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CHAPTER 9

Composting for Organic Waste Management

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9.1 INTRODUCTION

Organic solid waste management is a major challenge throughout the world, and a poor management can result in environmental deterioration and human health hazards. Effective management of organic waste relies on the availability and acceptability of the technology for the treatment. Every year about 1.3 billion tonnes of municipal solid wastes (MSW) are generated globally in urban setups alone and is expected to increase to 2.2 billion tonnes by 2025 (Hoornweg and Bhada-Tata 2012). About 30–50% of the MSW are putrescible; whose sustainable disposal requires appropriate technologies. Besides, significant quantities of biosolids, animal manures, agricultural wastes and other organic wastes generated also require suitable treatments. Most of the putrescible wastes in the MSW and other wastes were landfilled while only a small fraction was treated in the past. Decomposition of organic fractions in the landfills causes emission of greenhouse gases contributing to global warming, and odour causing human health hazards, and contaminates the groundwater and soil through leachate production if they are not properly managed. To prevent these environmental damages, recycling of these organic wastes is essential.

Considering the application, level of scientific expertise required and the demand for the recycled products, composts appear to be an ideal technology due to its robustness to handle a variety of organic wastes. Flexibility and the robustness make composting suitable for a broad range of situations; thus there is a composting system for nearly every type of organic waste i.e., simple systems for early stages of industrial development to relatively complex, mechanized

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systems for advanced industrial development (Chatzouridis and Komilis 2012). In the developing countries, constraints related to economics, technology, and qualified personnel have narrowed the choice of treatment and composting best fits these requirements. Composting in a rural setup is relatively easy because the odour and vectors could not attract the focus due to the large area of land available and the less dense population and human interaction although the problems are unsolved. However, performing composting in urban setting requires stringent controls over the process to prevent the odour and vectors, and the need of high and effective decomposition to shorten the composting time.

9.2 PRINCIPLES OF COMPOSTING

9.2.1 Basic Considerations

Composting is a controlled microbial decomposition of organic solid waste, under aerobic condition, where microorganisms convert waste into a chemically humus-like stable product. The term controlled indicates that the process is managed or optimized to achieve the desired objectives. The main objectives of composting are to decompose organic fraction of waste to a stable condition; reduce its volume, weight and moisture content; minimize potential odor; destruct pathogen and increase potential nutrients for agricultural application. Complete stabilization is neither practical nor desirable because complete stabilization would destroy all the slowly degradable organic matter that gives compost its soil-building properties. The degree of stabilization and pathogen destruction depends on the purpose of composting and intended use of the compost product. Achieving a stable and mature composting product depends on proper management of the process through controlling the following factors:

- Nutrient balance is determined by the ratio of carbon (C) to nitrogen (N) in the compost mix, which affects the microbial growth in the composting system. C is the energy source while protein is important for cell differentiation. The optimal initial C/N ratio should range from 25 to 35 to facilitate rapid composting which is consistent with the nutrient needs of the bacteria and fungi in the compost pile.
- Moisture content of the composting mix ideally should be 55–60% throughout the active period of the composting process. As a rule of thumb, the moisture content should neither be too dry to limit microbial growth nor too wet to fill the pore space to make oxygen supply a limiting factor.
- Oxygen supply at adequate levels enables biological processes to thrive with optimum efficiency and the oxygen content in the pile should be around 12 to 15%. Aeration affects temperature, moisture, carbon dioxide (CO_2) and oxygen (O_2) content of the air in the pile, and the rate of removal of potentially toxic gasses.

- Temperature increases during composting as a result of microbial activity; and a suitable insulation and controlling the temperature between 55°C and 65°C is a prerequisite for efficient and rapid composting. A temperature higher than 70°C will be inhibitory to the microbial degradation.
- pH is often self-regulating between 6.0 and 7.5, which is an optimal range for composting bacteria. However, some feedstocks require the addition of external pH adjusting materials such as lime for rapid composting since self-regulation takes longer time and odour problem are very serious during the low pH conditions.

