), and organic matter (OM)

$H = \Sigma A \div I$ **(3.6)**

Where;

H = average mg CO_2-C g^{-1} (TS, VS) d^{-1},

$\sum A$ = tally CO_2 generation measures from days one to four,

I = duration of experiment, four d.

COD value

Water-soluble carbon is measured as COD basis in a slurry (1:20, w/w) of shredded samples and deionized water were blended at ambient laboratory temperature (approximately 23ºC) to determine the COD. The mixture was shaken in a 500mL closed container at 180 excursions per minute for 20 minutes. The mixture was centrifuged at 9000 rpm for 15 minutes. Then COD was measured within the supernatant as described in TMECC 04.12-D [1].

pH and Electrical Conductivity (EC)

Slurry of compost and deionized water was blended at a ratio of 1:5, w/w basis. The mixture was shaken in a 250mL closed container at 180 excursions per minute for 20 minutes. After that, pH was measured by electronic pH meter (Orion 720) directly in the slurry. The mixture was centrifuged at 9000 rpm for 15 minutes. Then, EC was analyzed within the supernatant [1].

Ammonium

Slurry of compost and deionized water was blended at a ratio of 1:5, w/w basis. The mixture was shaken in a 250mL closed container at 180 excursions per minute for 20 minutes. The mixture was centrifuged at 9000 rpm for 15 minutes. Ammonium was analyzed according to TMECC 04.02-C [1].

Physical Parameters

Bulk density, porosity/pore space, free airspace and water-holding capacity were determined by as-received samples as described in TMECC 03.01-A and B [1].

Total Kjeldahl Nitrogen (TKN)

An air dried (dried for 24 hours at 75ºC) and milled sample was used to determine the TKN value. Total Kjeldahl nitrogen was analyzed according to TMECC 04.02-A [1].

Carbon/Nitrogen Ratio (C/N)

An air dried (dried for 24 hours at 75ºC) and milled sample was used to determine the C/N ratio. C/N ratio was measured with elemental analyzer.

Heavy Metals

An air dried (dried for 24 hours at 75ºC) and milled sample was used to determine the value of heavy metals. Heavy metals were measured by using ICP-OES device.

4. RESULTS AND DISCUSSION

4.1 Characterization of MSW

The solid waste, which has the same characteristics, was treated by three different methods. The characterizations of the solid waste both used in this study and the recent study by Altınbaş et al. [25] are given in the Table 4.1.

Table 4.1 : Characterization of municipal solid waste.

Parameter	Unit	Value	Value [25]
pH	-	7.15±0.07	6.1±0.6
EC	Mmhos/cm	8235±375	9458±2437
Moisture Content	%	58±1.20	59
Organic Matter	% dry solid	56±1	58
TKN	g / kg	10.56±0.01	13.5±1.5
NH_4^+-N	g / kg	0.05±0.03	0.3±0.2
COD	g / kg	29±9	100±60
C/N	-	30	23
C	%	33.3	28.6
N	%	1.1	1.4

4.2 Temperature

Temperature plays a major role in the composting process. It affects the rate of decomposition of the organic matter and therefore is important for the production of a stable and mature product. The temperature must be high enough to kill pathogens and weed seeds but not so high to kill the microorganisms.

Figure 4.1, 4.2 and 4.3 show temperatures in the piles and facility during eight weeks of composting. In turned windrow, temperature started to increase from 40°C and it reached its maximum value that was 73°C in the 6th day. After turning the piles, temperature values were increased each week as can be seen from figures. For the next two weeks, temperature was above the 55°C and then fluctuated around the value of 50°C. In the last week, it decreased to ambient temperature.

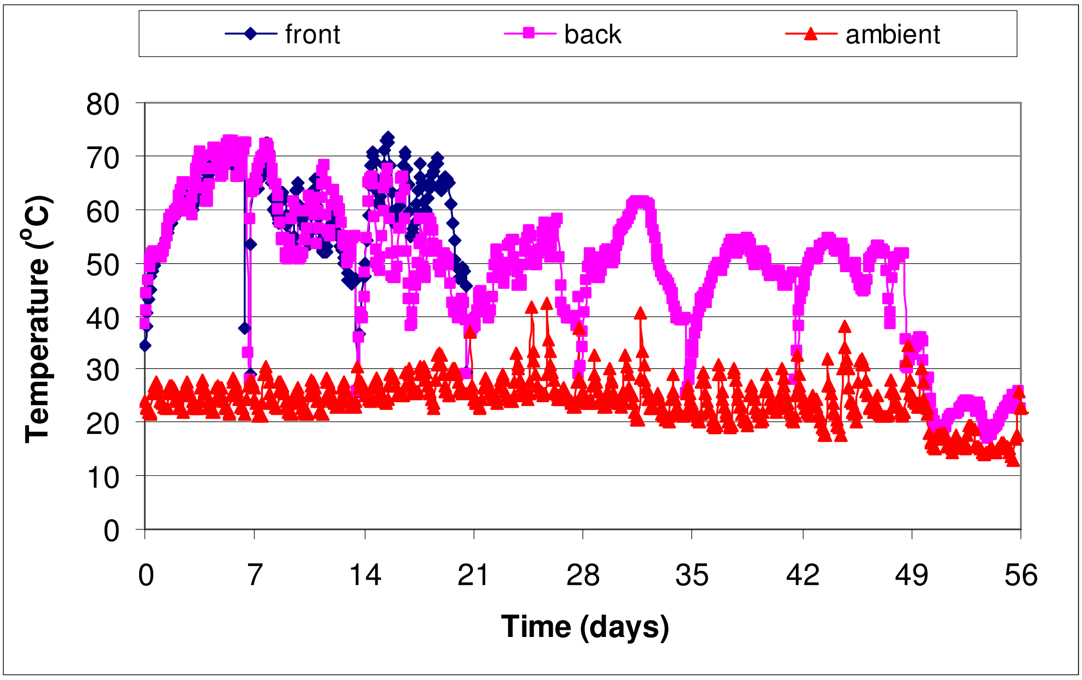

Figure 4.1 : Temperature profile of turned windrow.

