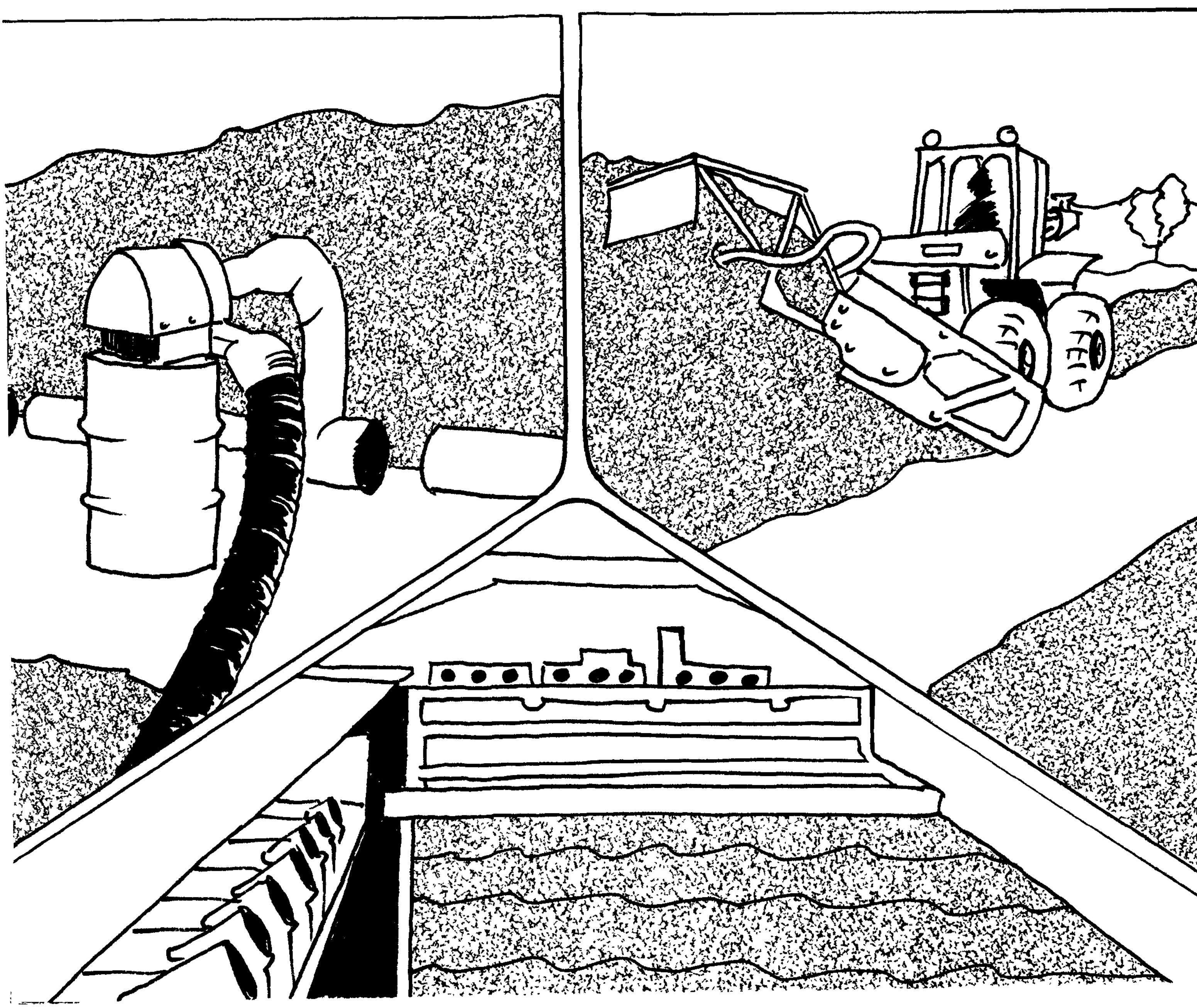
United States
Environmental Protection
Agency

Technology Transfer EPA/625/4-85/014

EPA

Seminar Publication

Composting of Municipal Wastewater Sludges



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Composting of Municipal Wastewater Sludges

August 1985

This document was published by:
U.S. Environmental Protection Agency
Center for Environmental Research Information
Office of Research and Development
Cincinnati, OH 45268

This seminar publication is wholly based on presentations made at U.S. Environmental Agency (EPA) Technology Transfer seminars on *Sludge Composting and Improved Incinerator Performance* in Columbus, Ohio; Philadelphia, Pennsylvania; Dallas, Texas; San Francisco, California; Atlanta, Georgia; and Boston, Massachusetts, from July to December 1984. This publication addresses only the composting portion of the seminars. The presentors were:

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Joel Thompson, Maryland Environmental Services, Annapolis, Maryland (Chapter 2).[1]

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[1]Joel Thompson is currently employed by the Washington Suburban Sanitary Commission, Hyattsville, Maryland.

Contents

Preface

Sludge management is a major problem for many municipalities. Ever increasing quantities of sludge are being generated as municipalities begin to comply with the wastewater treatment requirements of the Clean Water Act and as advances are made in wastewater treatment. In addition, some municipalities must seek new disposal alternatives as former sludge disposal technologies become environmentally unacceptable or too expensive.

The Clean Water Act of 1977, as amended, encourages the use of "innovative and alternative" technologies for sludge management. These include technologies that reduce costs, conserve or recover energy, reclaim or reuse water, recycle wastewater, improve operational reliability, or improve the management of toxic substances. In response to a need for information concerning innovative and alternative technologies for sludge management, the U.S. Environmental Protection Agency (EPA) sponsored six regional seminars on *Sludge Composting and Improved Incinerator Performance* in Columbus, Ohio; Philadelphia, Pennsylvania; Dallas, Texas; San Francisco, California; Atlanta, Georgia; and Boston, Massachusetts, in 1984. This publication is based on the sludge composting presentations made at those seminars.

Composting is a natural microbiological process that degrades sludge to a stable humus-like material that can be recycled to the land for use as a soil conditioner and low-grade fertilizer. Composting can have advantages over other sludge management alternatives, including lower energy requirements and capital investment than incineration; a more manageable product than land application; and a more productive, beneficial use of sludge than landfilling or ocean disposal. The process design is flexible and adaptable to a wide range of situations. It can be rapidly implemented and readily adapted to changes in sludge volume. Key features for successful sludge composting include odor control, operating flexibility, serviceability, product quality, marketing of final product, back-up arrangements for sludge disposal and utilization, and good community relations.

Because composting prepares sludge for use as a resource rather than as a waste and because it conserves energy, it qualifies as an alternative technology under the Federal Construction Grants Program. Certain composting methods or components may also qualify as innovative technologies if they have not been fully proved over time or are being employed for the first time in a state or locality. As either an innovative or alternative technology, a composting system can qualify for a higher percentage of Federal funding for eligible cost items than a system using standard technology.

This seminar publication provides practical information on current methods of composting municipal wastewater sludges. It is intended for government and private sector individuals involved in the planning, design, and operation of municipal sludge treatment and disposal systems. Chapter 1 presents general principles of the composting process and system design, including windrow, static pile, and in-vessel systems; public relations; aesthetic considerations; marketing and distribution of compost; economics; design and site layout considerations; monitoring; equipment selection; and public health considerations. Chapters 2 and 3 discuss in depth the experiences at the Dickerson, Western Branch, and Site II static pile composting operations in Maryland, and at the windrow operation in Los Angeles County. In-vessel composting is reviewed in Chapter 4. Chapter 5 discusses current and proposed regulations and guidelines that pertain to sludge composting.

This publication is not a design manual nor does it include all the latest knowledge about composting; additional sources should be consulted for more detailed information and design criteria and for the most recent information in this rapidly developing field. In addition, state and local authorities should be contacted for regulations and good management practices applicable to local areas.

1. Composting Facility Design

Introduction

Composting is one of several approaches to the management of municipal wastewater sludge. It is a biological process that converts sludge into a stable humus that can be applied to the land as a soil conditioner and low-grade fertilizer. During the past decade, an increasing number of municipalities have begun to compost their sludge. Approximately 115 sludge composting facilities are currently operational in the United States.

This chapter presents general principles for the design of municipal wastewater sludge composting facilities. Although these basic principles apply to all composting systems, there are many ways to compost, and each system must take into consideration the site-specific conditions.

Definitions

For this presentation, composting is defined as a method of solid waste treatment in which the organic component of the solid waste stream is biologically decomposed under controlled aerobic conditions to a state in which it can be easily and safely handled, stored, and applied to the land without adversely affecting the environment. Thus, composting is a controlled or engineered biological system.

Composting systems are generally divided into three categories: windrow, static pile, and in-vessel. In the windrow approach, a sludge/bulking agent mixture is composted in long rows (or windrows) that are aerated by convective air movement and diffusion and are turned periodically by mechanical means to expose the organic matter to ambient oxygen. In the static pile (or forced-aeration) approach, piles of a sludge/bulking agent mixture are aerated using a forced-aeration system installed under the piles to maintain a minimum oxygen level throughout the compost mass. In-vessel composting (also known as mechanical or enclosed reactor composting) takes place in partially or completely enclosed containers in which environmental conditions can be controlled. In-vessel systems may incorporate the features of windrow and/or static pile methods of composting. An estimated 90 percent of the operational facilities in the United States use static pile composting; the remainder use windrow methods. A few in-vessel composting systems are just starting up, and several others are under design or construction.

Compost is defined as the end product of the composting process. It is a stable humus-like substance with valuable properties as a soil conditioner. It also contains several macro- and micronutrients that are favorable to plant growth, although it is generally not high enough in nitrogen to be considered a fertilizer. The product is not completely stabilized, i.e., with 100 percent of the organic matter degraded. Rather it is stabilized sufficiently that the potential for odor generation is reduced to the point where the product can be readily stored and marketed. Heat produced during decomposition destroys many human pathogens, including many that survive other treatment methods.

Process Flow

Figure 1.1 shows the basic steps, or process flow, that apply to all types of compost systems. The two components of composting are the sludge and a bulking agent, which can consist of many different types of materials, including recycled compost, wood chips, sawdust, and shredded rubber tires. The bulking agent (except tires) serves as a carbon source during composting. It also increases the porosity and thus the surface area of the sludge that will be exposed to oxygen during composting, and it decreases the moisture level of the composting material. The first step in composting consists of mechanically mixing the bulking agent with sludge to create a sludge/bulking agent mix that optimizes the porosity, carbon content, and moisture level for composting.

The composting process takes place after mixing, and it generally requires 3 to 4 weeks to complete. During that time, the mix is aerated and biological processes decompose the sludge and generate high temperatures (above 55°C)[1] that destroy pathogens. The oxygen required to fuel the biological processes can be supplied in two ways:

- By mechanically turning the mixture so that the sludge is periodically exposed to oxygen in the atmosphere. Convective air movement and diffusion move oxygen into the windrow; turning increases porosity for air movement and helps to distribute anaerobic areas (if they exist) to the aerobic zone.
- By using a blower to force or draw air through the mix — a process known as forced aeration.

After composting, the material is usually cured for about 30 days. During this phase, further decomposition, stabilization, pathogen destruction, and degassing take place, which help to make the compost more marketable. After curing, some systems have a drying stage that can vary from several days to several months. This drying step is sometimes necessary if compost is screened to recover the bulking agent for recycling into the next batch. Compost that is not dry tends to stick together in balls and does not screen well.

[1]In this document, measurements of temperature are provided in °C. All other measurements are in English units with the metric equivalent in parentheses. This format reflects the way in which data were presented by the speakers.

Windrows and static piles at Beltsville, Maryland.

Drying may also be necessary if the bulking agent will be recycled in the windrow process.

Compost may then be stored and marketed or it may go through an additional screening step to produce a finer product. Screening is standard in most static pile systems because wood chips, which are relatively large compared to compost particles, are generally used as the bulking agent. Screening is often not necessary in windrow and in-vessel systems, however, because the bulking agent is usually sawdust, rice hulls, or some other small-particle organic material. The need for screening depends on the size and cost of bulking agent and the desired particle size of the finished compost.

