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Sustainable Operation of Composting in Solid Waste Management

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Abstract

In this paper the optimum design of windrow composting is discussed. There are many reasons to consider implementing centralized open-windrow compost technology in developing countries, especially in municipalities which are not subject to the severe space restrictions. Compared to mechanized or in-vessel operations, windrow composting has many advantages as discussed in the paper. Design aspects of windrow composting facility such as process design, composting area sizing, runoff collection pond sizing, land treatment design for runoff, and capital and operating cost estimation are discussed in detail. In particular, the process design components such as feedstock (solid wastes) recovery, feedstock preparation, composting, stabilization, curing, refining and storing are analysed. A detail cost analysis (Capital and O&M Cost) is made based on processing 3000 tons/yr of yard waste, food waste, etc. to produced 1,500 tons/yr. of finished compost is made.

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Keywords: Composting, vermicomposting, design, cost analysis;

1. Introduction

Composting is defined as “a process of biological decomposition and stabilisation of organic substrates under conditions, which allow development of thermophilic temperatures as a result of biologically produced heat, with a final product sufficiently stable for storage and application on land without adverse environmental effects”. Microorganisms such as bacteria, fungi, and protozoa are involved in the biological decomposition process. Decomposition comprises two stages of biochemical transformations, namely mineralisation and humification. During mineralisation, readily fermentable organic substances such as carbohydrates (sugars) and amino acids are degraded by the metabolic activities of microorganisms, producing heat, carbon dioxide and water. Mineralisation

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results in partially stabilised organic residual. The typical biochemical reaction pathways that occur during mineralisation are:

Carbohydrates → Simple sugars → Organic acids → CO_2 + H_2O + Organic matter

Proteins → Peptides → Amino acids → NH_4 compounds → N_2 or ammonia

During humification, humic (loose and fluffy) characteristic are imparted to the dense and partially stabilised organic matter formed as a result of mineralisation. Fungal and actinomycetes organisms are involved in humification process. To give microbial transformation a good start, oxygen in excess quantities is needed during the first stage of composting. On the other hand, less aerobic conditions are preferred during the humus formation stage, to avoid excessive mineralisation of the organic substances. Microbial reactions that occur during mineralisation and the early part of humication stages are exothermic (heat releasing), thus increasing the temperature of the composting heap. The heat hastens the rate of decomposition, and helps to produce safer compost material, by inactivating pathogenic microorganisms in the solid wastes. In accordance with temperature patterns, composting occurs in four distinct phases, namely, Latent phase, Growth phase, Thermophilic phase, and Maturation phase.