In aerated static pile, air was supplied from the front part of the pile, which caused different temperatures at the front and end of the pile. Aeration was more efficient in the front part of the pile as can be seen from the Figure 4.1. During the first week, temperature increased from 30°C to 60°C and reached the maximum value that was 70°C in the 24th day. After the fifth week, temperature was decreased and reached the ambient temperature at last week.

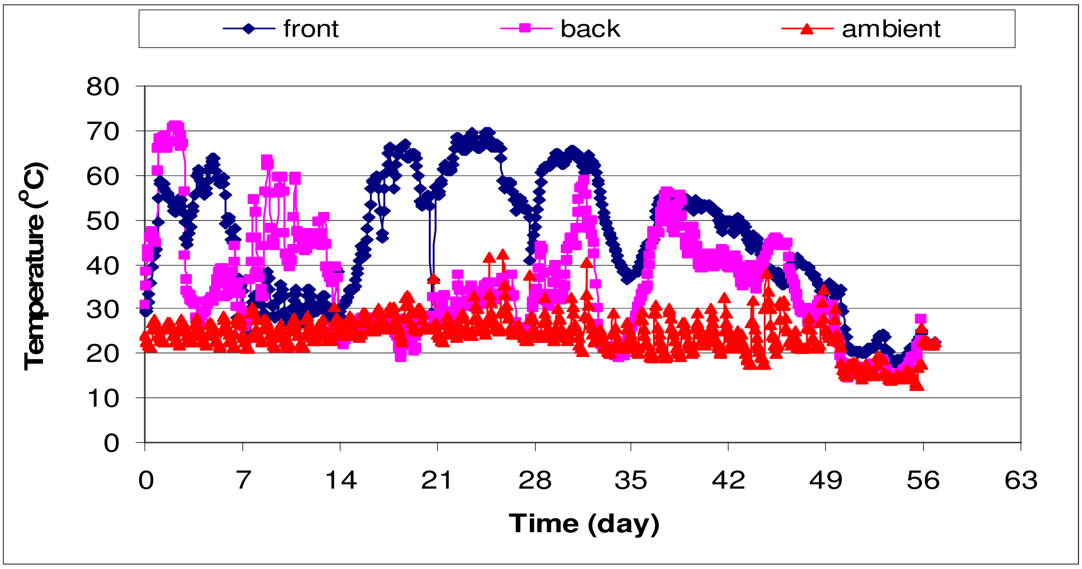

Figure 4.2 : Temperature profile of aerated static pile.

The temperature of in-vessel system increased from 40°C and reached the maximum value of 70°C during the first week. For the next five weeks, temperature was in the range of 60-70°C. After the sixth week, temperature cannot be measured because of the technical problems occurred in the facility. A recent study that was done by Altınbaş et al. showed that, the maximum temperature of 68°C was reached around the 17th day. High temperature values over 55°C lasted for approximately 22 days [25].

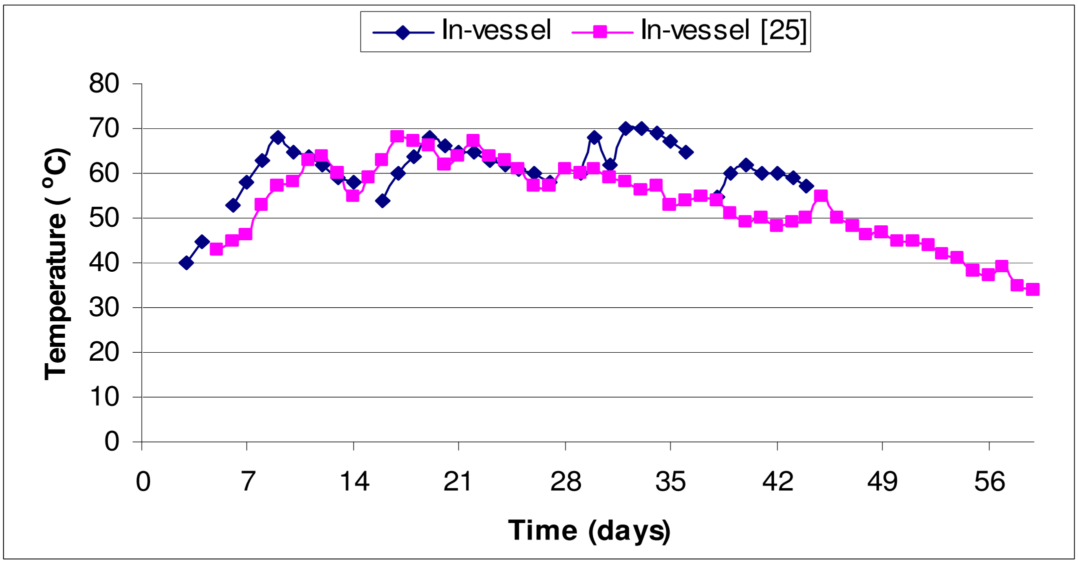

Figure 4.3 : Temperature profiles of in-vessel systems.

4.3 Moisture Content

In aerobic composting process, optimum water content is 40-60%. Moisture content of piles was kept between 35 and 60% by the addition of water once a week. Water was added to turned windrow when turning the pile by using a hose with flow meter. In aerated static pile, water was added over the pile. After the seventh week, there was no need for water addition because of the heavy rain.

Change of water content with time is shown in Figure 4.4. Moisture content of samples from in-vessel system was decreased from the value of 58% to 34% through the process. Recent studies also correlates with this result [25]. In pile systems, low moisture content of 30-35% was observed because the piles were placed in open area, affected from weather conditions which results in high amount of evaporation. However, the general variation was optimum for the degradation of organic matters and maximum respiratory activity.