Windrow Systems

In windrow systems, the sludge/bulking agent mixture is aerated by mechanically turning over the piles using a machine such as a front-end loader or specially designed equipment like the Cobey, SCARAB I, or Brown Bear (see *Equipment* section). The piles are turned frequently (e.g., daily) at first when the system has a high oxygen demand, and then about three times per week thereafter. The composted sludge is usually stockpiled for curing before distribution. The advantages and disadvantages of windrow composting are presented in Tables 1.1 and 1.2.

Static Pile Systems

Figure 1.2 is a schematic illustration of a static pile system. In static pile composting, the aeration system consists of a series of perforated pipes running underneath each pile and connected to a pump that draws or blows air through the piles. Many static pile facilities use 1- to 5-horsepower (hp) blowers that are cycled on and off. The pipes are covered with a layer of wood chips or other bulking agent that acts as a manifold to provide uniform aeration. The compost/bulking agent mixture is placed on top of this protective pad

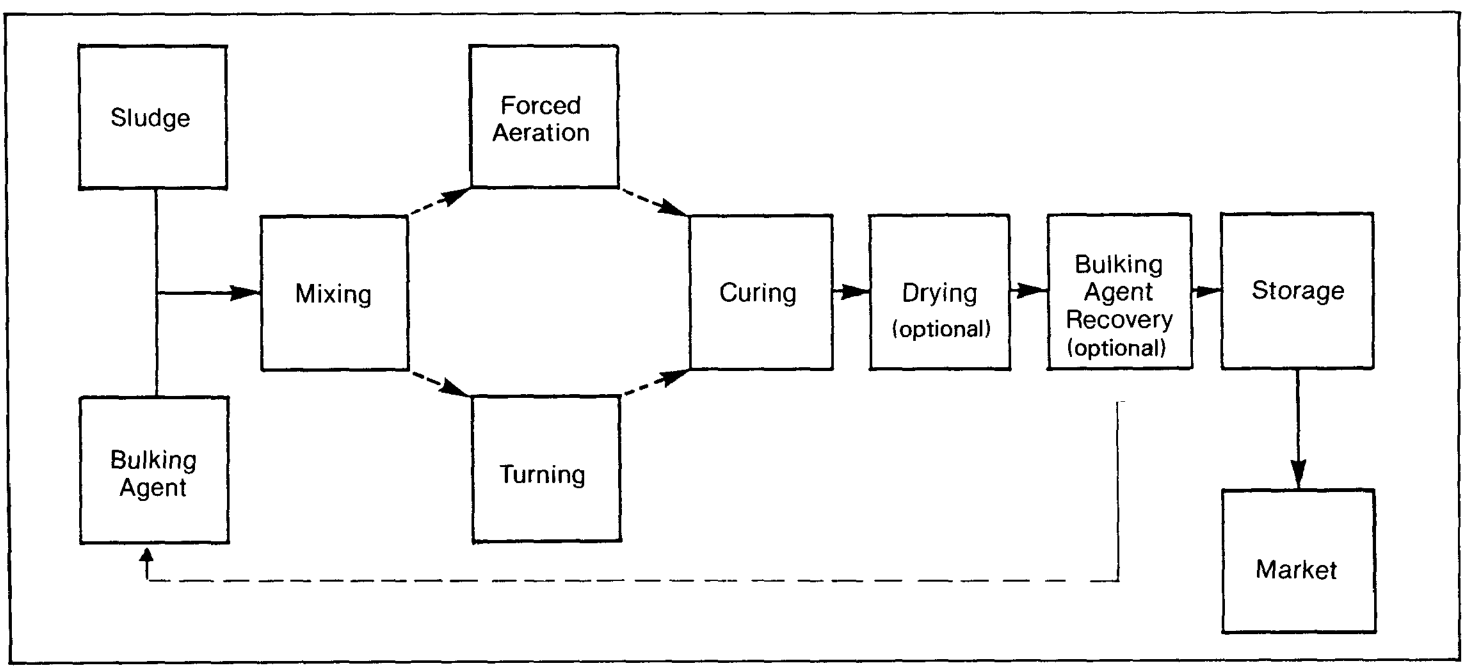
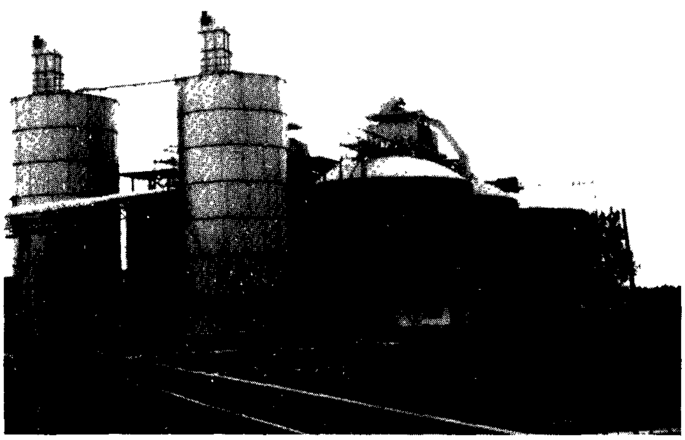


Figure 1.1. Composting Process Flow



In-vessel composting, Portland, Oregon.

to form a pile. The piles are then covered with screened or unscreened finished compost for insulation to help maintain uniform temperatures throughout the mass during composting and to provide more uniform aeration. Screened compost provides better insulation than unscreened compost because it is less porous. Several facilities use screened compost on the ends of the pile (the area farthest from the aeration pipe) and unscreened compost in the middle to create more uniform aeration throughout the system.

A static pile system should be constructed on an impervious surface to prevent migration of the leachate and/or condensate to the groundwater and to facilitate equipment operation. The static pile system is easy to implement. A pilot facility can be set up and made operational within 24 hours.

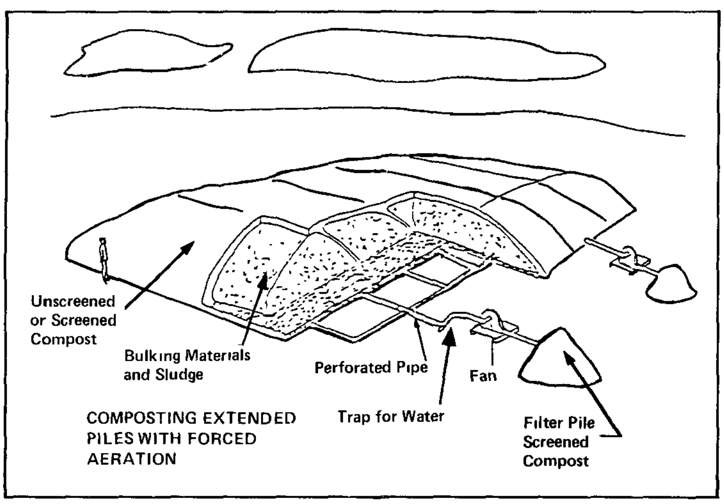


Figure 1.2. Schematic Diagram of Extended Aerated Pile

The advantages and disadvantages of static pile composting are presented in Tables 1.1 and 1.2.

In-Vessel Systems

In-vessel systems (also known as mechanical or enclosed reactor systems) are essentially just a different way of packaging the windrow and static pile systems. They are more space efficient than static pile or windrow systems because the materials can be piled higher. At present, very few in-vessel systems have begun operation in the United States, however, several facilities are in construction, design, or negotiation (see Table 4.1, Chapter 4). The advantages and disadvantages of in-vessel systems are presented in Tables 1.1 and 1.2.

Table 1.1 Advantages of the Three Composting Systems

Windrow Systems	■ Rapid drying of the compost because moisture is released as the piles are turned over. ■ Drier compost material, which results in easier separation of bulking agent from the compost during screening and relatively high rates of recovery for bulking materials when this function is practiced. ■ The capacity to handle a high volume of material. ■ Good product stabilization. ■ Relatively low capital investment: materials required are a pad for the piles, a windrow machine and, generally, a front-end loader.
Static Pile Systems	■ Low capital costs. The capital equipment required consists of a paved surface, some front-end loaders, a screen, relatively inexpensive blowers, and a water trap. (Capital costs will be higher if additional facilities such as roofs or buildings are included, but these are not essential items.) ■ A high degree of pathogen destruction. The insulation over the pile and uniform aeration throughout the pile help maintain pile temperatures that destroy pathogens. ■ Better odor control than windrow composting. The pile is kept aerobic at all times. Also with blowers in the suction mode, the odors can be treated as a point source. ■ Good product stabilization. Oxygen and temperature can be maintained at optimum levels.
In-vessel Systems	■ Space efficiency. ■ Better process control than outdoor operations. ■ Protection from adverse climatic conditions. ■ Good odor control should be possible. ■ Potential heat recovery depending on system design.

Table 1.2 Disadvantages of the Three Composting Systems

Windrow Systems	■ It is not space efficient. Substantial space is required between windrows, and the windrows themselves cannot be piled very high. Maximum dimensions for a windrow are a height of approximately 4.5 to 5 feet (1.4 to 1.5 meters) and a width of 12 feet (3.7 meters). Some prototype machines are being developed to build larger piles. ■ Although capital investment is relatively low, the equipment maintenance costs are significant. ■ Since the thoroughness of aeration depends on the skill and diligence of the equipment operator, windrow composting requires more monitoring than static pile composting to ensure that aeration and temperature rise have been adequate. Inadequate aeration can result in low, nonuniform temperatures, pathogen survival, and production of odors. ■ Odors tend to be released whenever the piles are turned, which can be a major public relations handicap for sites located near residential areas, particularly when raw and unstabilized sludges are being composted. ■ Unless covered, windrow systems cannot operate under adverse climatic conditions such as rain. Operations such as mixing and turning must generally cease during rainy spells, which is a problem for most systems where new sludge is generated daily. Furthermore, rainy conditions decrease the temperatures of the windrows and the efficiency of the curing process. This problem can be circumvented by constructing roofs over piles and mixing areas; however, this solution considerably increases capital costs. ■ It requires a larger volume of bulking agent than in-vessel systems, depending on the water content of the sludge.
Static Pile Systems	■ Greater land requirements than in-vessel systems. ■ Operations affected by climatic variability. Rain may hamper, but does not preclude, operations and may result in a less uniform product. Facilities can be covered to protect the piles from precipitation. Cold weather does not affect the system; however, cold weather composting may require certain operational modifications, and the low temperatures may be more difficult for the operator.
In-vessel Systems	■ Potentially higher capital costs. Equipment costs include the costs of design, manufacturing, and marketing the systems. These costs may be particularly high at present because very few systems have been sold relative to the investment that has been made in their design and manufacture. ■ Lack of operating data, particularly for large systems. Most enclosed reactor systems that are currently operating (in Europe) accommodate a relatively small volume of compost compared to static pile and windrow systems. A larger facility is now starting up in Portland, Oregon; its degree of success will be demonstrated in time. ■ Reliance on specialized mechanical systems, resulting in process delays and higher maintenance costs during breakdowns. ■ Potential for incomplete stabilization. Some systems propose only a few days for the biological processes, which may not be enough time to ensure a stable, odor-free product with acceptable pathogen destruction. ■ Compaction of compost mix in systems that do not provide for mixing in-vessel can result in inadequate air flow and an unstable end product. ■ Less flexibility in operational mode than with other systems.

Comparison of Composting and Other Sludge Management Options

Composting offers several advantages over the four other major sludge management alternatives: land application, landfilling, incineration, and ocean disposal. Unlike incineration, landfilling, and ocean disposal, composting offers a means of recovering a resource and productively using the sludge. The compost product is stable and odor resistant compared to sludge that is directly applied to land. Compost can be stored conveniently and is easily spread on the land using many different spreading systems. Sludge, by comparison, is difficult to handle and store.

Compared to incineration, composting uses very little external energy and the process can be initiated rapidly — in as little as a month — with relatively low capital investment. Process design can be flexible and adaptable to a wide range of situations, including changes in the nature and processing of wastewater at the treatment plant and resultant varying solids production. Also, depending on the system chosen, the sludge may not need to be digested or otherwise stabilized before composting.