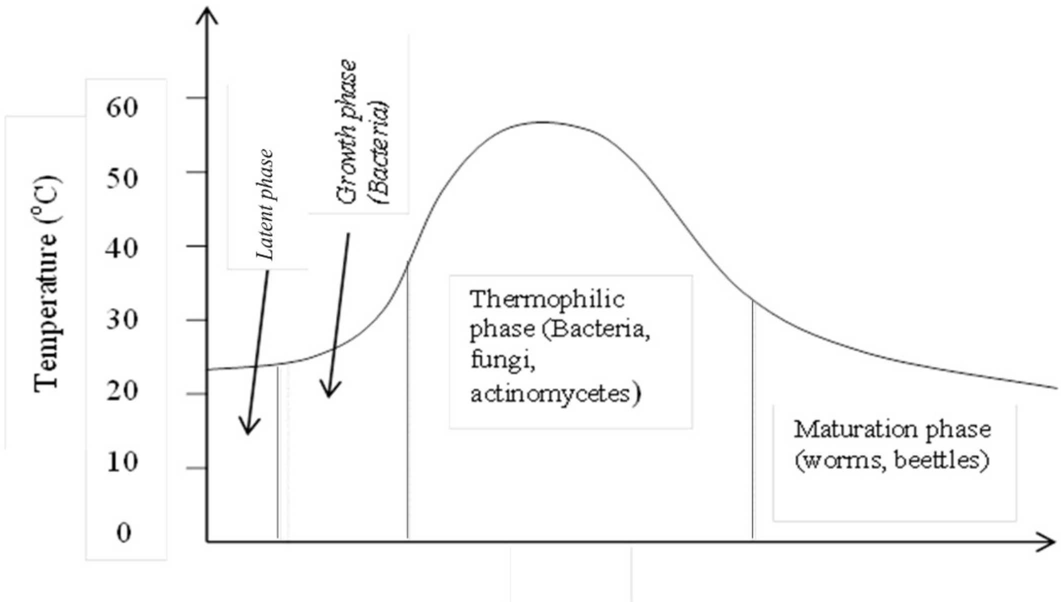

Fig. 1. Temperature pattern and microbial growth in compost piles[1]

Maturation phase: This phase is characterised by fall of temperature of the heap back to mesophilic level, and subsequently to the ambient level. Humification process completes resulting in mature compost.

Because microbes are the active agents in the composting process, factors that are conducive to their activities and proliferation are the determinants of the pace and effectiveness of the process. The ratio of carbon-to-nitrogen (C-N ratio), particle size, and moisture content are important factors. These factors depend on the composition of the waste composted. A C-N ratio in the range of 20 – 30 is generally recommended as optimal. Higher ratios lead to longer composting periods and, at lower ratios, nutrient nitrogen is lost more rapidly by conversion into gaseous forms (as ammonia or nitrogen), affecting the compost quality. Moisture content of the wastes affects the availability of oxygen for microbial reactions and, is to be maintained at an optimal range of 50-65%. Smaller particle sizes favour faster biodegradation.

Completion of the composting process and the maturity of the compost are identified from the decline of temperature of the waste heap, lack of attraction to insects, absence of obnoxious odour, and the appearance of white or gray colour due to the proliferation of fungi and actinomiycetes. The objective of this study is to discuss the optimum design of windrow composting. Capital, operation and maintenance (O&M) costs of windrow composting is also discussed.

2. Methods of composting

2.1 Static piles

For centuries, natural decomposition of solid organic matter has been exploited by the agricultural communities worldwide to prepare humus like end-product (compost) from nightsoil, and animal and agricultural waste. However, scientific understanding of the composting process, and its practical applications started only around the 1930s. Most municipal authorities in Asian countries claim to compost solid wastes, which is carried out in static piles. It is the most basic, unmanaged method of composting. Static piles are simply heaps of compostable organics which decompose spontaneously through predominantly anaerobic processes. Anaerobic composting takes long periods (typically 6-8 months) and does not normally provide high enough temperatures to destroy pathogenic organisms. It also creates problems of odor and disease vectors, such as flies.

However, to speed the rate of decomposition, discourage vermin, and avoid the production of noxious odours, several modifications to simple static piles may be employed. These include adjusting the size of the pile to optimize surface area to volume ratios, introducing large particles to improve aeration, adjusting carbon to nitrogen ratios towards optimality by using appropriate blends of different co-compost materials, and using various bulking agents as cover to discourage vermin. For example, the traditional Chinese ground-surface aerobic composting pile uses a cover layer of rice straw or mud, pierced by bamboo tubes to provide aeration.

The major benefit of static piles is that once they have been constructed, they require virtually no further maintenance. On the other hand, decomposition is usually slower and less consistent and the finished product tends to be of a lower quality than that produced through a turned windrow operation. Since access to heavy equipment such as wheeled front-end loaders may be limited for most municipalities of developing countries due to high cost or restricted availability, the static pile approach can be explored as a potentially less equipment-intensive alternative to the more sophisticated windrow composting systems.

2.2 Windrow composting

In spite of scientific knowledge, the composting process continued to be operated under anaerobic conditions till the 1950s. In the early 1950s, the basic process control information for rapid decomposition by way of maintaining aerobic conditions in waste heaps were evaluated. It was assessed that aerobic conditions can be maintained by the turning of decomposing material, adjusting the moisture content, and grinding or shredding the waste material to a smaller and fairly uniform size. Composting in aerobic conditions helped to reduce odor and fly nuisances. These findings have paved the way for mechanized windrow composting plants that employ mechanical means for turning and aeration of wastes, and for controlling temperature and moisture content, resulting in much reduced composting periods and greater sanitary efficiency.