Moisture content increases the bulk density and the transportation cost of the product. If compost is too dry, it is difficult to work with, while if compost is too wet, it becomes heavy and can be hard to apply. The moisture content of delivered composts was suitable because it has to be between 40-55% [3]. The moisture content of turned windrow compost was 44% and aerated static pile was 42%.

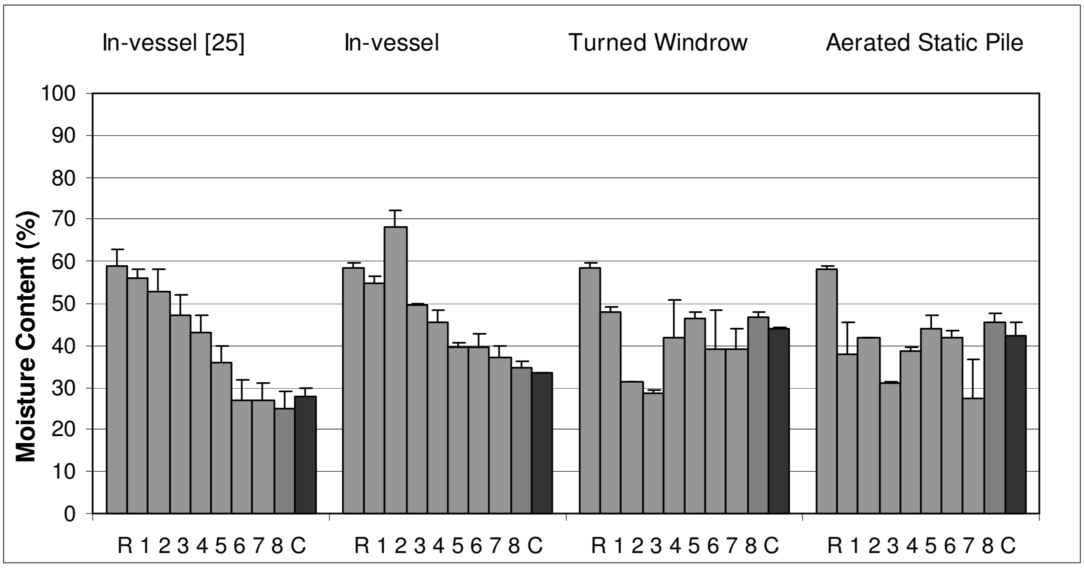

Figure 4.4 : Change of moisture content (R: Raw MSW, C: Compost, and numbers represent weeks of the process).

4.4 Organic Matter

Organic matter gradually decreased over time due to decomposition. Therefore, more stable product was obtained at the end of the process. Change of organic matter value is given in Figure 4.5. The feedstock had 56% of organic matter. At the end of the process, organic matters of composts were; 46% in in-vessel system, 44% in aerated static pile and 40 % in turned windrow. Organic matter decreased from 58% to 40% at a recent study performed for in-vessel system [25]. These are suitable values for compost products because high quality composts usually contain at least 40% organic matter [3]. Organic matter is an important ingredient in each type of soil and has an important role to play in maintaining soil structure, nutrient availability and water holding capacity. Eventually, these values show that there was a better organic matter reduction in turned windrow system.

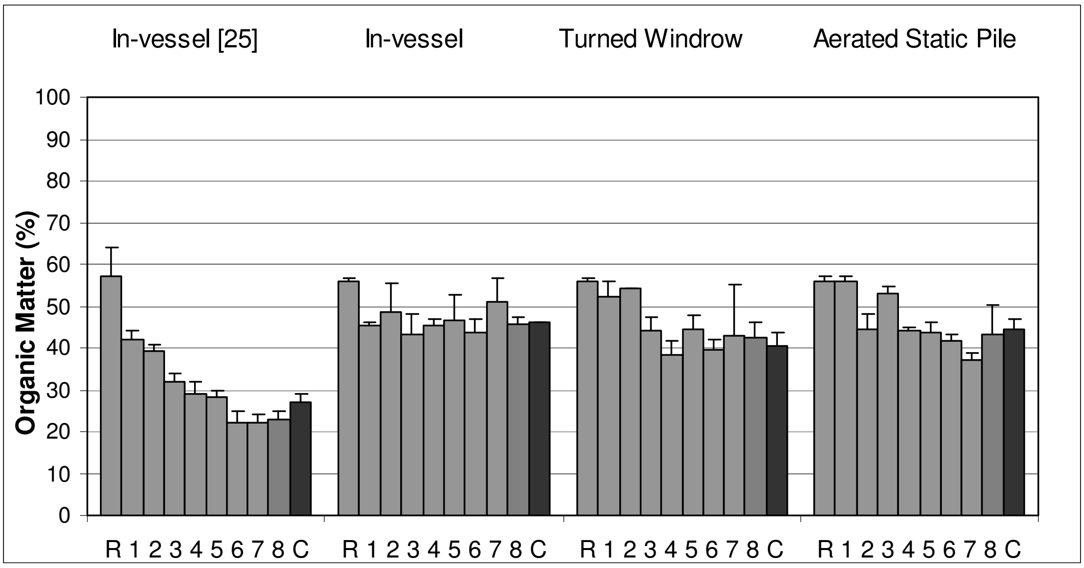

Figure 4.5 : Change of organic matter.

4.5 Water Extractable Carbon (WEC)

Water extractable carbon (WEC) parameter indicates the quantity of easily degradable organic compounds and it is expected to decrease during the composting process. The decrease of WEC was due to the consumption of the readily biodegradable substrates by indigenous microflora. The increase of WEC values at the beginning of the study can be explained by the dissolution of organic matter. After that, values were declined through the process in all systems (Figure 4.6). As can be seen from the Figure 4.6, decompostion of organic matter was slowed down after the third week.