Public Relations

As experience at the Dickerson, Maryland, site (see Chapter 2) illustrates, good public relations are critical to the success of a compost facility. In general, the earlier the public is involved in a project, the greater are its chances of success. One vehicle for public involvement is a citizens advisory committee. The committee can meet with site representatives, designers, and local officials on a regular or as-needed basis to air local concerns, and it can serve as the focal point for distributing information to the local community. Where possible, the committee should become involved in decision making, for example, determining the architectural treatments and landscaping. An open house or other opportunities for the public to visit a site will also help allay concerns.

Aesthetic and Environmental Considerations

The four major aesthetic concerns expressed by local communities are odor generation, noise, sightliness, and the influence of traffic patterns on transportation requirements. These considerations can greatly influence public opinion about a compost site during siting, design, and operation. Inadequate attention to them can delay or cancel a project and can hamper operations at existing facilities. These concerns should be addressed during the siting phase of a project to help ensure that public relations problems will not occur or at least will be controllable after the facility has been sited. Some constructive approaches to alleviating aesthetic concerns have included: constructing low buildings and obscuring them behind a barrier of trees (the approach taken at Cape May, New Jersey); scheduling sludge deliveries to avoid rush hour traffic and evening hours; and fining drivers for sludge spills during transportation. The potential for runoff, groundwater contamination, noise, and disruption during construction and operation must also be addressed in the work plan for a facility.

Marketing and Distribution

Distribution is the final step in all composting programs but one of the first that should be considered when designing a system. The compost may be sold or given to retailers, or it may be distributed directly to bulk and/or individual users. In a few cases, compost is used as landfill cover. Whatever approach is taken, the use or disposal capacity must equal or exceed the compost supply to prevent a large accumulation of compost on site. Many municipalities hire specialists to investigate and develop markets for their compost.

The first step in setting up a distribution program is to conduct a marketing study to identify the market for the compost. Major potential users for compost are listed in Table 1.3.

Table 1.3 Major Compost Users

Private Residential	■ Garden Applications for Food ■ Nonfood Applications
Private Food	■ Field Crops for Food and Feed ■ Garden Crops for Food and Feed ■ Fruit Trees
Private Nonfood	■ Greenhouses ■ Nurseries ■ Golf Courses ■ Landscape Contractors ■ Turfgrass Farmers ■ Industrial Park Grounds ■ Cemeteries ■ Fertilizer Companies
Public Agencies	■ Public Parks ■ Playgrounds ■ Roadsides and Median Strips ■ Military Installations ■ Public Grounds
Land Reclamation	■ Landfill Cover ■ Strip-Mined Lands ■ Sand and Gravel Pits
Landfill-Compost Disposal	

In most localities, private homeowners will constitute only a small fraction of the market. Most sales will go to bulk users. Some compost facilities market exclusively to bulk users, finding that the added expense of producing and packaging a separate product for individual use is not justified by the market size. Although application of lime-stabilized and digested sludge is widely accepted by the agricultural community, agricultural uses of compost have tended to be minimal due to such factors as the cost of the material and the low availability of nitrogen from compost in the first crop season.

When potential users have been identified, factors such as distance to the markets, transportation costs, and the costs of competing products (e.g., topsoil, peat moss, potting soil, manure, and mulch) must be analyzed to determine the viability of the market. A decision must be made as to whether the municipality will market the compost directly or will distribute it to retailers who will be responsible for marketing and sales. Unit prices for compost generally range from $8 to $29 per ton ($9 to $32 per metric ton [mt]). Although this income does not make the composting operation self supporting, income from sales can help offset operational costs. Many facilities have chosen to market the compost at the wholesale rather than the retail level.

To successfully distribute compost, a demand for the product must be created through a comprehensive marketing program. Potential users should be familiarized with the material and its uses through such means as distribution of informational materials; participation in county fairs, nursery shows, and flower shows; and educational programs at local agriculture schools. Opportunities for the public to see and touch the material will help alleviate any negative preconceptions due to its association with sludge. To establish user confidence, it may be prudent to supply the compost to new users at no cost so that they can gain experience with the material. An ongoing citizens participation program (see *Public Relations*) can also enhance product marketing and acceptance.

Attention must be paid to product image. The compost facility should be designed to generate the type of product most suitable for the identified users. If necessary, compost quality can be enhanced by screening, addition of nutrients, and mixing with other materials to create products such as mulches and potting soils. A product name and logo should be developed. Product standards and quality controls should be instituted so that the public can be assured that they are receiving a high quality product. Signs with the product name and logo should be displayed in retail outlets to advertise the product.

Guidelines for use should be prepared. One user question that may need to be resolved involves identifying a means of spreading the product, since much standard agricultural equipment will not spread compost. Application rates should be specified. User education may help to reduce seasonal fluctuations in compost demand that can lead to accumulation of materials, creating odor and storage problems. For example, many users may apply compost in the spring, when fall application would be more productive. Increasing fall demand is particularly important in states where cold weather limits much of the outdoor demand for compost. In such cases the winter compost must be stockpiled until spring, so it makes sense to distribute as much compost as possible before winter to miminize storage requirements. Alternatively, users with offsite storage capacity should be identified.

Alternative options such as landfilling or municipal use should be identified to handle unexpected problems during composting, reductions in demand, and/or batches of compost that do not meet the marketing standards.

The long-term market potential should also be considered. For example, is the demand from the identified user groups expected to increase, decrease, or remain stable in the future? Is it likely that new user groups may develop? Will more distant markets develop over time as the local communities become familiar with the product?

Although marketing studies are essential to determine the marketability of the material, their predictions are only estimates. The marketability of the product will be determined only by an actual distribution program. The program should be monitored carefully and modified if necessary to ensure that distribution keeps pace with supply.

Economics

Composting involves the capital costs of equipment, site development and construction, and operation and maintenance (O&M) costs for labor, bulking agent, energy, materials, and supplies. Figures 1.3 and 1.4 show the projected capital and O&M costs in 1984 for static pile facilities as a function of sludge solids content. Figures 1.5 and 1.6 show how estimated capital and O&M costs in 1978 for an in-vessel composting system vary with the sludge solids content. (The B.A.V. system is an in-vessel system operating in the Federal Republic of Germany.) These figures provide examples of approximate composting costs for illustrative purposes only.

As Figures 1.3 and 1.4 illustrate, both capital and O&M costs decrease dramatically with increasing solids content, making dewatering an important aspect of the composting system. Both capital and O&M costs of dewatering should therefore be balanced against similar costs for composting wetter versus drier sludges.

Tables 1.4 through 1.6 provide actual economic and operating data for small (≤1 dry ton/day [≤0.9 dry mt/day]), medium (2 to 9 dry tons/day [1.8 to 8.2 dry mt/day]), and

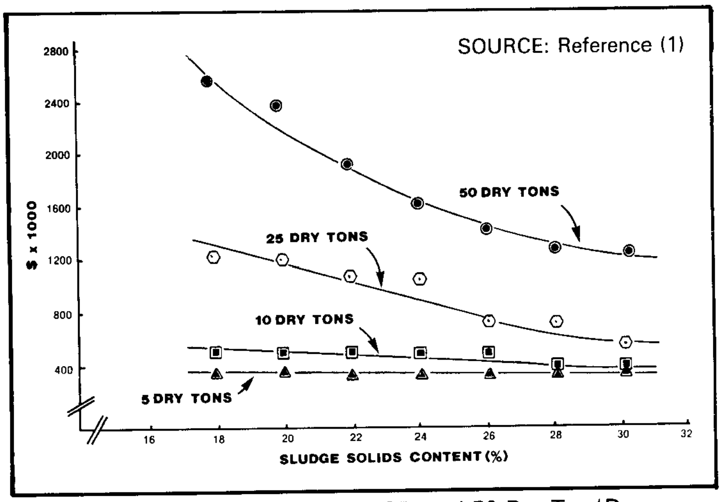


Figure 1.3. Capital Cost for 5, 10, 25, and 50 Dry Ton/Day Static Pile Compost Facilities as a Function of Sludge Solids Content

Table 1.4 Economic and Operating Characteristics of Small Static Pile Sludge Composting Facilities (≤1 Dry Ton/Day)[a]

Facility	Average Sludge Composted[b] (Dry Tons/Day)	Solids Content of Sludge (%)	O&M Costs[c] ($/Dry Ton of Sludge)	Marketing Compensation ($/Dry Ton of Sludge)	Capital Costs ($/Dry Ton of Sludge)	Person-hours Per Day Per Dry Ton Sludge	Dry Tons Per Hectare Per Day of Site Space
Swampscott, MA	0.3	25	423.08	21.45	146,666	5.8	2.23
Old Town ,ME	0.3	11	408.40	43.00	916,666	16.3	0.49
Gardner, ME	0.9	20	—	—	—	8.3	1.11
Durham, NH	1.0	15	78.28	—	660,000	4.4	2.86

SOURCE: Reference (3).
[a]Measurements are given in English tons. One English ton = 0.907 mt.
[b]Based on a 5-day week.
[c]Based on values provided by the authority; may include dewatering and transportation.

large (≥10 dry tons/day [≥9 dry mt/day]) static pile and windrow facilities. As these tables demonstrate, both capital and O&M costs vary substantially from one facility to another within each category. These variations are due to several factors such as method of cost accounting used, inclusion of dewatering costs, inclusion of transportation costs to offsite locations, amortization, and local considerations. Due to these variations, it is essential that each municipality perform its own cost estimate.

Another important economic factor to consider is replacement costs. Regardless of the method of composting employed, equipment has a useful life and must be replaced periodically. For example, Table 3.5 in Chapter 3 lists life expectancies for equipment at a large windrow facility.

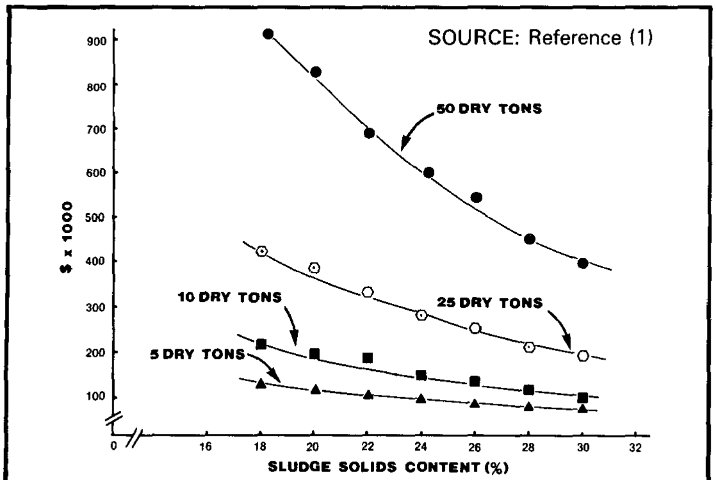
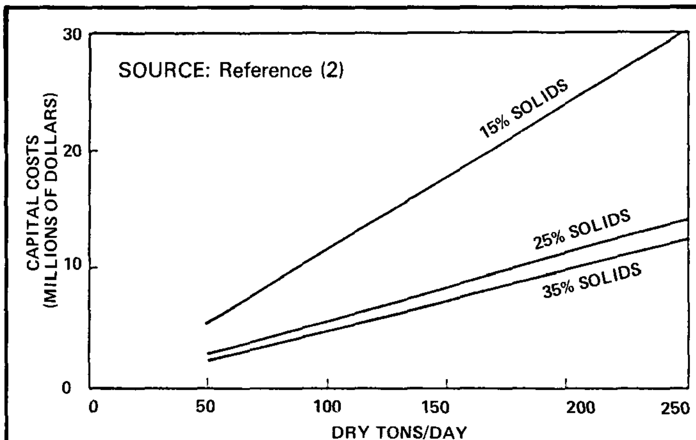
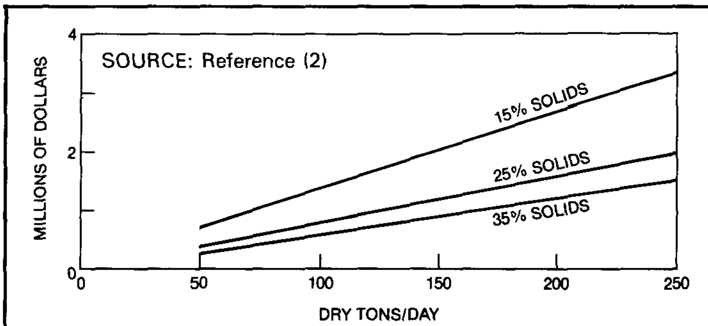


Figure 1.4. Annual Operation and Maintenance Cost for 5, 10, 25, and 50 Dry Ton/Day Static Pile Compost Facilities as a Function of Sludge Solids Content



The B.A.V. system is an in-vessel system operating in the Federal Republic of Germany. The data shown are estimated costs for hypothetical facilities that are larger than those currently operating.