Windrow composting systems consist of linear rows of compost materials which are turned, manually or mechanically, to improve aeration and mixing of compost constituents. Decomposition rates are faster than for static-pile systems, and finished compost is more homogeneous. In western nations, many municipalities have successfully used low-tech, aerobic, turned open-windrow composting operations to process yard and garden wastes. A smaller number have expanded their operations to process organic wastes from large-volume industrial generators.

There are many reasons to consider implementing centralized open-windrow compost technology in developing countries, especially in municipalities which are not subject to the severe space restrictions[2]. Compared to mechanized or in-vessel operations, windrow composting:

- Compost reduces the amount of waste to be disposed. Complete recovery of yard waste will reduce the amount of waste generated by an average of 12% while the addition of food waste will divert another 11.2%.
- Easy to implement and operate.
- Handles a large volume of material.
- Low capital costs.
- Requires minimal equipment and infrastructure, much of which may already be owned by municipalities.
- May be easily scaled to meet demand, from small-scale to large-scale operations.
- Is less prone to technical perturbations and breakdowns.
- May be started and ended with relative ease.
- Produces high-quality compost.
- Relatively simple to learn and implement (although the importance of good management practices and field experience cannot be overemphasized).
- Has a long and successful track record in other parts of the world

Potential drawbacks to open-windrow operations include:

- Relatively high open space requirements for compost pad establishment
- Requirement for large quantities of high-carbon co-compost, not always easily available
- Requirement for clean, source-separated organic materials free from contamination
- Often produces odors andrequires large buffer zones due to odor and vectors.
- May require processing of rainwater runoff.
- Easily affected due to the vagaries of climate (high ambient temperatures, windy conditions, monsoon season etc.). Compost can become anaerobic in rainy conditions.

2.2.1 Design of windrow composting facility

Unlike backyard composting, design of commercial-scale composting operation requiring proper process design and management. The design of a composting facility is very complex because of the large number of variables that impact the process, facility size, equipment needs and operating cost. The design process for a turned windrow composting facility involves five steps which are:

- process design
- composting area sizing
- runoff collection pond sizing,
- land treatment design for runoff, and
- capital and operating cost estimation

2.2.1.1 Process design

A well-designed commercial operation has seven defined steps
- feedstock (solid wastes) recovery
- feedstock preparation
- composting
- stabilization,
- curing
- refining and
- storing

Feedstock recovery is the process of removing the compostible fraction from a mixed waste stream. Feedstock preparation involves processes that initially establish optimal particle size, nutrient balance and moisture content of the feedstocks to facilitate microbial growth. Particle size reduction, addition of carbon or nitrogen amendments and addition of water are performed during this step. Recommended targets include particle sizes of 5 to 25 mm, a C:N ratio of 30 to 45 and a moisture content of 60 to 65%.

Kitchen wastes, fruit and vegetable market wastes are generally too wet and too rich in nitrogenous compounds to be processed effectively on their own in open windrows. To improve carbon to nitrogen ratios and ensure adequate aeration of the maturing compost, a fibrous high-carbon co-compost material is generally used. Locally available high-carbon materials like coconut hulls and palm fronds, saw dust and waste paper can be used for this purpose.

Though they are rich in carbon, abundant, and waste products in their own right, coconut palm fronds and hulls are tough, bulky, fibrous, and resistant to decomposition if left in their original form. The exterior surfaces of intact palm fronds and coconut hulls are smooth and relatively impervious, and persist for months to years in the natural environment before eventually decomposing. To increase the rate of decomposition and render adequate amounts of carbon available for the composting process, the fronds and hulls need to be chopped either manually or mechanically into smaller pieces.

Preparation of windrows: In simple, low-volume windrow composting systems, organic materials may be transported and processed by hand, and windrows may be created manually. In larger-scale operations, some degree of mechanization is usually employed. Wastes can be transported to the site by a lugger box or container truck (large volume generators) or in roll-off containers (small volume generators). A front-end loader is used for adding new organic wastes, shaping and turning windrows, adding co-compost, and moving materials about on the composting pad. In larger operations, equipment size is scaled up accordingly, and specialized windrow turning machinery may be employed.