In in-vessel system, COD was increased from 28 to the maximum value of 94 g/kg in two weeks, and then decreased to 9 g/kg at the end of the process. Similarly, in aerated static pile maximum value was reached in the second week and with continuous drop, 18 g/kg COD was measured for the compost product. In turned windrow system, compost product had 8.2 g/kg of COD which shows the best organic matter reduction. While the initial COD was 100 g/kg and it dropped to 25 g/kg following three weeks according to the recent study of in-vessel system. In the compost product, this value was 11 g/kg [25].

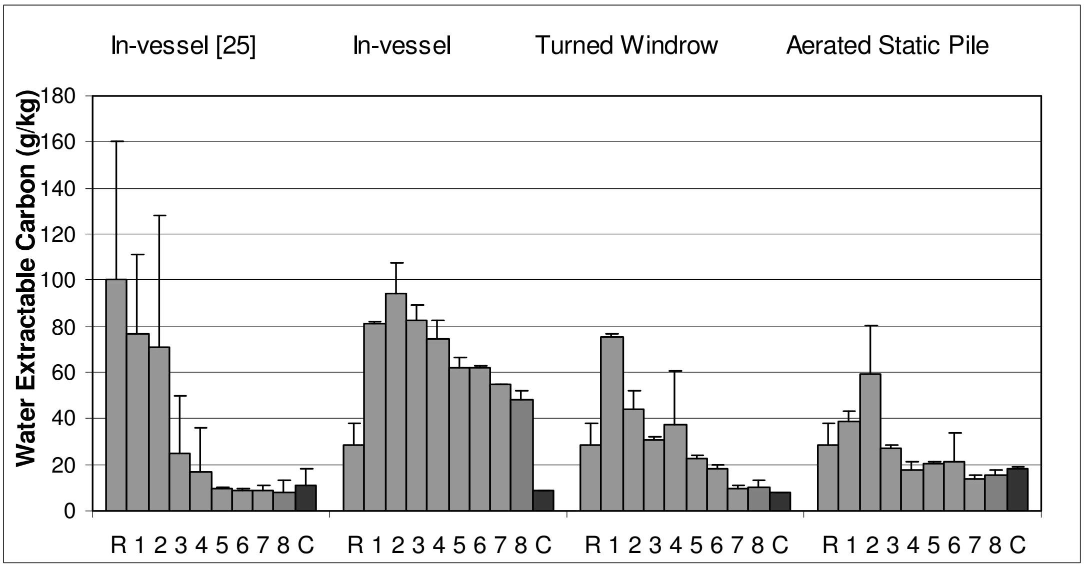

Figure 4.6 : Change of WEC.

4.6 C/N

The percentage of the carbon decreases during the composting process because of the organic matter degredation. The amount of nitrogen seems to be slightly increased because of the mass loss. However, it was almost unchanged. During efficient composting, the C/N ratio is expected to decrease as a consequence of degradation of organic matter and mineralization. This was in the range of the optimum ratio (20-35) for successful composting. Although there is no single parameter that determines the stability of compost product, it can be said that C/N ratio less than 18 is ideal for ready to use compost [5].

4.7 Respirometry

Respirometry analysis is a measure of the total biological activity in the composting material and results from the degradation of organic material; the formation of CO_2 is the last step of carbon mineralization. During the composing process, oxygen is consumed, and CO_2 and water are released. Respirometry rates increased for three weeks in active fermentation period and then at the end of the process, respirometry rates decrease because compost becomes stable (Figure 4.7).

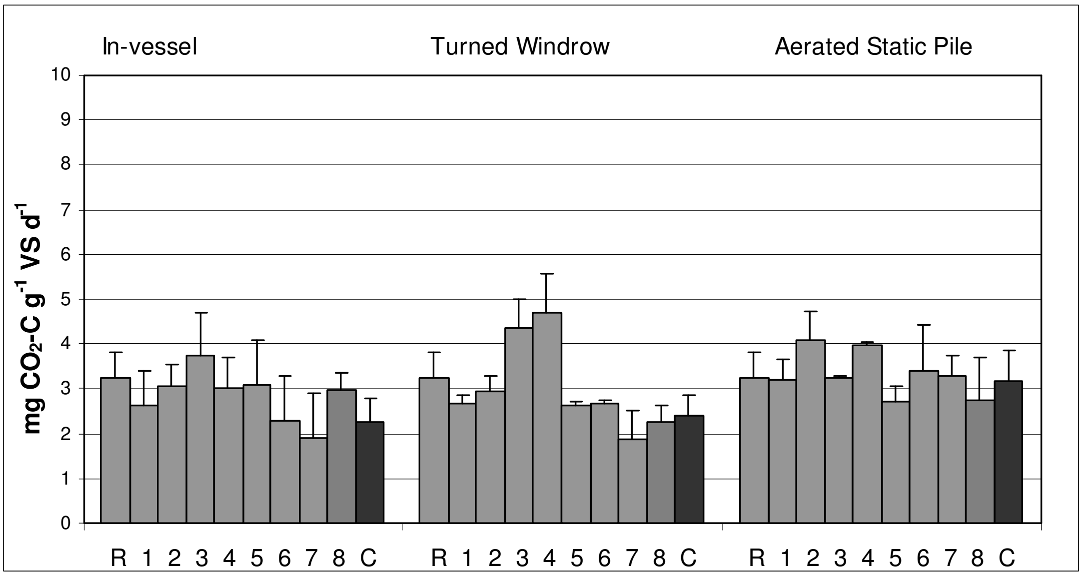

Figure 4.7: Change of CO_2 evaluation rate.

Respirometry of the compost products were 2.24, 2.41 and 3.17 mg CO_2-C g^{-1} VS day^{-1} in in-vessel system, turned windrow and aerated static pile, respectively. All of the compost products were classified as "mature" according to the maturity indices published by the California Compost Quality Council (CCQC) (Table 4.2) [26].