Figure 1.5. Capital Costs for B.A.V. Composting System



The B.A.V. system is an in-vessel system operating in the Federal Republic of Germany. The data shown are estimated costs for hypothetical facilities that are larger than those currently operating.

Figure 1.6. Estimated Annual O & M Costs for B.A.V. Composting System

Table 1.5 Economic and Operating Characteristics of Medium Sludge Composting Facilities (2-9 Dry Tons/Day)[a,b]

Facility	Average Sludge Composted[c] (Dry Tons/Day)	Solids Content of Sludge (%)	O&M Costs[d] ($/Dry Ton of Sludge)	Marketing Compensation ($/Dry Ton of Sludge)	Capital Costs ($/Dry Ton of Sludge)	Person-hours Per Day Per Dry Ton Sludge	Dry Tons Per Hectare Per Day of Site Space
Bangor, ME	2.1	23	31.26	35.75	7,174	1.1	2.1
Morganton, NC	3.2	14	75.22	32.18	33,916	7.4	5.3
Occoquan, VA	3.6	19	44.70	0	412,500	2.8	4.4
S. Portland, ME	3.9	14	157.42	25.00	639,534	4.1	3.7
Stratford, CT	4.5	20	—	—	—	10.6	11.1
Middletown, NJ	4.5	21	169.22	0	946,000	5.3	5.9
W. Warwick, RI	5.0	14	37.77	0	—	2.2	3.1
Hampton Roads, VA	6.8	16	140.04	43.00	322,666	7.0	4.2
Merrimack, NH	8.0	21	101.73	7.15	22,988	3.0	9.8

SOURCE: Reference (3).
[a]All facilities are static pile except Occoquan, VA, which is a windrow facility.
[b]Measurements are given in English tons. One English ton = 0.907 mt.
[c]Based on a 5-day week.
[d]Based on values provided by the authority; may include dewatering and transportation.

Table 1.6 Economic and Operating Characteristics of Large Static Pile Sludge Composting Facilities (≥10 Dry Tons/Day)[a]

Facility	Average Sludge Composted[b] (Dry Tons/Day)	Solids Content of Sludge (%)	O&M Costs[c] ($/Dry Ton of Sludge)	Marketing Compensation ($/Dry Ton of Sludge)	Capital Costs ($/Dry Ton of Sludge)	Person-hours Per Day Per Dry Ton Sludge	Dry Tons Per Hectare Per Day of Site Space
Portland, ME	10	18	—	21.45	198,198	5.9	13.8
Camden, NJ	24	25	88.21	0	66,707	3.2	6.4
Windsor, Canada	24	28	53.57	0	33,333	1.3	9.9
Blue Plains, DC	68	18	174.16	14.30	72,752	1.7	28.0
Philadelphia, PA	130	20	192.31	7.15	11,538	1.7	21.4

SOURCE: Reference (3).
[a]Measurements are given in English tons. One English ton = 0.907 mt.
[b]Based on a 5-day week.
[c]Based on values provided by the authority; may include dewatering and transportation.

A lifecycle cost analysis can be a useful tool in evaluating economic alternatives. This analysis considers capital costs, O&M costs, *and* replacement costs over a 20-year period.

Design Considerations

Within each of the three basic approaches to composting — static pile, windrow, and in-vessel — there are many different choices of design and operation. Some choices will be more appropriate than others depending on the particular situation. A good system should be reliable, consistent, flexible, and free of malodors, and it should meet the expectations of the municipality.

An essential step in the decision-making process is to perform a site-specific feasibility and pilot study. This study is normally performed by an engineering consulting firm. However, it is critical that the municipality play an active role in determining the type of system for their community. The involvement of the municipality is particularly important because composting is a living process that requires attention to keep the system running properly. The municipality will ultimately operate the system and therefore must completely understand the operational requirements. When an engineering consultant is evaluating and recommending options, the municipality should ask questions and make sure they understand all the data.

Frequently, municipalities will get locked into one particular system based on the advice of a consultant or vendor and will not adequately consider the other options open to them. In such cases, feasibility studies amount to justifying a predetermined choice, rather than equally assessing the possible choices to make the best decision. The desire to justify a predetermined choice can result in inadequate attention being paid to aspects of the technology that may be difficult to implement. The ultimate result can be a system that creates frequent problems and is more expensive to operate than was originally expected.

Although compost systems can be rapidly implemented, rapid startup should be avoided. Design parameters should be carefully defined and tested through pilot studies if possible for each individual facility. Facilities should be designed with sufficient flexibility to accomodate unexpected changes in key parameters (see *Process and Operational Specifications* in this chapter). Inadequate attention to design can create problems in the long term.

Process Parameters

Several process parameters are critical to composting. One of these is the moisture level in the sludge/bulking agent mixture, which is a function of the individual moisture content of the sludge and bulking agent and the relative proportions of these materials in the mix. To ensure adequate composting, the sludge/bulking agent mixture should have a moisture level no greater than 60 percent for static pile and windrow composting and no greater than 65 percent for in-vessel composting. One purpose of the bulking agent is to reduce the moisture of the sludge, which contains 70 to 87 percent water (13 to 30 percent solids). Climate and precipitation are important factors that can affect moisture levels in static pile and windrow systems.

Another key parameter is the carbon-to-nitrogen (C:N) ratio of the sludge/bulking agent mix. Many references recommend a C:N ratio in the range of 20:1 to 30:1 as optimal for composting. One danger with applying C:N ratios in the design of composting systems is the way in which the carbon component is measured. Carbon is generally measured by burning off all the volatile matter in an oven at 450°C. This process measures the total volatile carbon content. However, not all the volatile carbon is biologically available to the organisms that compost the sludge. As a result, even when the measured C:N ratio appears favorable, enough easily degradable carbon may not be available for composting. The volatile solids content of the composting mix should be greater than 50 percent.

The pH of the sludge/bulking agent mixture should generally be in the range of 6 to 9. Lime-stabilized sludge has been composted at pH 12; however, it may take longer for the composting process to achieve the temperatures required to destroy pathogens. The bulking agent may have a significant impact on the pH of the mix. For example, sawdust may be acidic. The composting process tends to neutralize, so compost has a relatively neutral pH (approximately 6.8), regardless of the sludge pH.

The type of sludge composted affects the process. Both raw and digested sludge can be successfully composted, however, raw sludge has a greater potential for odors, which can be a problem, particularly with windrow systems. Raw sludges generally have more energy available and will therefore degrade more readily and have a higher oxygen demand. They will achieve higher temperatures faster; however, unless sufficient air is applied to satisfy the oxygen demand and cause evaporative cooling, excessively high temperatures and odors will result.

The level of oxygen in the pile during composting affects the process. An atmosphere containing 5 to 15 percent oxygen is required throughout the pile to ensure aerobic conditions.

Process and Operational Specifications

Process specifications include such factors as bulking agent, desired moisture content of the sludge/bulking agent mix, feed rate of sludge and bulking agent into the system, retention time of materials at each of the various phases of composting, and energy requirements. Operational parameters include number of workers and electricity and fuel use.

One of the most common operational problems at a compost facility is variation in the sludge and bulking agent; for example, changes in solids concentrations, volatiles content, and pH. These types of problems are generally handled by changing the mixing ratios and aeration rates. In establishing process parameters, it is therefore important to consider contingencies that may be caused by unanticipated changes in conditions. For example, what happens if the sludge solids content is 18 percent yet the facility was designed for 22 percent sludge solids content? What if the bulking agent becomes unavailable? What if sludge generation exceeds expectations for brief or extended periods of time? What kind of backup requirements are necessary? For each parameter, the range of possible values under various conditions should be determined.

Mass Balance

Mass balance is a critical step in the design of a compost facility. It establishes how much of each material (sludge, bulking agent, wood chips, etc.) is used during each phase of the operation and its fate during the process. This information is essential for determining design parameters such as ratio of sludge to bulking agent, size of the compost pad, equipment and storage needs, etc. An individual mass balance sheet should be calculated for every facility since the key parameters vary from one facility to another.

Figure 1.7 is an example of a mass balance sheet. On the left is listed each of the components involved in composting: sludge, the bulking agent, compost, mix, etc. For each of these substances, the following parameters must be measured or calculated:

- Total volume (in cubic yards [yd^3] or cubic meters [m^3]).
- Total wet weight (wet pounds [lb] or wet kilograms [kg]).
- Total solids content (dry lb or dry kg) calculated by multiplying percent solids of the material by total wet weight.
- Volatile solids content (dry lb or dry kg). Volatile solids are an indication of the amount of energy in the mixture that is available to the organisms. They affect moisture reduction and temperatures during composting.
- Water content (lb or kg).
- Bulk density (wet lb/yd^3 or wet kg/m^3). This parameter can be calculated if the wet weight and volume of the components are known. Table 1.7 provides bulk densities of various process components.
- Percent water content.
- Percent volatile solids content.

Table 1.7 Typical Bulk Density of Various Composting Process Components

Material	Density (lb/yd^3)	Density (kg/m^3)
Digested Sludge (20% solids)	1,800	1,070
Raw Sludge (20% solids)	1,400-1,650	830-980
New Wood Chips (60% solids)	550	325
Used Wood Chips (55% solids)	800	475
Unscreened Compost	1,000	595
Screened Compost (3/8-inch [1-centimeter (cm)] mesh)	1,150	685

SOURCE: Reference (1).

MIXTURE: ____________________

RECOVERY: ____________________

	TOTAL (yd^3)	TOTAL (lb)	TS (lb)	VS (lb)	WATER (lb)	B.D. (lb/yd^3)	WATER (%)	VS (%)
SLUDGE								
COMPOST								
MIX								
COMPOSTING LOSS								
UNSCREENED COMPOST								
DRYING LOSS								
DRIED COMPOST								
CHIPS, SCREENED								
COMPOST, SCREENED								

Figure 1.7. Materials Balance

The first step in performing a mass balance is to fill in the information for the sludge and bulking agent. This information can then be summed to determine the parameters for the compost mix. The percent solids of the mix is a key parameter. It must be at least 40 percent to ensure adequate composting in windrow or static pile systems. A wetter mixture is likely to cause problems. (In-vessel systems have higher horsepower blowers and therefore may be able to successfully compost a mixture with a slightly lower solids content, but this conjecture has not yet been adequately demonstrated.)

For a 20 percent solids sludge, the volume ratio necessary to achieve a mix of at least 40 percent solids is approximately 2.5 to 2.7 parts bulking agent to 1 part sludge depending on the solids content of the bulking agent (see Figure 1.8). (Volume measurements are used instead of mass because materials are generally measured with a front-end loader or truck of known volume.) In this case, wood chips at 65 percent solids are used as the bulking agent. If the water content of the sludge is too high, this ratio must increased until the moisture content is 60 percent or less. With wetter sludges, a ratio as high as 5:1 or 6:1 may be necessary to achieve a mixture with a 40 percent solids content. Since this is a substantial amount of material, some facilities with particularly wet sludges have tried to reduce costs by operating using a lower ratio mixture with less than 40 percent solids in the mix, but this procedure compromises the effectiveness of the composting process and invariably causes problems.

In some cases, sludges may not be quite as dry as engineering data suggest. For example, a sludge that is purported to have a 20 percent solids content may in fact have only an 18 percent solids content most of the time. For this reason, it is prudent to conduct a mass balance using a slightly lower sludge solids content to anticipate the types of problems that may arise.