If these factors are balanced and properly managed, the decomposition of organic matter can be maximized and this can significantly reduce the composting time. Besides the efficient composting process can generate sufficient heat to destroy weed seeds, pathogens, and fly larvae.

A typical composting process can be divided into four distinct phases covering the active composting and curing stages mainly characterized by the temperature changes and also the types of microorganisms that dominate the at various temperatures.

1. **Initial mesophilic phase:** During this first phase, a diverse population of mesophilic bacteria and fungi proliferates, degrading primarily the readily available nutrients and thereby raising the temperature to about 45°C. At this point their activities decrease, and heat resistant bacteria become dominant.
2. **Thermophilic phase:** After a short lag period (not always discernible) there occurs a second more or less steep rise of temperature. This phase is characterized by the development of a thermophilic microbial population comprising bacteria, actinomycetes and fungi. The temperature optimum of these microorganisms is between 55°C and 65°C, their activities terminate at temperature higher than 70°C. The pH typically decreases since organic acids are produced. Additionally, pathogenic microbes and helminthes eggs are eliminated as a result of heat generated during this process. Thus, the organic compost is safer for use by farmers.
3. **Cooling phase:** The phase is characterized by a gradual temperature decline as a result of declining readily available organic substrates and a decrease in microbial population. Mesophilic microorganisms having survived the high temperature phase or invading the cooling down material from the outside succeed the thermophilic ones and extend the degradation process as far as it is intended.
4. **Compost maturation phase:** The final stage is known as stabilization or curing phase, where the temperature declines further and remains about 25–30°C or close to ambient. In this step, the process of humification of organic compost occurs resulting in increases in humic matter content and cation exchange capacity (CEC) of the compost.

9.2.2 Microorganism and their Succession during Composting

The composting mass contains a wide variety of microorganisms with different temperature preferences, such as the mesophiles and thermophiles, and the turning operation can deliver the microorganisms to various temperature conditions. Initial microbial population is highly influenced by the substrate; however, the air passing through the composting mass add a significant microbial load resulting the eventual change in the diversity as influenced by the prevailing temperature and other corresponding physicochemical conditions. For example, in source-separated household waste, only few mesophilic fungi were observed initially while after certain period, as the decomposition proceeded, numerous thermophilic bacteria and fungi were observed (Ryckeboer et al. 2003a). Similarly, initial low pH of the food wastes favours the proliferation of fungi and yeast and slow down bacterial growth.

Bacteria are small and fast decomposers responsible for initial decomposition of most easily available nutrients. A wide variety of bacteria, such as *Clostridium thermocellum, Streptomyces* spp., *Ruminococcus* spp., *Pseudomonas* spp., *Cellulomonas* spp., *Bacillus* spp., *Serratia, Proteus, Staphylococcus* spp., and *Bacillus subtilis* were reported to produce diverse group of enzymes involved in saccharification of organic substrates that are useful in the degradation of organic substrates dominated by plant biomass. Many workers have studied *Acetivibrio cellulolyticus* as it differs from most of the cellulolytic organisms in its ability to utilize only cellulose, cellobiose or salicin for growth (Perez et al. 2002; Huang et al. 2010). *Cellulomonas* sp. is important and extensively studied aerobic cellulolytic waste degrading microorganism. It is amusing to note that *Bacillus* strains are known for their ability to enter into resting states and are good producers of secondary metabolites that could contribute them further advantages over competitors under conditions of slow growth on cellulosic substrates. The aerobic, mesophilic *Sporocytophaga myxococcoides* has been illustrated as one of the most active cellulolytic bacteria, produces several carboxyl-methyl cellulases, at least two of which act as endoglucanases (Crecchio et al. 2004; Zhang et al. 2011).