Depending on the source of solid wastes, bulking (organic) matter may be blended with the wastes. This can be done using the bucket of the loader at the receiving end of the compost pad. To prepare the windrow, a thin layer of bulking agent is placed and the blended feed stock is moved over and placed on top of this layer. This is then lightly topd-ressed with another small amount of bulking agent in order to conceal fresh food from vermin or other vectors.

The amount of bulking agent (high carbon co-compost) required to blend with incoming food waste was about half that required in temperate regions. Typically in Canada, food waste is blended with a bulking agent at a ratio of about two parts bulking to one part food waste. The ratio of green waste/ kitchen waste to bulking agent in tropical developing countries can be reduced to about one to one, with no adverse effects. Reducing the amount of bulking agent cuts down on expenses and labours for sourcing, transporting, and processing the coconut wastes, and also reduces the size of the compost pad and storage area required. Furthermore, upon screening of finished compost, larger particles of high-carbon bulking agent can be recycled into the composting process, further reducing demand.

Using a standard, one meter long bi-metallic thermometer, temperatures shall be measured, preferably on a daily basis, typically at 2 metre intervals along the compost piles in small-scale facilities. The sampling interval commonly used at large scale commercial facilities is about 5 - 10 metres. A daily site report to keep track of temperatures, the moisture content of the compost piles, and all activities and significant events that occurred at the site is to be maintained. Depending on temperatures and the last time the windrow was watered, the windrows are to be turned with the front-end loader either daily or every second day.

Water may be added to the compost pile via a water truck on a weekly basis applying water until the compost reached field capacity (i.e., the point at which additional water applied to the pile runs off and is not retained). Water is added, when necessary, by a water truck if there is no onsite source. Moisture content can be monitored subjectively in case of lack of facilities at the composting site. If, following the turning of the windrow, a handful of material tended to hold together when squeezed, the moisture content was deemed to be adequate. If, however, water dripped from a squeezed handful, the moisture content was too high.

Composting, stabilization and curing are steps where conditions are maintained to accelerate microbial decomposition and stabilization of the feedstock (solid wastes). Typically temperature is maintained in the thermophilic range [45-65°C] and feedstocks are mixed periodically to homogenize them and provide aeration. These processes require 30 to 180 days depending on the type of feedstocks and desired level of stability of the final product. In order to maintain rapid composting, feedstocks are blended to provide an initial C:N ratio of approximately 30 and a moisture content of 60%. It is necessary that feedstocks available for composting are free of contaminants and are reduced to a particle size of from 5 to 25 mm.

A compost product is stable when its biological activity is minimal. This can be characterized by low oxygen uptake rates and low biological heat production. Stable compost is also likely to be odor-free. Refining of the compost involves screening, metals separation, removal of inert contaminants, etc. Refining and storing are optional steps that depend on market needs. Each of these seven process steps requires adequate space and equipment, which can affect the capacity, efficiency and the cost of operation.

2.2.1.2 Composting area sizing

An operation that is not sized and designed properly can have such common problems as poor product quality, high cost of operation, operating below capacity, and odour nuisances. The required land area for composting is calculated by converting feedstock throughput from mass (tonnes/yr) to volume (m^3/yr) using individual feedstock bulk densities. The total daily throughput is calculated by a direct sum of individual feedstock throughputs and assuming 250 operating days per year. This calculation assumes that volumes are additive. The estimated facility size therefore is conservative because in practice blending two materials would result in a lesser volume than estimated.

The duration of composting, anticipated shrinkage and amount of product storage are selected for design. In addition, duration and shrinkage for the curing process, windrow dimensions and buffer distance required around the facility are input. Windrow dimensions and spacing between windrows are selected based on equipment choice. A specific windrow turner can be chosen based on cost and/or capacity. Choosing higher capacity equipment results in a lower calculated operator time impacts the labour requirements for the operation. Product storage period is specified by the user based on the desired amount of product needed for a seasonal market. The user selects the windrow length. The total number of windrows is obtained by dividing the total feedstock on the composting pad by the volume of a windrow, which is calculated using windrow length and cross-sectional dimensions. The total amount of wastes in the composting pad at any time is calculated with shrinkage assumed to be linear over time. This assumption adds a safety factor because most often during composting the volume reduction is more rapid during the initial stages. Buffer zone area is added to calculate additional land area requirements. Total composting area is the total of composting, curing, storage and buffer areas.