Figure 1.9 and Table 1.8 illustrate the application of mass balance to an extended static pile compost facility that handles 10 dry tons (9 dry mt) of sludge per day. The various components that must be considered in a mass balance are labeled Item 1 through 8. Item 1 represents sludge; Items 2 and 3 represent the bulking agent (in this case new and recycled wood chips, respectively). Each of these three components has a different moisture content and bulk density. This information is used to calculate the parameters for the resulting mix (Item 4). In this example, the sludge (Item 1) has a solids content of 20 percent, and the wood chips (Items 2 and 3) have a solids content of 70 percent. This solids content input results in a mixture (Item 4) with a 41 percent solids content[1], which is favorable for composting.

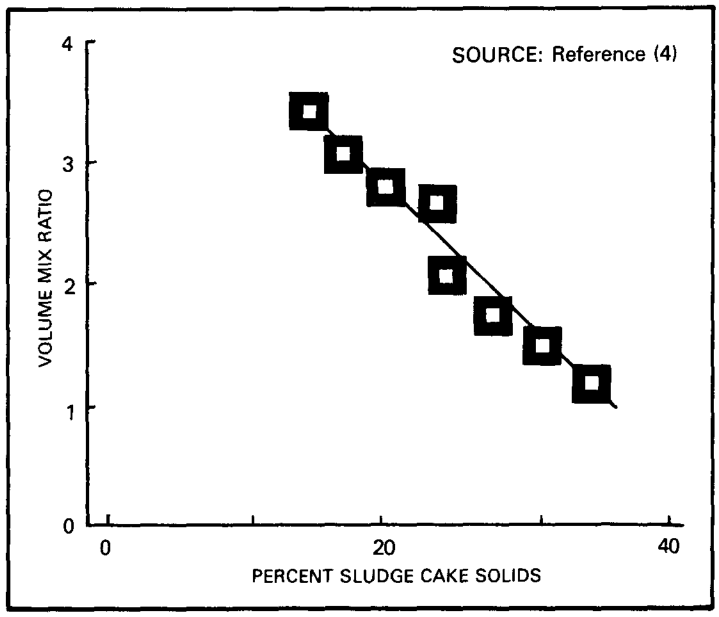


Figure 1.8. Relationship of Volumetric Mixing Ratio to Percent Sludge Solids to Achieve a 40% Solids Mixture Using Wood Chips at 65% Solids

The mass balance calculation of Items 1 through 6, which are all materials that make up the compost pile, can be completed without pilot studies during the design of a compost system. The volume and characteristics of the composted material before screening (Item 7) and the screened compost (Item 8) must be determined through pilot studies because material is lost during the composting, curing, and drying processes. Volatile solids are lost during composting. In the example in Figure 1.9, the volatile solids content of the sludge/bulking agent mix is reduced from 80 percent before composting to 65 percent after composting and 45 percent after screening. Water is lost throughout the various phases of the composting process through evaporation, leaching, and condensation. The loss of water decreases bulk density since the water in the pores is replaced by air, which is considerably lighter. However this decrease in bulk density is offset by the tendency for bulk density to be increased as the material is decomposed into finer particles, reducing the available porosity. Drying causes further water loss. In Figure 1.9, drying and screening reduce compost moisture content by 5 percent.

The volumes of the different materials indicate the amount of material that must be moved around the facility during the various phases of composting. This volume will influence equipment selection and hence the overall cost of operations. In this example, there are 87.5 yd^3 (67 m^3) of sludge; 52.4 yd^3

[1] $[(70 \times 20\%) + (13.1 \times 70\%) + (39.4 \times 70\%)]/122.5$

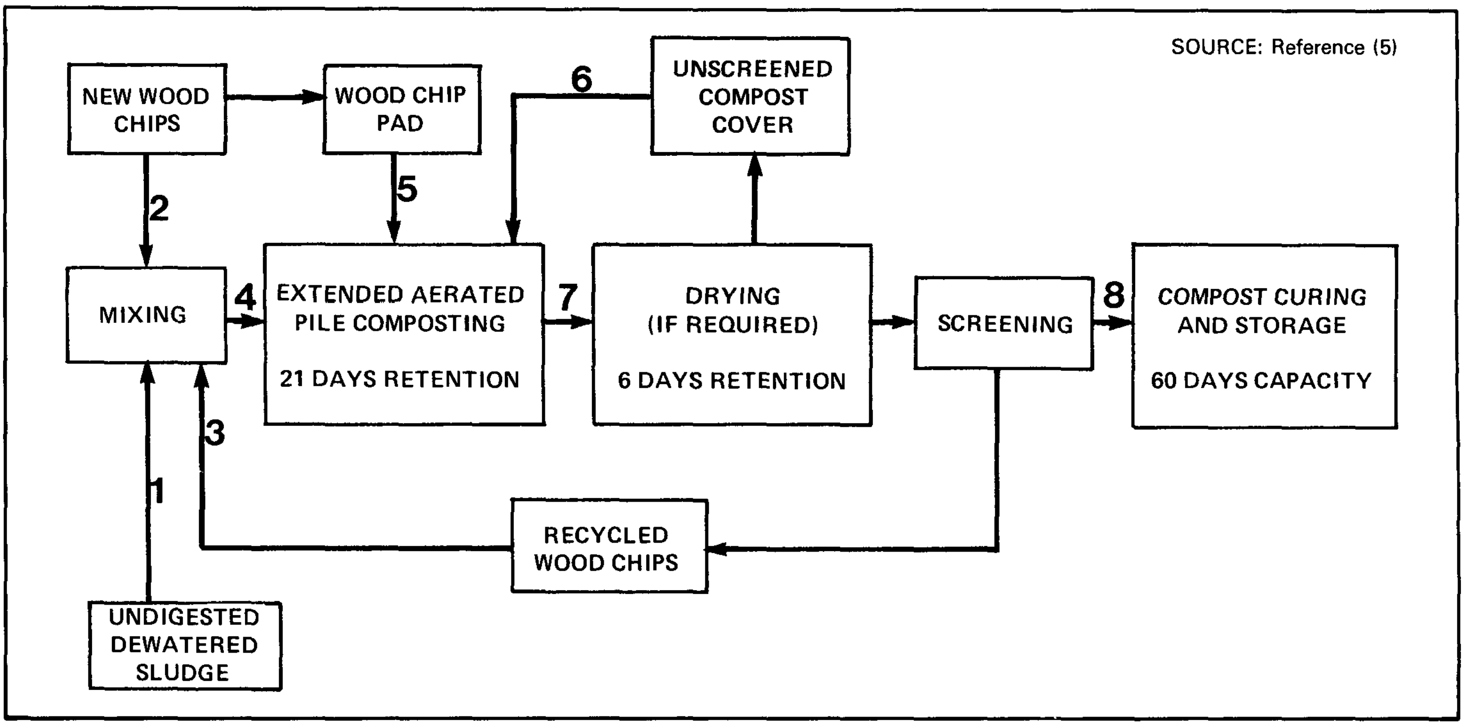


Figure 1.9. Process Flow Diagram for Extended Pile Compost Facility
(10 Million Gallon per Day [MGD] Activated Sludge, 5-Day/Week Operation)

Table 1.8 Materials Balance for Process Flow Diagram (Figure 1.9)

Component	Weight: Wet Tons	Weight: (Wet Metric Tons)	Percent Solids	Density: lb/yd³	Density: (kg/m³)	Volume: yd³	Volume: (m³)	Percent Volatile Solids
Undigested Dewatered Sludge	70	(64)	20	1,600	(950)	88	(67)	75
New Wood Chips	13	(12)	70	500	(295)	52	(40)	90
Recycled Wood Chips	39	(35)	70	600	(355)	131	(100)	80
Mix	123	(112)	41	900	(535)	271[a]	(207)	80
Wood Chip Pad	9	(8)	70	500	(295)	34	(26)	90
Unscreened Compost Cover	19	(17)	65	725	(430)	51	(39)	65
21-Day Compost Pile	90	(82)	65	725	(430)	248	(190)	65
Screened Compost	32	(29)	60	975	(560)	66	(51)	45

SOURCE: Reference (5).

[a]Although this hypothetical mix volume is presented here as the sum of the volumes of the component parts (dewatered sludge, new wood chips and recycled chips), in reality the mix volume will be significantly less than the sum of the parts.

(40 m^3) of new wood chips; and 131.3 yd^3 (100 m^3) of recycled wood chips. A volume of 248.3 yd^3 (190 m^3) of compost must be screened every day. Screening reduces the original sludge volume by about 26 percent to 65.6 yd^3 (50 m^3) of finished compost plus the recycled bulking agent.

The importance of conducting a mass balance during the design phase of composting cannot be overemphasized. It influences all aspects of the operation. One of the most frequent problems encountered in composting facilities is excess moisture. For example, moisture from compost piles may become trapped in an enclosed composting facility (see photo), causing corrosion and electrical short circuits. Mass balance calculations will help prevent these problems by making designers aware of the amount of moisture that must be vented or collected during the composting process.

Compost Product

One of the first steps in designing a facility is to identify the compost users and determine the kind of product they will need. Should the product be bagged? Will it be used by homeowners, for land reclamation, nurseries, sod farming, etc.? The answers to these types of questions will help determine which characteristics of the compost will be important goals to be factored into design.

Texture, for example, can affect the marketability of the material. Homeowners may prefer a finer product over one that contains clearly identifiable pieces of bulking material. On the other hand, the reduced porosity in a fine product may make it less suitable as a soil conditioner for agricultural or horticultural use. Coarsely textured material can be marketed as a mulch. Moisture content is also important. A wet product is difficult and messy to handle. Too dry a product creates dust, which is considered a nuisance by many users.

Enclosed composting building, Portland, Maine.

Table 1.9 Typical Static Pile Bulking Materials

Primary Bulking Materials	
Bark	Refuse
Corn Cobs	Rice Hulls
Leaves	Sawdust
Paper	Straw
Peanut Hulls	Wood Chips
Secondary Bulking Materials[a]	
Compost	Fly Ash
Dried Sludge	

[a]Used as a supplement to a primary bulking agent. Cannot be used alone.

The metals content may limit its use to nonfood-chain applications. At high levels, the presence of salts and metals may affect plant growth (see *Public Health Considerations* in this chapter). High levels of metals or salts may require careful monitoring of the product before distribution. The content and chemical forms of nitrogen, potassium, phosphorous, and trace nutrients, as well as the general growth characteristics of the compost, will affect its value as a fertilizer and soil conditioner. Another important characteristic that may affect use is pH. Color and odor may affect its marketability. Achieving the desired characteristics may require process modifications.

The size of the user market should be estimated. If it is not sufficient to absorb the predicted compost production, additional users must be identified. The additional user groups may require a different type of product.

Having defined the desired characteristics, the next major question to ask is: How much will it cost to achieve these characteristics? For example, a particular type of screen may be necessary to achieve a desired texture. Is it worth the additional cost, or should the product use be redefined?

Bulking Agent

The bulking agent is a critical parameter in any composting operation. Several different bulking agents have been successfully used in composting operations, including wood chips, sawdust, shredded tires, leaves, and chipped brush (see Table 1.9). The bulking agent affects the process and the quality of the product. Bulking agent characteristics such as moisture content must be factored into a mass balance calculation to evaluate the feasibility of the operation. Bulking agent characteristics will also affect the screening requirements.

The bulking agent must be available locally at an affordable cost in sufficient quantities to meet the needs of the compost facility. The price of the bulking agent is often tied to the transportation cost. Provisions at a compost site for handling full truckloads of bulking agent can greatly reduce the overall cost.

The availability of the bulking agent in the future, and the ability of suppliers to meet increased needs that may occur if the sludge quantities increase, should be determined. An alternative bulking agent supply or an alternative bulking agent should be identified in case of any problems.