Fungi tend to be present in the later phase of composting because of their preferred foods include hard-to-degrade ingredients such as waxes, complex proteins, hemicelluloses, lignin, and pectin. Fungi are less sensitive to environments with low moisture and pH than bacteria, but because most fungi are obligate aerobes (require oxygen to grow), they have a lower tolerance for low-oxygen environments than bacteria. Fungi also cannot survive above a temperature of 60°C. A diverse spectrum of cellulolytic fungi (Herrmann and Shann 1997) have been isolated and identified over the years. Cellulolytic microbes are primarily carbohydrate degraders and cellulose is the most abundant source of substrate for the growth of fungi at thermophilic phase. Besides, most cellulolytic fungi can utilize a variety of other carbohydrates in addition to cellulose. While several fungi can metabolize cellulose as an energy source, only a few strains are capable of secreting a complex of cellulase enzymes, which could have practical appliance in the enzymatic hydrolysis of cellulose.

During the initial stage of the composting process, the microbial biomass increases drastically. The changes in chemical properties of the substrates also impact the succession of the microbes. Initially, the easily available organic matter triggers the fast growing heterotrophic microbes; while the degradation of polymeric material is a slow process and their degradative products can be used by other microorganisms (Ryckeboer et al. 2003b). Quantitatively, the main components of organic matter are carbohydrates, protein, lipids and lignin. Different microorganisms participate and produce different enzymes needed for degradation of these substrates. Depending on the input substrates, nitrogen may also be available in significant quantities. At a C/N ratio from 25 to 35, microbial activity is vigorous resulting in the "active phase". In general, the highest microbial populations and enzyme activities are observed during this phase.

Heterogeneous and non-uniform composting mass tends to have confined alcove with fluctuating physicochemical conditions that was observed to impact the survival of specific microbial communities. Gram-negative bacteria and fungal population expanded with increasing temperature of up to ~55°C, but decreased at higher temperature; while increase in population once the composting mass cool to ≤55°C. During the active phase, due the high temperature, fungal activity was described to be comprehensively inhibited while Gram-positive bacteria tend to dominate this thermophilic phase; and the populations decrease when the temperature decreases below 50°C. The most persuasive factor is temperature, which itself is an outcome of the microbial activities. In addition, the O_2 level tends to affect the microbial diversity and dominance. For example, a member of the *Bacillaceae* was the major dominating population (98%) when thermophilic conditions and an optimum aeration were maintained (Wichuk and McCartney 2007).

Furthermore, the low O_2 condition highly influences the fate and dynamics of nitrifying and denitrifying microbial communities (deGuardia et al. 2008). During the initial stage of composting, presence of micro-environment devotes to the activities of anaerobic bacteria; however, when the clusters are cracked during the subsequent composting process, these sites are disclosed reducing the anaerobic condition. Similarly, not all microorganisms have similar obligation in terms of water requirement and a difference in moisture content can cause a shift in the composition of the microbial diversity. In general, high water content favours bacteria over fungi. Too high a moisture content has a negative effect on the biological activity due to the increased compaction that tends to prevent the movement of air through the matrix.

9.3 SUBSTRATES FOR COMPOSTING

Natural decomposition occurs in any pile of waste material even if the C/N ratio, moisture content, and aeration are outside the recommended limits for composting; however, the decomposition proceeds at a slow rate and generate rotting

Table 9.1. Selected physicochemical properties of some composting substrates

Parameter	*Sludge*	*Pig manure*	*Horse stable bedding waste*	*Abattoir blood meal*	*Food waste*
Moisture content (%)	73–85	72–82	62–63	58–66	55–74
pH	5.3–8.3	6.7–7.3	7.0–7.2	8.2–9.8	4.6–6.6
Total organic carbon (%)	20.7–32.2	32.9–39.4	39.7–42.3	32.0–36.1	48.2–58.8
Total nitrogen (%)	3.7–10.6	3.2–3.8	1.2–1.6	12.0–14.1	1.9–6.7
C/N ratio	3.1–6.4	9.0–11.1	25.9–33.7	2.3–2.9	7.5–17.7
Organic matter (%)	57–66	78–84	91–91	96–98	83–98

Sources: Wong 2005; Wong et al. 2009; Wong 2010, Wong et al. 2011, 2012

odors (USCC 2008). To hasten the rate of microbial activity during composting, the ingredient and conditions are to be adjusted optimally. The important ingredients of a compost mix are the substrate, and/or bulking agent. The substrate is the waste to be treated while an amendment and bulking agents are used to adjust the C/N ratio, pH, bulk density and moisture content. The bulking agents create a good physical structure enabling the air movement and maintaining sufficient free air space. Physicochemical properties of many composting substrates are not directly suitable for the composting. Substrates that are available in huge quantities include biosolids, organic fraction of the MSW mainly containing the food wastes and livestock wastes; and their composting properties relevant are presented in Table 9.1.

