Compost Wizard©: Modeling A Compost Facility

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Abstract

Waste management planners and engineers are sometimes faced with questions of how much land, equipment, labor, and investment is required for a proposed composting operation. The numerous factors that impact process design and costs such as type of materials composted, location of facility, cost of labor, etc. make it tedious to make these assessments quickly. To address this situation, a user-friendly computer program was developed which can be used to design a composting operation based on current scientific and regulatory recommendations. The program uses critical user-inputs such as types of feedstocks, types of equipment, number of workers and location of the facility, to develop a preliminary design of the composting process and facility, and an estimate of capital and operating costs. The user can quickly generate many different design scenarios that can be used to estimate the feasibility of composting as a waste management option.

Keywords: Composting, Process design, Computer tool

Introduction

Composting is a biological process for stabilizing organic waste materials (feedstocks), where bacteria and fungi utilize the feedstocks as carbon and energy sources, converting them to stable value-added compost product used in landscaping or agriculture. Because composting is environmentally friendly and allows reuse of natural resources, it is becoming a popular waste management option. For example, the number operations that compost yard trimmings has risen 280% in the last decade to over 3,800 facilities nationwide (Goldstein and Madtes, 2000). Many states have goals of diverting and recycling 25 to 50 % of materials currently going

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to landfills. This trend has created opportunities for small businesses to start mid-scale composting operations (15 to 150 tonnes/day) targeting yard trimmings, livestock manure, food waste and some industrial organic byproducts.

Unlike backyard composting, commercial-scale composting is a complex operation requiring proper process design and management. A well-designed commercial operation has seven defined steps: [1] feedstock recovery, [2] feedstock preparation, [3] composting, [4] stabilization, [5] curing, [6] refining and [7] storing (USCC, 1994). Each of these seven process steps require adequate space and equipment, which can affect the capacity, efficiency and the cost of operation. 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 odor nuisances.

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. For this reason, a computer software tool can be particularly useful for preliminary screening in feasibility studies. Some software tools for composting process design have been developed in the past (Pike, 2000; Person and Shayya, 1994; Brodie, 1994) but they do not address turned windrow systems, leachate collection and treatment, nor the economics of the composting operation.

To address these needs, a user-friendly computer program for the design of a composting operation (Compost Wizard©) was developed by adapting techniques and information from a variety of sources. A typical Compost Wizard© user would be a designer or project evaluator who will need to provide critical user-inputs such as feedstock properties, geographical location of proposed facility, etc. and obtains process information; i.e. facility size and cost information as outputs. The user can quickly vary inputs and rapidly generate several design scenarios from which the feasibility and the appropriateness of composting can be estimated.

Description of design process

The design process for a turned windrow composting facility involves five steps: process design, composting area sizing, runoff collection pond sizing, land treatment design for runoff, and capital and operating cost estimation. The software program is in spreadsheet form in Microsoft Excel® with multiple sheets that are linked to each other. The modules of the design program utilize user-inputs and previously calculated outputs from other modules for calculations.

Composting process design

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% (Haug, 1993; Epstein, 1997). It is assumed that feedstocks available for composting are free of contaminants and are reduced to a particle size of from 5 to 25 mm. Feedstock quantities (tonnes/day), feedstock properties (C:N ratio, moisture content and bulk density) and target process conditions are required as inputs. Starting with a randomly chosen mix ratio, the fraction of each feedstock in the mix is iteratively adjusted until a total C:N ratio of 30 (or other user selected value) is obtained.

Composting area sizing

The required land area for composting is calculated by Compost Wizard© 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.

The duration of composting, anticipated shrinkage and amount of product storage are input by the user. 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. Choosing higher capacity equipment results in a lower calculated operator time. This impacts the labor requirements for the operation, which are calculated later in the economics module.

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. The total amount of feedstock in the composting pad at any time is calculated with shrinkage assumed to be linear over time. The user inputs a buffer distance that is used to calculate additional land area requirements. Total composting area is the total of composting, curing, storage and buffer areas and is displayed as a graphical sketch.

Runoff collection pond sizing

In many states, depending on the type of feedstock processed, regulations require the collection and subsequent treatment of all surface runoff from a composting site. In Georgia, composting of biosolids or mixed wastes requires a collection pond with a capacity greater than the expected runoff from a 24 hour-25 year rainfall event (GA EPD, 1996). The design criterion used in Compost Wizard© is 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.

In Compost Wizard©, the user selects the geographical region where the facility will be located. The program then automatically references the 30-year historical weather data for that region and bases the design on the month with maximum precipitation in that region. The detention pond is sized to collect this projected maximum runoff. The user specifies desired pond depth and length at the surface. The pond is sized and its volume, width at the surface, and surface acreage are calculated using the method described by Crites and Tchobanoglous (1998).