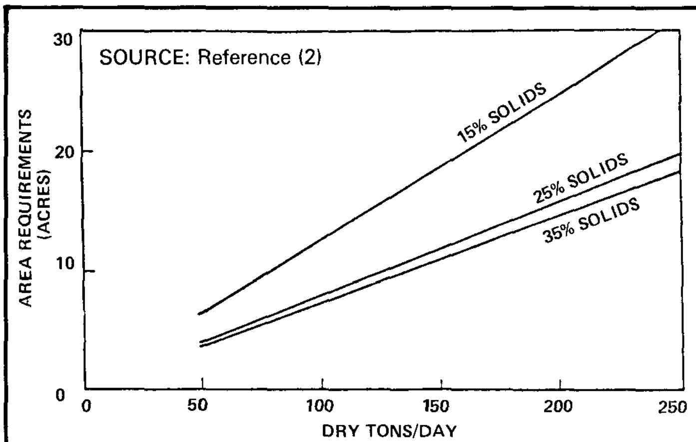
Site Specifications

Size

A composting facility must have sufficient area to accommodate:

- Bulking agent storage.
- Mixing.
- Composting pad.
- Curing.
- Screening.
- Product storage.
- Contingency, such as unexpected surges in sludge volumes.
- Materials handling.

Figure 1.10 shows how site area requirements for an in-vessel facility increase with increasing moisture content of sludge. (The B.A.V. System is a type of in-vessel system currently operating in Germany.)



The data shown are estimated area requirements for hypothetical facilities that are much larger than the B.A.V. in-vessel facilities operating in the Federal Republic of Germany.

Figure 1.10. Estimated Area Requirements for B.A.V. Composting System

In addition, the future capacity of the site must be considered. How much and how rapidly will the community's sludge generation increase in the future? Will the site be expected to handle some or all of this increase? Should composting be performed at one large site or at two or more smaller plants? Should the site be temporary or permanent?

Layout

The layout of a composting site must respond to considerations such as materials flow, traffic patterns, leachate and runoff, and public relations. Key questions include:

- What is the access to the area? Will a road have to be built?
- Can runoff be diverted directly into an existing sewer system or does a separate pond have to be built?
- Is a buffer zone necessary around the site from either a regulatory requirement or public relations (noise, odor, or visual) standpoint?
- Can the site be located next to the wastewater treatment plant? Would local residents object to having sludge trucked through their communities? What are the costs of transporting the sludge?

Leachate, Condensate, and Runoff

Leachate and precipitation runoff controls are major considerations in site layout. There are three basic sources of moisture at a compost site:

- Condensate — moisture in the air that is pulled through the pile.
- Leachate — liquid that drains from the compost mix.
- Runoff — precipitation that reaches the pad directly without going through a compost pile.

The amount of condensate generated during composting is a function of the moisture content of sludge and ambient conditions. Generally, approximately 10 to 30 gallons of condensate are generated per dry ton per day (38 to 114 liters/mt/day). The amount of leachate generated is similar; most precipitation that falls on a compost pile is absorbed or evaporated. The biological and chemical oxygen demands (BOD and COD) of the leachate are fairly high (Table 1.10), but have little impact on the treatment process because of the small quantities of leachate generated. Pooling of

Table 1.10 Analysis of Condensate, Leachate and Runoff From a Static Pile Composting Operation (mg/liter)

Source	Biological Oxygen Demand (BOD)	Chemical Oxygen Demand (COD)	Phosphate Phosphorus (PO_4-P)	Nitrate Nitrogen (NO_3-N)	Organic Nitrogen	Ammonia Nitrogen (NH_3-N)	Total Kjeldhal Nitrogen (TKN)	Alkalinity[a]	pH
Condensate	2,000	4,050	1.87	0.73	139	1,140	1,279	4,030	7.7
Leachate	2,070	12,400	2.13	0.46	655	905	1,560	2,930	7.7
Runoff[b]	91	613	0.31	0.16	58	115	173	361	8.2

SOURCE: Reference (1).

[a]Expressed as mg/liter $CaCO_3$

[b]Runoff characteristics are a function of rainfall rate and volume.

leachate and runoff is also of concern and can create both odor problems and the potential for ice formation during winter months, which is dangerous for heavy equipment operation.

In static pile and windrow systems, leachate and condensate can be controlled by installing collection devices underneath the piles and connected to a system consisting of condensate traps, leachate pumps, and a collection pond. To prevent pooling of runoff, the compost pad should have a slope of at least 2 percent. Another approach to runoff control is to construct a roof over part or all of the compost operation. Several U.S. facilities are performing the mixing and screening steps under roofs, as these steps expose a large portion of the compost surface area to the air and are therefore most sensitive to precipitation. Drying operations are also candidates for roofing protection. Static, forced-aeration compost piles are much less sensitive to moisture since only the surface, which is a layer of finished compost, is directly exposed to precipitation.

Odor Considerations

Odor control is the single most important factor that determines whether a composting facility will be permitted to operate. Odors are primarily generated by the sewage sludge rather than the compost mix. They tend to be created in facilities where sludge piles are left exposed to the atmosphere before mixing and also where composting is incomplete, for example due to inadequate aeration. The best form of odor control is to minimize odor generation by maintaining the correct oxygen supply and temperatures during composting and by keeping the compost site clean and orderly. (Although these measures will not totally eliminate odors from negatively aerated static piles, they can reduce odors to very low levels.) In addition, one or more odor control approaches should be instituted.

Compost is a good natural scrubber for odors produced by sulfur compounds. Several facilities have controlled odors by constructing a small pile of recycled compost over the manifold of a negative (suction) aeration system. One problem with this approach is that the small piles can rapidly become saturated, particularly in humid weather. When this occurs, the piles must be changed frequently, which increases the maintenance cost. To alleviate this problem, several facilities have enclosed their scrubber piles. Some compost facilities have treated air from the negative aeration system with a wet scrubber that dissolves the odorous compounds. Another approach is to oxidize the odor-forming compounds in the condensate and leachate or to scrub the gases through carbon-type filters. However, activated carbon tends to clog rapidly and is effective for only a relatively short period of time. It also requires substantial maintenance and is fairly expensive.

Equipment

The composting process requires equipment to mix the sludge and bulking agent, manipulate piles, aerate piles, and screen compost. Table 1.11 lists some of the main equipment options for these processes.

Mixing Equipment

Mixing the sludge and bulking agent is an essential step in all composting operations. The goal of mixing is to create uniform porosity and coating of the bulking material with sludge throughout the mixture. Nonuniform porosity will short-circuit the air flow, resulting in nonuniform composting and a poorer quality product. The other goal of mixing is to spread the sludge evenly over the bulking agent. Composting takes place at the surface where there is contact with oxygen, so the process will be enhanced if the surface area of the sludge can be increased by contact with the bulking agent.

Table 1.11 Composting Equipment

Mixing	**Pile Manipulation**
Compost Machines	Conveyors
Front-end Loaders	Flails
Mixing Boxes	Front-end Loaders
Pugmills	Outfeed Devices
Rototillers	Windrow Machines
Aeration	**Screening**
Stationary Piping	Flexing Screen
Moveable Piping	Rotary
Flexible	Trommel
Nonflexible	Vibratory Deck
Blowers	
Multiple	
Single	
Positive Pressure	
Negative Pressure	
Both Positive and Negative Pressure	

Brown Bear machine used for mixing sludge and bulking agent at St. Paul, Minneosta compost site.

Pugmill mixing devices are used at several compost sites. Sludge and the bulking agent are fed in from hoppers. Paddle wheels inside the device mix the materials, and the mix is then dropped onto a conveyor. This is a highly reliable device that produces a good mix. It is relatively small — approximately 12 feet (4 meters) long and 1.5 to 2 feet (0.5 to 0.6 meters) wide. In several of these devices, the feed rate and thus the sludge/bulking agent mix ratio can be readily varied. One problem with the pugmill system has been adequate feeding from the wood chip hoppers. This problem has been experienced by several facilities, however, it has been largely resolved.

Other types of mixing devices used at several composting facilities are machines such as the Brown Bear, the Cobey composter, and the SCARAB I. To use the Brown Bear, sludge and wood chips must be laid down in alternating layers. An auger on the Brown Bear then turns over and mixes these layers. The advantages of this device are that it can be implemented quickly and can handle large volumes of material. However, the system requires substantial space, it is messy, and there is significant potential for odor generation because sludge is often left on a pad for some time before being mixed. There is also the danger of an uneven mix if the original layers of sludge and wood chips are not uniform. The operator can correct this problem by using a front-end loader to redistribute the materials, but this may not happen if the operator is under pressure to complete the job within a certain period of time.

A third type of mixing device is known as a mixing box. The sludge and bulking agent are weighed by a built-in electric scale and mixed using augers enclosed in a metal cylinder. All these mixing boxes have outfeed devices, and some have extender conveyors on the side. These devices serve the dual function of mixing the material and building the piles. They provide a very uniform material within approximately 3 minutes. Originally designed for mixing agricultural feed, which is a much lighter material than sludge, some devices have been more successful than others at mixing compost. Problems have included insufficient power and capacity. However, several systems have operated successfully at compost sites. Middletown, New Jersey, and Windsor, Ontario, are two facilities that currently use these devices. One advantage of the mixing box is that it is not subject to outdoor conditions.

Most compost facilities — particularly smaller facilities — use a front-end loader for mixing. This is one of the least expensive mixing options since a front-end loader is already required for other parts of the composting operation. Since the quality of the mix depends to a large extent on the amount of time spent by the operator, front-end loaders are less foolproof than other mixing systems.

The composting facility in Hampton Roads, Virginia, uses an augmented front-end loader approach. This facility constructs a layer of wood chips, and then uses a truck to place a layer of sludge on top. The sludge and wood chips are mixed with a front-end loader for 20 to 30 minutes, which provides a mixture with about 44 percent porosity. This material is then put into a manure spreader, which increases the porosity to 60 percent. This final step increases the materials handling requirements but provides the significant benefits of reducing blower head loss and improving compost

Agricultural rototiller at Hampton Road, Virginia compost site.

quality. As with the other outdoor mixing approaches, this method is subject to odor and space problems.

A final type of mixing equipment is the agricultural rototiller. This device provides an adequate mix for composting, but not as complete a mix as the pugmill, the manure spreader, or mixing box. The Windsor, Ontario, facility used rototillers for several years but has recently converted to mixing boxes. The advantages of rototillers are that they are readily available and provide a fairly uniform mix.

The cost of the various mixing systems depends on many factors. Even within a single approach, costs can vary significantly depending on auxiliary features such as bin size and the length of conveyor systems. More expensive systems, such as the compost machines, can be cost effective for large facilities where the machines would be used continuously. The potential for schedule disruptions due to equipment failure should also be considered. The simplest machines — the front-end loaders and rototillers — can be readily replaced in the event of equipment failure, however, they do not routinely provide as good a mix as other devices.

Pile Manipulation Equipment

Pile manipulation equipment is used to move materials within a site. A major requirement of manipulation equipment at a compost site is that it preserve the porosity of the material. Pile manipulation devices used at compost sites include front-end loaders, conveyors, flails, outfeed devices, and windrow machines.

Aeration Systems

Aeration systems are a component of static pile and in-vessel composting systems. Aeration for the different in-vessel systems is discussed in Chapter 4. Static pile aeration has two basic components: conduits (e.g., pipe) to conduct the air flow, and blowers. The conduits may be stationary or moveable and the materials may be reusable or disposable.

Stationary Systems

In stationary, or enclosed piping aeration systems, the aeration channel is a square- or V-shaped channel formed into the concrete composting pad. Piping is placed in the channel and covered with wood chips to provide a manifold effect. A metal grate is then placed over the channel to cover and protect the pipe. Some stationary systems use no pipes and rely on the channel to control the air flow. Stationary systems must have provisions for drainage to prevent precipitation and condensation from accumulating in the channels. Also, the channels must be narrow enough and the protective metal grating strong enough to support heavy equipment.

The advantages of a stationary system are: reduced time required for pile set up; reduced operational costs because less pipe and fewer wood chips are required; and decreased possibility of crushed pipe. One major disadvantage of stationary versus moveable systems is the higher capital cost of constructing concrete channels rather than an asphalt pad. There is also significant potential for pipe clogging, which reduces the air flow. Therefore, stationary systems require periodic maintenance and checking for excessive head loss. Pile design flexibility and aeration modifications are much more limited with stationary systems. The configuration cannot be changed in response to research findings or operational experience.