9.3.1 Biosolids

Composting of biosolids has been a practice for nearly a century by now with notable works from Clay Kellogg Sr., Roger T. Haug and others (Johnson 1996; Haug 1993). The huge volume of biosolids and the unacceptable option of landfill disposal have made composting an attractive alternative for biosolids treatment. The disposal of biosolids is an expensive and environmentally serious issue due to the potential pathogens and pollutants in biosolids. Composting followed by land application represents one of the most economical means for the treatment and final disposal of biosolids. Biosolids is highly heterogeneous across the regions and a generalized design is very difficult to propose if a rapid, optimal and effective composting is targeted. The heavy metal contents and the chemicals used for sludge settling and dewaterability provide unique properties for biosolids in different countries. However, some general properties can be used to draw a basic level of operational strategies. Generally, biosolids is characterized by high moisture content, neutral pH and a bulk density of ∼1.0 (Lau et al. 2001), which will reduce the free air space (FAS) and the physical structure required for composting. In addition, biosolids contains high N contents, which requires a good bulking agent with high C content and good moisture absorbing capability (Wong et al. 2001).

Traditionally, most studies on sewage sludge composting have been carried out using conventional outdoors technologies such as windrows and static piles. However, odour and leachate formation are critical in the acceptance of sludge composting. In contrast, rotary drum composters are considered to produce uniform end product without any odour or leachate related problems provided adequate biofilter or other odour removal mechanisms are included. There were lot of reports on the composting of biosolids and some of the previous works clearly demonstrated the feasibility of obtaining quality compost from biosolids (Wong et al. 1997; Fang et al. 1998, 1999; Wong and Fang 2000; Chen 2012; Cukjati et al. 2012; Gould et al. 2013; Maulini-Duran et al. 2013). One critical issue is heavy metal contents of the sludge composts. Since heavy metal contents of biosolids often vary geographically (Wong and Henry 1988; Tyagi et al. 1991), the compost obtained from different sources could vary significantly and the interpretation with the compost heavy metal standards should be done carefully. Often, the labile fractions rather than the total metal concentrations tend to determine the biosolids compost toxicity upon application. Therefore, minimizing the mobility of heavy metals during biosolids composting using various additives, such as coal fly ash and lime, have received significant attention in the past (Wong et al. 1997; Ho and Qiao 1998; Fang et al. 1999; Zorpas et al. 2000; Chiang et al. 2011; Wong and Selvam 2006).

Agricultural residue, yard waste or dry plant material, shredded tires and wood chips are some of the commonly used bulking agents. Rice straw, used as bedding material in horse stables was also demonstrated to be a good bulking agent for sludge composting in a pilot-scale in-vessel composting (Wong et al. 2011). The bulking materials not just improve the physical and chemical structure of the sludge, also tend to dilute the toxic substances such as heavy metal contents of the compost product. Recently, a recyclable plastic bulking agent was reported to successfully establish the thermophilic temperature enabling reuse of the bulking materials (Zhou et al. 2014). However in such cases, the reduction in organic matter will increase the heavy metal contents jeopardizing the quality of the final compost. Therefore, caution should be exercised when selecting an ideal bulking agent.

Obtaining a farm-suitable compost from biosolids in terms of heavy metals is a challenge. Table 9.2 presents the heavy metal contents of the biosolids co-composted with horse stable straw bedding waste at two different initial C/N ratios as obtained through different mixing ratios of these substrates. Heavy metals contents indicate that the compost product is not suitable for organic farming while suitable for general agricultural purposes (Wong et al. 2011). Especially, cadmium, chromium and selenium contents are higher than the limits for organic farming. Although it is suitable for agricultural application, during continuous