Table 4.2 : Maturity of indices (CCQC).

Method	Very Mature	Mature	Immature
mg CO_2-C g^{-1}VS day^{-1}	<2	2-8	>8

4.8 pH

The pH value also affects the composting process. Changes in the pH of the compost material are presented in Figure 4.8. The pH of feedstock was around 7.15±0.07 and low values were observed for two weeks. These acidic values were observed as a result of the formation CO_2 and organic acids. After that, it increased and remained stable until the end of the process. This pH increase is generally attributed to the release of CO_2 and ammonia production from the degradation of the proteins. The pH range during the process indicated that enough air was provided to the piles. pH of the compost products were 7.7, 7.68 and 7.33 in in-vessel system, turned windrow and aerated static pile, respectively. The pH of feedstock was around 6.1 at recent study in in-vessel system and increased to around 7.3 during the first three weeks; it remained stable until the end of the process [25]. In general, it is known that pH of the composting mixture should be in the range of 6–9 [27].

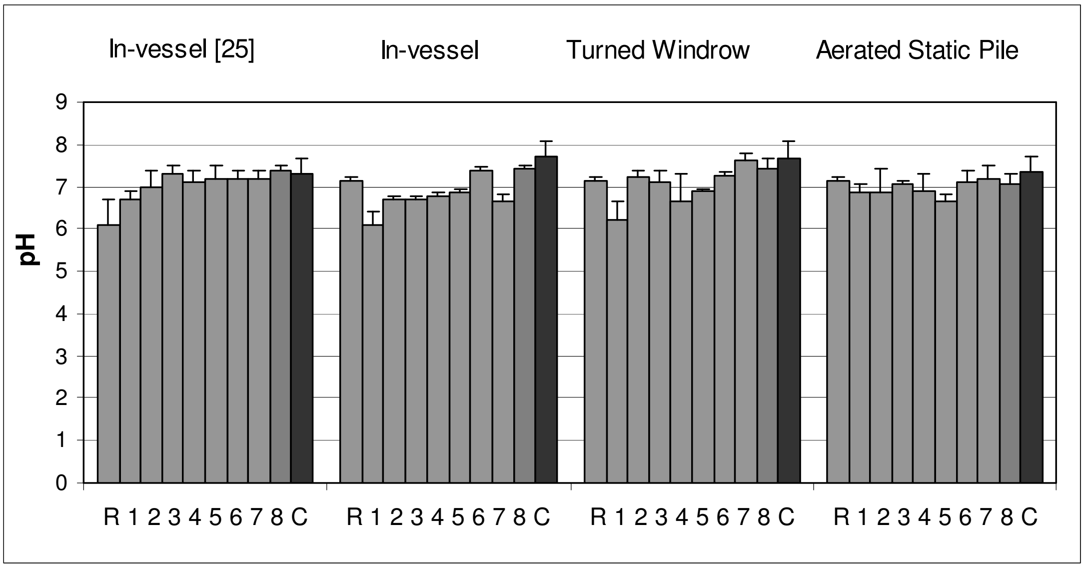

Figure 4.8 : Change of pH.

4.9 Electrical Conductivity

Electrical conductivity reflects the amount of dissolved salt concentration. EC values of composting systems are given in Figure 4.9. EC values were increased after the piles formed and wastes loaded to the fermentation tunnel as a result of the degradation of the organic matter and release of dissolved salt concentration. After that, it was decreased because of the evaporation of ammonium ion.

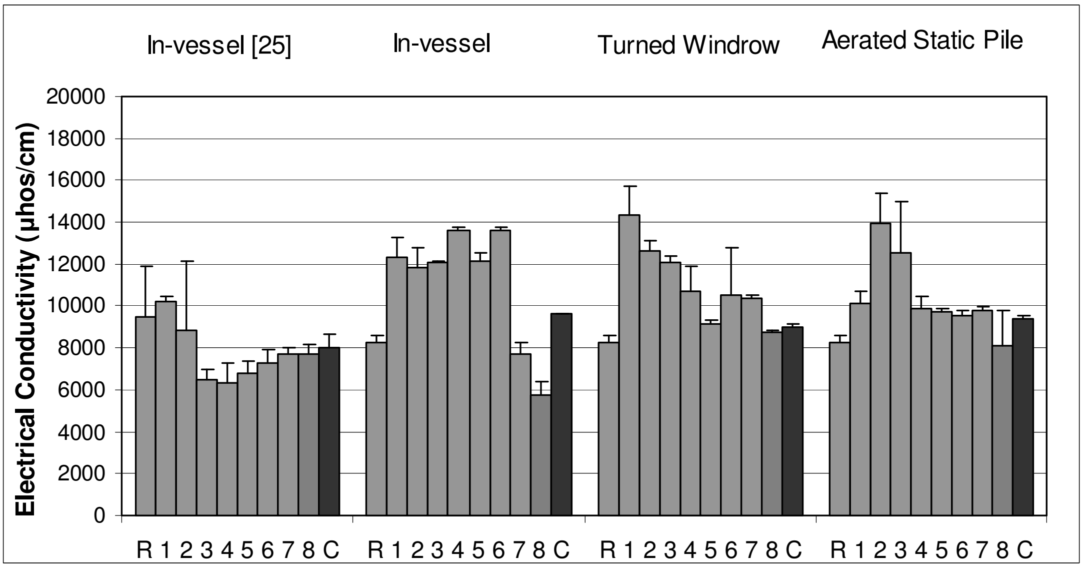

Figure 4.9 : Change of EC.

EC of raw MSW was 8200 μhos/cm and compost products were 9000-10000 μhos/cm. Altınbaş et al. measured lower values than the ones obtained at this study. Additionally, EC of the compost was approximately 7000 μhos/cm [25]. EC is an important parameter to evaluate the compost quality in terms of phytotoxic potential when used for soil application.