The composting facility in Denver, Colorado, is an example of a stationary pipeless system. The channels are approximately 1.5 feet (0.5 meters) deep and 15 inches (38 cm) wide, with a shoulder to hold a metal grate. Air is blown through the channel and flows through holes that are spaced about every 3 or 4 inches (8 to 10 cm) on both sides of the protective metal grate. A fabric cloth topped with a protective layer of sand covers the metal grate and provides the manifold effect. This system experienced some clogging and head loss problems, so a plastic covering is being evaluated.

Moveable Systems

A moveable system consists simply of piping laid on the ground surface. It is far more widely used than stationary systems. The piping can be flexible plastic, rigid plastic, or steel. Flexible piping is considered disposable and is discarded after each composting period (approximately 21 days).

Moveable systems have many advantages: virtually no maintenance; low capital costs; design flexibility; and ease of modification. For example, if a facility determines that more air should be drawn through the pile without increasing electrical use, moveable pipes can be moved closer together. Stationary systems do not offer this flexibility. The flexible piping is expensive, however — up to 40 cents a foot ($1.30 per meter) — which substantially elevates operational costs since new piping must be purchased frequently. It is also susceptible to crushing. The reusable rigid steel or plastic pipe is generally maintenance free and is fairly resistant to being crushed. It provides the same pile design flexibility as flexible piping, however, the capital costs are higher and provisions must be made for recovering and storing the pipe between uses. Pulling rigid pipe out of the pile requires manpower and space to maneuver and can be a hazard to personnel.

Blowers

Single or multiple blowers can be used at a composting facility. Multiple blowers offer flexibility, since the aeration rate can be varied over the compost period and from one pile to another. Single blowers have higher O&M costs and much less flexibility, which increases the potential for problems.

Aeration can be positive or negative or a combination of both. Negative, or suction, aeration was used in the original forced-aeration composting system at Beltsville, Maryland. One advantage of this approach is that any odors are funneled into a point source and can therefore be more readily controlled. Experience with compost systems suggests that an interchangeable negative/positive mode may be the best approach. Generally, a suction mode should be maintained for the first 8 to 14 days of composting until the odors generated during the initial composting phase have diminished and temperatures that meet Processes to Further Reduce Pathogens (PFRP) requirements (see *Primary Pathogens* in this chapter) have been achieved. Then the blowers should be reversed to provide positive aeration, which will accelerate the drying of the compost.

From a biological point of view, the microorganisms need only about 5 grams (gm) of oxygen per gm of dry solids to stabilize the material. Drying, however, requires approximately 9 to 10 times more air. Most of the initial work at Beltsville, Maryland, was designed in terms of maximizing temperatures for pathogen destruction at the expense of drying potential. The parameters developed at Beltsville were published in several EPA guidance documents (including reference [5]), and have served as the design basis for many subsequent facilities, which are consequently underdesigned

Multiple blower system at compost site in Blue Plains, DC.

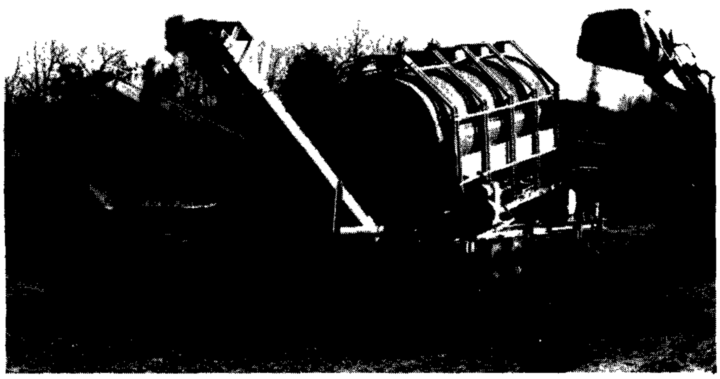
in terms of aeration capacity for optimum drying capability, odor control, and stabilization.

Experience during the past few years suggests that whatever electrical power is theoretically needed to maintain the necessary oxygen supply during composting should be quadrupled to ensure that larger blowers can be accommodated later if necessary. It is much easier to install excess electrical power during construction than to try to increase capacity after a facility becomes operational. The O&M costs are the same whether or not the excess power is used. Installing excess capacity is therefore generally recommended.

Calculating the aeration rates and electrical power supply needed for a facility depends on the distribution system, head loss, blower size, etc., and will not be covered in this publication. This information is available in literature from blower manufacturers. In Windsor, Ontario, a 1-hp blower is used to aerate 120 to 140 wet tons (109 to 127 wet mt) of 26 to 30 percent solids sludge cake. Research at Camden, New Jersey, suggests that about 1,500 cubic feet (ft^3) of air per hour be supplied per dry ton of sludge (47 m^3/dry mt/hr) [5]. Newer findings and experience suggest that more air may be advisable.

Screening Equipment

One piece of equipment that is essential to static pile composting is a screening device to separate the bulking agent from the composted material before marketing. Screening has several advantages: it enables a portion of the bulking agent to be recovered and recycled; it reduces the volume of material to be marketed; it produces a better quality product; and it enables the coarseness of the material to be varied by using screens of different sizes. Screening tends



Screen used at Beltsville, Maryland site.

to be a very difficult process because it is very sensitive to the moisture content of the composted material; too high a level of moisture makes screening difficult. This can be a major problem with static pile composting.

Several different types of screening devices are available, including vibratory decks, rotary screens, and trommels. In evaluating the various alternatives, the following factors should be considered:

- Ability to change screen size and produce compost with different textures.
- Ability to screen compost with different moisture contents.
- Separation efficiency.
- Ability to handle compost with different bulking agents.
- Ease of cleaning.

Equipment Selection

Some key questions to consider when determining the equipment needs for a system include:

- How reliable is the equipment?
- How rapidly can the equipment be repaired in event of failure? What is the availability of parts? Can repairs be made locally? Can they be made at the facility? Are special tools required to perform repairs?
- What kind of backup equipment is needed?
- Has the equipment been used successfully at compost facilities? For example, can the hydraulic system of the front-end loader tolerate the sludge material getting behind the hydraulic hoses without breaking them?

Table 1.12 Suggested Parameters and Sequence of Sampling for a Municipal Sludge Composting Operation

Media	Parameter	Frequency
SLUDGE	Moisture Content	Initial and Periodic (Monthly) Depending on WWTP[a] Process Changes
	Heavy Metals and Toxic Organics	Initially to Establish Range: Periodic Sampling Thereafter
	Pathogens	As Required by Local and State Regulations
	pH	Initially and as WWTP Process Changes
SLUDGE AND BULKING MATERIAL	Moisture Content	Initially to Adjust Bulking Material Ratio: Periodic as Related to Sludge Consistency
COMPOST a. Process	Temperature	Daily Until 3 to 5 Consecutive Days Above 55°C are Recorded in the "Toes" of the Pile. Weekly Thereafter
	Oxygen	Initially to Set Blower Operations; Periodic Depending on the Temperature Changes in the Pile
	Odors	Daily to Identify and Correct Any Odor Problems from Scrubber Piles, Blower Operations, or Improper Cover
	Blowers	Daily
COMPOST b. Product	Heavy Metals	Initially and as Required by Authorities
	Soluble Salts	Initially and as Changes Occur in the WWTP Operation
	Plant Nutrients	Initially — Establish Range
	Pathogens	As Required by Health Authorities
SITE	Meteorological	Establish Norms for Use in Design
	Leachate and Runoff	Initially for Design Purposes

SOURCE: Reference (1).

[a]WWTP=Wastewater Treatment Plant.

- How versatile is the equipment under different operating conditions? For example, if a screen is being selected, can the equipment successfully screen compost over a range of moisture levels? Can it successfully screen compost with different bulking agents? Can it produce compost with different textures?
- What kind of power needs does the equipment have? Would this power be sufficient to produce the desired results under all conditions?
- What is the expected lifetime of the equipment? What are the maintenance requirements and costs? Will these increase over time?

One important way to get information about equipment is to talk to and visit equipment operators at other compost sites. Equipment vendors should be able to provide names of other clients who can serve as references. In evaluating information from this source, it is important to be aware how the facility being designed differs from the reference facility. Any differences may cause the equipment to perform better or worse at the new facility than at the reference facility.

Monitoring

Monitoring the sludge, bulking agent, compost process and product is essential from an operational, marketing, and public relations standpoint. Table 1.12 lists suggested parameters for monitoring. The section on *Primary Pathogens* in this chapter describes time-temperature and indicator-organism monitoring for pathogens.

Public Health Considerations

The three major public health concerns from a regulatory viewpoint are primary pathogens and heavy metals in the compost product, and secondary pathogens (including *Aspergillus fumigatus*) at the compost site.

Primary Pathogens

Primary pathogens can infect most individuals, regardless of their state of health. The primary pathogens that may be found in sludge are viruses, bacteria, protozoa, and parasites such as helminth worms. One important concept concerning the survival of these pathogens is the D-value. A D-value is the time it takes to achieve a $\log_{10}$ destruction of a specific organism at a specific temperature. Table 1.13 gives D-values for five organisms that may be found in sludge. According to these data which were obtained under laboratory conditions, it would take 7.5 minutes at 60°C to achieve a $\log_{10}$ destruction of *Salmonella*.

Table 1.13 D Values for Destruction of Various Microorganisms by Heat

Organism	D-Value (Minutes at 60°C)
Adenovirus	0.15
Ascaris Ova	1.3
Poliovirus	1.5
Staphylococci	3.3
Salmonella	7.5

SOURCE: Reference (6).

Table 1.14 Temperatures Attained During 21 Days of Static Pile Composting of Raw Dewatered Sludge[a]

Bulking Material	Ratio of Bulking Material to Sludge (Dry Wt.)	Avg. Max. Daily Temp. °C	Max. Temp. °C	No. of Days Minimum Temp. Exceeded 60°C
Wood Chips	1.5:1	80	82	6.5
Paper Cubes	1:1	74	80	8
Auto Salvage	1:1	74	80	3.5
100% Leaves	2.5:1	77	77	9
60% Leaves 40% Wood Chips	2.5:1	77	84	10
Peanut Hulls	2:1	77	81	8
Shredded Tires[b]	1.8:1:1.5	77	81	14

SOURCE: Reference (4).

[a]These temperatures were achieved during early developmental research for sludge composting. It is now realized that temperatures this high are not optimal for composting. Ideally, temperatures should not exceed 60°C.

[b]The ratio for shredded tires includes compost added to reduce the moisture content of the sludge.

Table 1.14 shows temperatures attained during some early experiments at the composting facility in Beltsville, Maryland, using a variety of bulking agents. Temperatures were recorded over 21 days of composting. The lowest average maximum daily temperature was 74°C, and the number of days during which the minimum temperature exceeded 60°C was never less than 3.5. A comparison of these data with the D-values suggests that significant pathogen reduction probably took place during these composting trials. Tests by Burge et al. [7] showed that *Salmonella*, fecal coliform, and total coliform were virtually destroyed after 10 days of composting (Figure 1.11). Data from Burge et al. [7] indicate that virus populations are reduced during both windrow and static pile composting (Figure 1.12). Burge and Cramer [8] looked at pathogen destruction during windrow composting as a function of depth within the windrow (Figure 1.13).