2.2.1.3 Runoff collection pond sizing

It is important to plan for the collection and subsequent treatment of all surface runoff from a composting site. The design is normally based on the highest monthly rainfall from a 30-year historical weather data set, which will provide a pond volume greater than the 24 hour-25 year rainfall event. Installing surface drainage channel along the perimeter of composting pad to remove surface runoff during the monsoon rains and a collection and treatment pond can be the simplest of the arrangements for the purpose.

2.2.1.4 Capital and operation and maintenance (O&M) costs

The cost of composting is a function of the number of unit operations, type of equipment, number of employees and throughput of the operation. The capital costs include compost pads, grinder, compost mixer, trommel screen, front-end loader, windrow turner, and offices.

The use of additional feed materials, such as paper and mixed municipal solid waste, will require additional capital investment and materials processing labor. The number of operator hours for windrow turning is calculated based upon the total amount of material on the pad, the capacity of the turner and the number of turns for a given cycle. Similar calculations are performed for other unit operations and for general materials handling. The minimum required number of employees is calculated assuming one employee for every 2,500 - 3000 person-hours per year operator time. The user can specify additional employees for miscellaneous operations such as, quality control laboratory, management, etc. Energy costs are calculated using the total power rating of all equipment, fuel consumption rate and total operating hours. The operating costs depend on the volume of material processed. In general, annual maintenance and repair costs are estimated to be equal to 10 - 15% of the total cost of equipment. The cost of composting reported in the literature varies as a function of the scale of operation, type of feedstock and type of technology used. Because of the wide range of conditions that impact cost, feasibility studies require information involving specific conditions to calculate the cost of composting.

Investments in composting infrastructure and operating expenses are relatively modest, but in the absence of mechanisms to recoup these investments, municipalities will be reluctant to spend scarce local funds on such initiatives. The State and Central level governments should establish a program to encourage waste diversion initiatives at the local level, especially given that many such initiatives cost less in the long run than conventional disposal practices. The economic feasibility of composting can be understood from the typical benefit-cost analysis of composting in a developed country situation presented below. Though the values under different items may be much higher than in a developing country situation, the analysis will help to understand the methodology and steps involved in such analysis. Assumptions made in the analysis are:

- Process 3000 tons/yr. of yard waste, food waste, etc.
- Produce 1,500 tons/yr. of finished compost.
- Capital costs: $600,000 (does not include land costs)
- Solid waste disposal costs: $28/ton
- Cost to pickup and haul waste to landfill: $50/ton
- Operating costs (labor and maintenance): $165,000/yr.
- Avoided topsoil purchases due to use of compost: $25/ton

Table 1. Annual operating cost comparison of windrow composting and landfill

	Composting	**Disposal**
Operational Costs:		
Labor and maintenance:	$165,000	$0
Landfill costs:	$0	$84,000
Transport/waste pickup costs	$0	$150,000
Total Operational Costs:	$165,000	$234,000
Total Recovered Income		
(Topsoil Savings)	$37,500	$0
Net Annual Cost/Benefit:	$127,500	$234,000

Annual Savings for Diversion Method over Disposal: $106,500.
Capital Cost for Diversion Equipment/Process: $600,000.
Payback Period for Investment in Equipment/Process: 5.6 years.

3. Conclusion

Windrow composting is beneficial as (i) reduce the amount of waste to be disposed. Complete recovery of yard waste will reduce the amount of waste generated by an average of 12% while the addition of food waste will divert another 11.2%, (ii) is easy to implement and operate, (iii) handles a large volume of material, (iv) involves low capital costs, (v) requires minimal equipment and infrastructure, much of which may already be owned by municipalities, (vi) may be easily scaled to meet demand, from small-scale to large-scale operations, (vii) may be started and ended with relative ease and (viii) produces high-quality compost.

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