4.10 Ammonia and Total Kjeldahl Nitrogen (TKN)

In composting material almost all nitrogen content were made of organic nitrogen. Therefore ammonia concentration was very low (<2 g/kg). Change of ammonia concentration in all systems is shown in Figure 4.10. Ammonia reached maximum values at the beginning of the process because of the rapid degradation of nitrogen-containing organic matter and conversion of organic nitrogen into ammonia. Then, ammonia concentration was decreased. High temperatures (60-70 °C), low C/N ratios, high pH and high aeration rates could be the reasons for high volatilization of ammonium [28, 29].

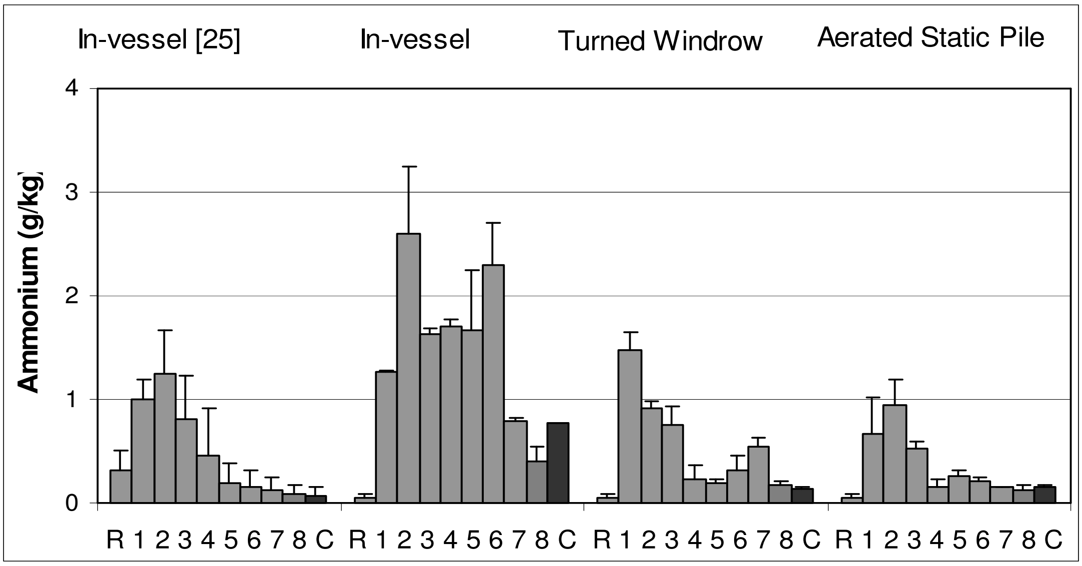

Figure 4.10 : Change of ammonia concentration.

Ammonia concentration of composts was 0.1 g/kg in piles and 0.7 g/kg in in-vessel system. Also, at recent study, ammonia concentration was remained at very low levels (<1.2 g/kg) during the composting process [25]. Less than 0.5 g/kg ammonium concentration is recommended for the land application of compost product, otherwise toxic effect of the ammonium ion would be observed on plants [30].

TKN of compost feedstock was 10.56 g/kg, it increased to 12 and 15 g/kg in in-vessel and pile system through the process.

4.11 Pore Space, Free Air Space, Water Holding Capacity and Bulk Density

Physical parameters of composting mixture were determined at the beginning, in the middle and at the end of the process (Figure 4.11, 4.12, 4.13, 4.14). In all systems, pore space changed between 70-90%, as a result of the composition of MSW. The presence of unsorted large inert materials provided necessary pore space for microbial activity, because microorganisms use pore space for transportation of food and oxygen. As a result of organic matter degradation pore space decreased through the composting process. The free air space was 65% in the feedstock, and it decreased to 25-40% due to the degradation of organic matters through the composting process.

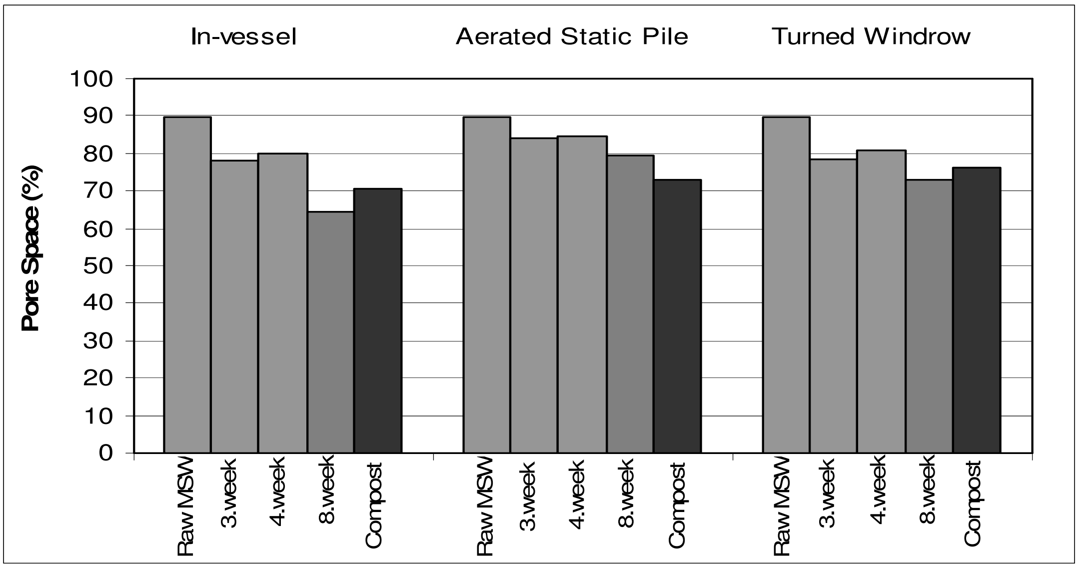

Figure 4.11 : Change of pore space.