Land treatment design

The land treatment system design is adapted from regulatory guidelines (GA EPD, 1992; US EPA, 1981). Since the collected runoff is directly sprayed onto the land, the land area required for treatment is controlled by either the hydraulic budget of the soil, i.e. the water infiltration capacity of the soil, or the nitrogen balance of the cover crop that consumes the applied nutrients. The Compost Wizard© requires that the user input the soil hydraulic conductivity value, which can be obtained from the USDA-NRCS soils database. Typical values for Georgia soils range from 1.4×10^{-6} to 14×10^{-6} m/sec depending on soil type. Using the hydraulic budget calculation, the total land area required for treatment is determined.

To address nutrient loading, a nitrogen balance on the cover crop in the treatment area is conducted. The user specifies the cover crop and inputs values of total nitrogen and ammonia nitrogen concentrations in the runoff. Typical values for composting are 20 to 25 and 1 to 2 mg/L, respectively (Nutter and Overcash, 1999; Cabrera, et al., 1998). The nitrogen balance includes inputs to the system from the applied runoff and precipitation, and losses from the system through ammonia volatilization, denitrification and plant uptake. The amount of land base for treatment and the residual nitrate concentration in ground water are variables in solving the nitrogen balance. The land base required is varied to achieve the user specified residual nitrate concentration (typically 5-10 mg/L). The plant uptake rates are obtained from Plank (1989) while the ammonia volatilization and denitrification parameters are obtained from USEPA (1981). The greater of the two estimated land treatment areas, based on the hydraulic budget method and the nitrogen balance method, is used as required land area needed for treatment.

Capital and 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. This module allows the user to input wages for skilled and unskilled labor, equipment, number of windrow turns per cycle, optional road access, land costs, construction costs, insurance, etc. Typical costs and capacities for equipment are provided.

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 2,000 person-hours per year operator time. The user can specify additional employees for miscellaneous operations such as, quality control laboratory, management, etc. Energy costs, insurance and annual maintenance and repair costs are estimated using values typically used in engineering cost estimation (Peters and Timmerhaus, 1991; J. Sellers, personal communications, Athens, Georgia, 22 January, 2001).

The second portion of this module calculates a cash flow statement using adjustable inputs on tipping fee, bulk product sales, interest rate and life of loan. The total cash flow summary is provided to allow users to change inputs and estimate the $/tonne cost of processing and the expected net income.

Program validation

The Compost Wizard© was validated by comparing the program outputs to the design and operations of an existing 41-tonnes/d biosolids composting facility in southeastern Georgia. This facility composts 32 and 9 tonnes/d of yard trimmings and municipal wastewater biosolids, respectively. The total processing time for composting and curing to achieve the level of stability desired is 45 days. The facility is located adjacent to a wastewater treatment plant and all the runoff from the site is diverted to the treatment plant, therefore no collection pond or land treatment is required. The equipment used on site includes two tractors, a windrow turner, a front-end loader, one small dump truck and two side discharge trailers. Two operators run the facility, which was established in 1996 and was funded from a state grant and a low interest loan.

The results of the program calculations closely match the actual size of the facility, with an over prediction of 2.3% (Table 1). Because land was available on the site, and minimal construction costs were involved, the total capital costs for this facility was predicted to be $225,000, a value 3.2% lower than actual costs incurred. The program prediction for operating and maintenance of equipment was $22,500/year, which was 51% higher than what the facility reported. Total processing cost was calculated to be $18.8/tonne, which was 32.5% higher than what the facility reported. It should be noted that the facility is a county run operation, and in the authors' experience, costs may be underestimated because of sharing resources between departments.

Summary and conclusions

Composting at the commercial scale of 15 to 150-tons/day is a complex process involving many steps. Often cost and feasibility of composting is not well understood because of the complexity of the design process. To facilitate the quick assessment of costs, feasibility and initial design of the composting operation, a spreadsheet based design program, Compost Wizard©, was developed. The program requests user input on the proposed operation and conducts a process and facility design. Useful process outputs include amount of additional amendment required, make up water required, amount of land required for composting, curing, storage, and land treatment, size of runoff collection pond and estimated capital and operating costs.

A limited validation was conducted by comparing predicted results with actual process information from a commercially operating facility. Results showed that predictions matched actual with a high degree of accuracy in sizing, and to a lesser level in operating costs. Total costs were over-predicted by 32.5%. The program was used in a real world feasibility study conducted at a southwestern Georgia county for a proposed 187-tonnes/day MSW composting operation and proved to be a valuable tool at analyzing the impacts of various design options on cost and feasibility. In particular, it allows the user to estimate processing costs and compare these to other alternatives.

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Table 1. Comparison of predicted design with actual design at a commercial composting facility.

	Design Program	Validation	% Error

	Calculation	Case Study	
Total land required, ha	1.73	1.69	+ 2.3
Pond size, ha	0.24	n.a.	-
Land treatment, ha	4.13	n.a.	-
Capital costs, $	225,500[1]	232,887	- 3.2
Operating cost, $/yr			
Maintenance	22,550	14,927	+ 51.0
Total O&M	145,427	118,527	+ 18.5
Processing cost, $/tonne	18.75	12.87[2]	+ 32.5

[1]Does not include pond or land treatment costs.

[2]Estimated from facility records that avoided landfill tip fees are over $250,000/yr; Current tip fee $38.5/tonne.