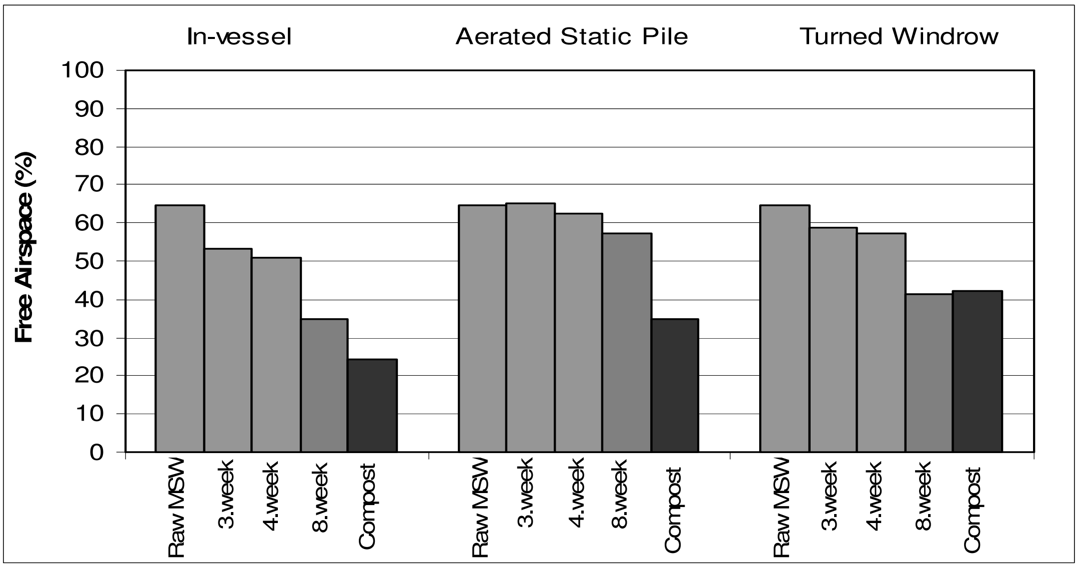

Figure 4.12 : Change of free air space.

Water holding capacity is one of the important features of the compost quality. During the process, it increased from 25% to 35-45% because of the degradation of organic matter. Similarly, bulk density increased from 0.13 g/cm^3 to 0.3, 0.28 and 0.23 g/cm^3 in in-vessel system, aerated static pile and turned windrow, respectively.

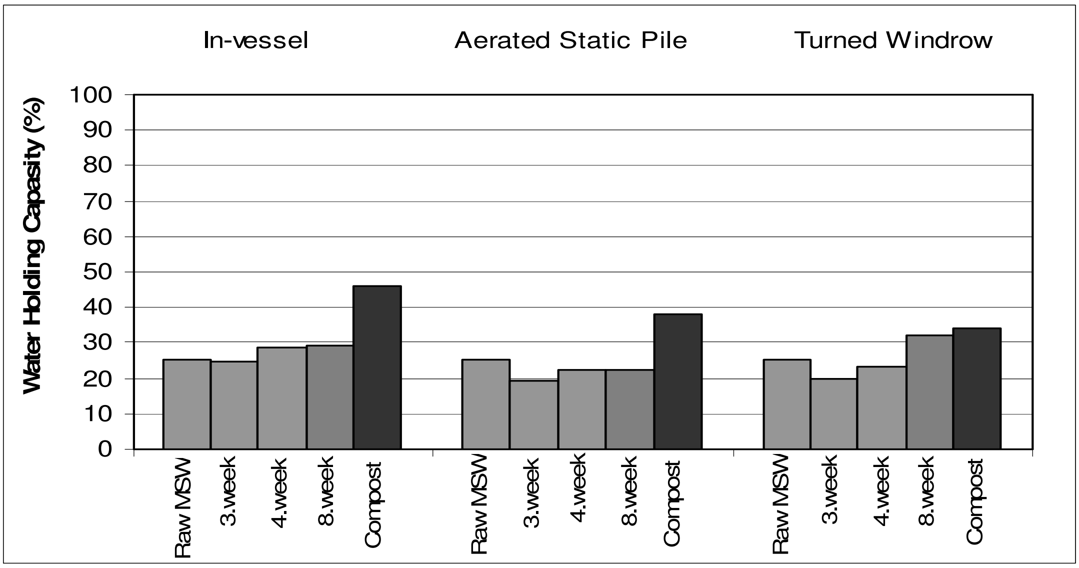

Figure 4.13 : Change of water holding capacity.

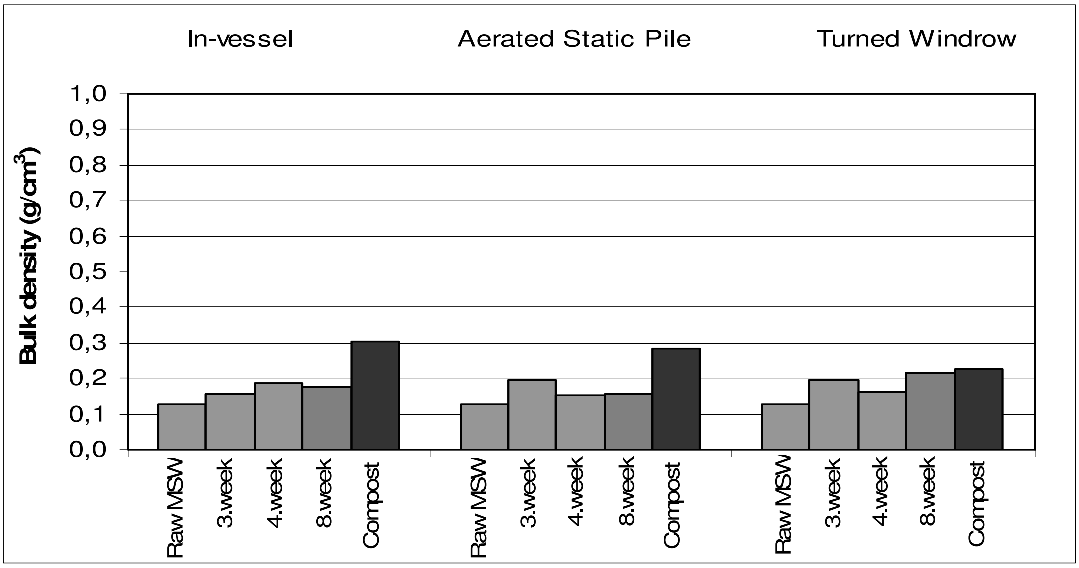

Figure 4.14 : Change of bulk density.

4.12 Heavy Metals

The term includes the metals cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn). Cd, Hg, and Pb are toxic to humans and animals; yet others such as Cu, Ni and Zn can be phytotoxic. Table 4.3 shows the heavy metal values for the raw materials and compost products. As can be seen from the table, heavy metal values were increased because of the total mass reduction.

Table 4.3 : Heavy metal content of raw materials and compost products (R: Raw material, C: Compost product).

Parameter	Unit	In-vesel [25]		In-vessel		Aerated Static Pile		Turned Windrow	
		R	C	R	C	R	C	R	C
Cu	mg / kg	130	561	147	560	147	1022	147	309
Pb	mg / kg	60	92	130	129	130	275	130	168
Zn	mg / kg	251	727	488	630	488	617	488	478
Cd	mg / kg	0.7	1.2	3.4	1.5	3.4	1.2	3.4	2.3
Cr	mg / kg	423	467	95	271	95	140	95	133
Ni	mg / kg	162	175	129	87	129	64	129	53
Hg	mg / kg			<1	<1	<1	<1	<1	<1
P	mg / kg			2031	2232	2031	3405	2031	2812

4.13 Product Quality

Characterization of compost product of in-vessel, aerated static pile and turned windrow is given in Table 4.4. pH of composts were in the range of 7.3-7.7. EC of compost product was 9000-9500 μmhos/cm which was higher than the feedstock value. Moisture content of compost from in-vessel system was 34%, from turned windrow and static pile was 40-45%, because the rain effect. Also, composts had 40-45% of organic matter.

Table 4.4 : Characterization of compost products.

Parameter	Unit	In-vesel [25]	In-vessel	Aerated Static Pile	Turned Windrow
pH	-	~7	7.70	7.33±0.06	7.68±0.1
EC	μmhos/cm	~7000	9650	9380±156	8985±191
Moisture Content	%	~25	34	42±3.19	42±3.19
Organic Matter	%dry solid	~25	46	44±2	40±4
TKN	G / kg	~11	12.3	15.65±0.59	15.58±0.27
NH_4^+-N	G / kg	0.08	0.765	0.155±0.02	0.136±0.02
COD	G / kg	11	9.1	18.08±0.86	8.3±0.02
C/N	-	17	45	24	21
C	%	21	26	26	23
N	%	1.6	0.6	1.1	1.1

Composts from pile systems were stored in the facility after sieved from to observe their maturity (Figure 4.15).

Figure 4.15 : Composts of turned windrow and aerated static pile.

5. CONCLUSIONS

The composting process provided an acceptable degree of treatment for municipal solid wastes by using pile methods. The results of the investigations prove the usefulness of pile composting methods similar to the current in-vessel system for municipal solid wastes. Both at turned windrow and in-vessel system sufficient temperatures were reached to kill the pathogenic microorganisms and obtain sanitation. In aerated static pile method, aeration was supplied from the front side of the pile which results with higher temperature values. But at the back side of the pile low temperatures were obtained because of unsufficient air supply. Although it does not applied at this study, bulking agent addition could be advantageous for municipal solid waste composting. Especially for homogenization of feedstock and effective aeration, bulking agents such as trimmings and prunings could be used at composting process to increase the pore space of composting material.

The products of all composting systems have suitable organic matter values specified by standards. However, variation of organic matter parameter did not represent the active fermentation and maturation phase definitely. On the other hand, evaluation of WEC values showed that active fermentation period was completed in three weeks at turned windrow and aerated static pile systems, and 3-4 weeks at in-vessel system. These results correlate well with temperature profiles both at in-vessel and aerated static pile systems.

Results of respirometry test were parallel with the change of COD, because at aerated static pile and turned windrow systems there was an increase of CO_2 production in the first three weeks and then it decreased in maturation phase. However, respirometry test of in-vessel system did not represent such a variation of CO_2 production because of the problems occured at the facility.

In all systems moisture content, pH and ammonium parameters had suitable values through out the process, and compost product had acceptable values for these parameters which were determined by standards. EC values were also favorable for a typical composting process period.

The physical parameters measured demonstrated that the proper conditions were provided during the entire process. Additionally, results showed that sufficient aeration was applied to the system and the products had suitable values for utilization as soil conditioner.

As a result, turned windrow system had similar results with in-vessel system by means of the variation of general composting parameters. On the other hand, turned windrow system overcomes aerated static pile due to the simplicity of operational conditions and lower capital costs. Municipal solid wastes contain high amount of easily biodegradable organic matter that can be easily composted by turned windrow method as an alternative low cost technology for in-vessel composting systems.

Additionally, combination of in vessel systems with pile systems could be a good solution for treatment of municipal solid wastes. At this process, in-vessel composting is used for active fermentation phase and then turned windrow composting for maturation phase. By this way, the main part of composting process occurs at more controlled conditions, at in-vessel facility. After that, maturation of compost is achieved by more economical and simpler pile composting method. The only limitation of pile composting system is possible odor problem and it could be solved by chosing appropriate location for facility.

At the end of this study, it was proven that the compost products are valuable resource for agricultural land. Recycling of composted municipal solid wastes as soil amendment is an environmentally friendly and sustainable waste management option.

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