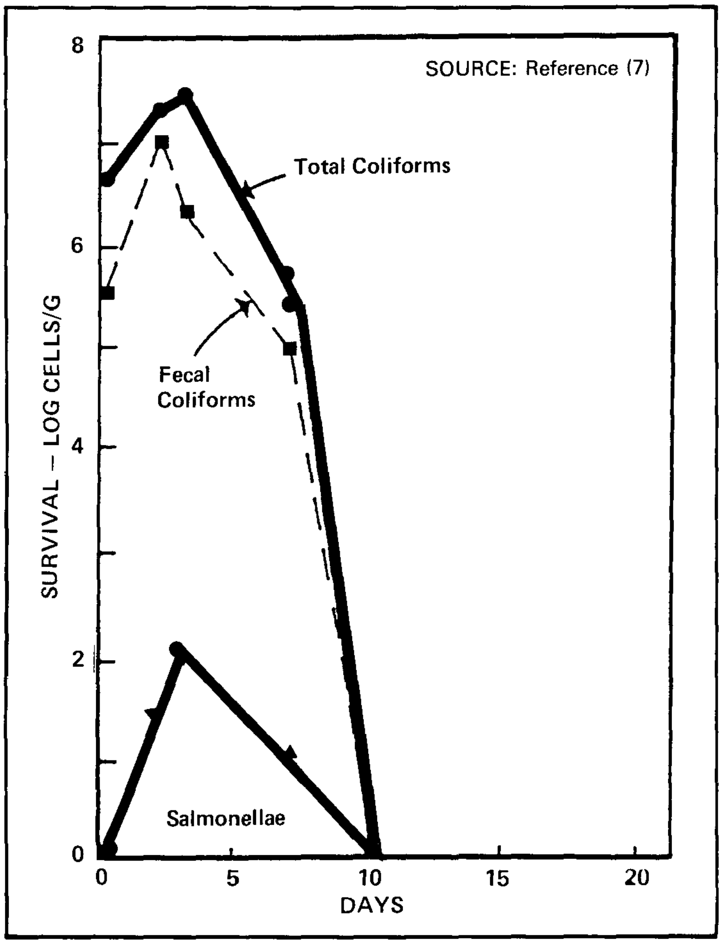
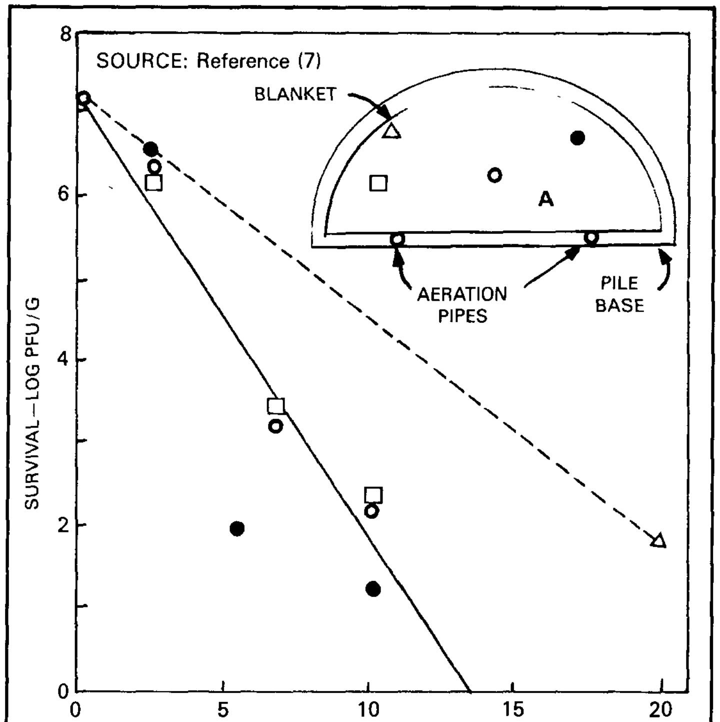


Figure 1.11. Destruction of Salmonellae, Fecal Coliforms, and Total Coliforms During Forced Aeration Composting of Raw Sludge



A shows pile cross-section with approximate location of sampling sites. PFU/G = plaque-forming units.

Figure 1.12 Destruction of f_2 Bacterial Virus During Forced Aeration Composting of Raw Sludge

They found good destruction of *Salmonella* at all pile depths after 15 days. The destruction of total coliform and fecal coliform was good at depths of 80 to 100 cm after about 15 days; however, it was not as good at depths of 20 to 40 cm from the pile surface, and at 0 to 20 cm, it was poor. One reason for the relationship between pile depth and pathogen destruction in windrows is the lack of an insulating cover layer on the windrow pile; this makes the surface layer of windrows sensitive to ambient temperatures.

Based on these and other similar data, the EPA issued the 40 CFR Part 257 regulations, which define Processes to Significantly Reduce Pathogens (PSRP) and Processes to Further Reduce Pathogens (PFRP) that must be followed in composting systems. Static pile, windrow, and in-vessel composting meet PSRP criteria if the pile achieves temperatures of 40°C for 5 days, with temperatures greater than 55°C for 4 hours. Under these conditions, pathogens are considered to be significantly reduced. For most compost uses, however, another, more stringent level of control is mandated. This level is PFRP. To meet PFRP criteria, in-vessel and static pile systems must achieve temperatures of 55°C for 3 days. The products of PFRP processes are considered safe for unrestricted direct contact use. Because operational data have shown that pathogen destruction varies with pile depth in windrows, the PFRP criteria for windrow composting are more stringent. They require that windrows maintain a temperature of 55°C for 15 days and that the piles be turned over at least five times.

Although not required by EPA regulation, compost at some locations is monitored for levels of indicator organisms that are present in large numbers before composting and that are more resistant to destruction than most other similar pathogens. Total and fecal coliform and *Salmonellae* are often used as indicators of bacterial survival. Eggs of *Ascaris lumbri-*

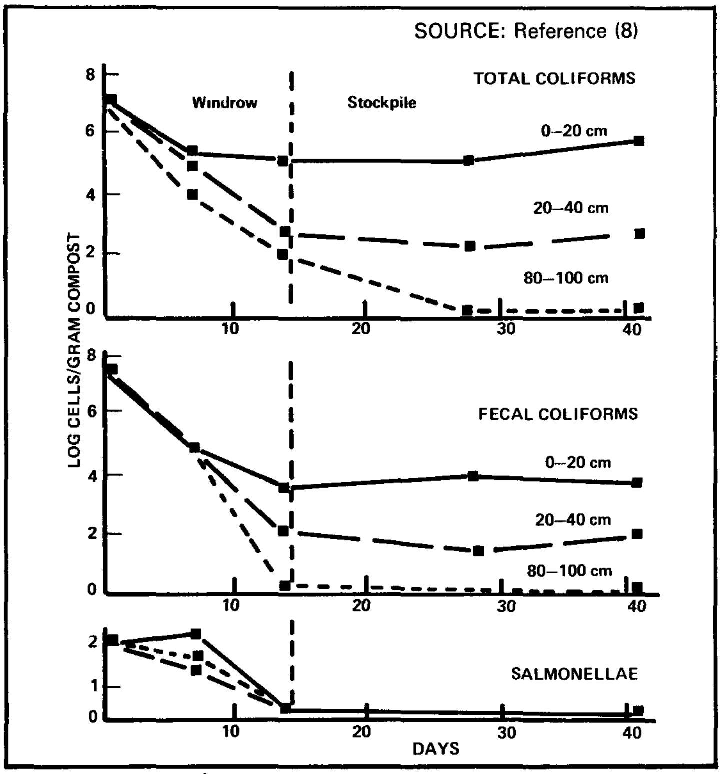


Figure 1.13. Pathogen Survival at Three Depths During Windrow Composting

coides, one of the most resistant pathogens, are used as indicators of parasite survival. Tests for these organisms are relatively simple and rapid. If indicator organisms have been sufficiently reduced, it is assumed that all pathogens have been adequately destroyed. Even with these results, curing for 30 days can be an additional safeguard to ensure adequate pathogen destruction.

Secondary Pathogens

Aspergillus fumigatus is a common fungus that tends to proliferate in the warm environments, including rotting leaves and compost piles. This fungus — a secondary pathogen — can cause a respiratory condition, called aspergillosis, in susceptible individuals, such as the immunosuppressed, the elderly, and individuals with asthma or other respiratory ailments. *Aspergillus* spores are ubiquitous. They are found in all natural environments. A few years ago, when there were few data on how composting operations affected the ambient atmospheric levels of *Aspergillus* spores, local communities expressed concern about whether composting would lead to an increased incidence of aspergillosis because of the propensity of *Aspergillus* for growing on the wood products that serve as bulking agents for most composting operations. Two recent [9,10] studies have shown that composting does temporarily elevate spore levels at the compost site during certain operations such as mixing, but it does not significantly increase levels in the local community. Concerns about the health of site personnel can be addressed by screening out susceptible personnel, using air-conditioned enclosed cabs, and/or equipping potentially susceptible operators with masks.

Heavy Metals

Heavy metals are a public health concern because of their potential to (1) enter the food chain if food crops or livestock feed are grown on compost-amended soil or if cattle forage in a compost-amended area; and (2) harm children who may consume nonfood substances such as soil or compost. Many heavy metals are not usually present in large enough concentrations to pose a threat, are bound by the soil system in highly insoluble forms so that they are unavailable to plants, or are not taken up by plants in appreciable amounts. Cadmium has been the metal of greatest concern associated with land application of sludge and sludge products since it can be taken up in the edible portions of plants in significant concentrations. If a sludge contains heavy metals, public health concerns about the compost quality can be addressed by crop management, e.g., by not growing food-chain crops on compost-amended soil, or by growing only crops that are known not to take up the metals of concern, or by controlling pH (high pH reduces metal uptake).

The acceptable heavy metals content of sludge compost from a public health standpoint depends, therefore, on how the sludge will be used. Several states regulate the heavy metals content of sludge compost. The projected metals content of sludge compost is an important factor to determine during the planning phase of a compost system as it may affect the marketability of the compost.

Since composting is a biological process, it does not eliminate metals. Any metals in the sludge will be present in the compost in virtually the same quantities. Composting may, however, dilute the concentrations of the metals to some extent, depending on the type and proportion of bulking agent. Table 1.15 provides examples of sludge heavy metal content and Table 1.16 shows some examples of the dilution effect. Using wood chips as a bulking agent and assuming a 75 percent recovery of the bulking agent, the concentration of metals is reduced by about 25 percent. A dilution factor of 25 percent is a reasonable assumption for most composting operations that use wood chips as the bulking agent.

Table 1.15 Total Elemental Composition of Sewage Sludges from a Number of Municipalities in the United States[a]

Component	Concentration[b]		
	Minimum	Maximum	Median
		%	
Organic C	6.5	48.0	30.4
Inorganic C	0.3	54.3	1.4
Total N	0.1	17.6	3.3
NH_4^+-N	0.1	6.7	1.0
NO_3^--N	0.1	0.5	0.1
Total P	0.1	14.3	2.3
Inorganic P	0.1	2.4	1.6
Total S	0.6	1.5	1.1
Ca	0.10	25.0	3.9
Fe	0.10	15.3	1.1
Al	0.10	13.5	0.4
Na	0.01	3.1	0.2
K	0.02	2.6	0.3
Mg	0.03	2.0	0.4
		ppm	
Zn	101	27,800	1,740
Cu	84	10,400	850
Ni	2	3,515	82
Cr	10	99,000	890
Mn	18	7,100	260
Cd	3	3,410	16
Pb	13	19,730	500
Hg	1	10,600	5
Co	1	18	4
Mo	5	39	30
Ba	21	8,980	162
As	6	230	10
B	4	757	33

SOURCE: Reference (11).

[a]Data compiled from over 200 samples from eight states.

[b]Values expressed on 110°C weight basis.

Table 1.16 Composition of Raw and Digested Sludge and Their Respective Composts[a]

Component	Raw Sludge	Raw Sludge Compost	Digested Sludge	Digested Sludge Compost
pH	9.5	6.8	6.5	6.8
Water (%)	78	35	76	35
Organic carbon (%)	31	23	24	13
Total N (%)	3.8	1.6	2.3	0.9
NH_4^+-N (ppm)	1,540	235	1,210	190
P (%)	1.5	1.0	2.2	1.0
K (%)	0.2	0.2	0.2	0.1
Ca (%)	1.4	1.4	2.0	2.0
Zn (ppm)	980	770	1,760	1,000
Cu (ppm)	420	300	725	250
Cd (ppm)	10	8	19	9
Ni (ppm)	85	55	–	–
Pb (ppm)	425	290	575	320
PCBs[b] (ppm)	0.24	0.17	0.24	0.25
BHC[c] (ppm)	1.22	0.10	0.13	0.05
DDE[d] (ppm)	0.01	0.01	–	0.008
DDT (ppm)	0.06	0.02	–	0.06

SOURCE: Reference (12).

[a]Sludge from the Blue Plains Wastewater Treatment Plant, Washington, D.C. Compost produced at the U.S. Department of Agriculture composting facility, Beltsville, Maryland.

[b]Polychlorinated biphenyls as Arochlor 1254.

[c]The gamma isomer of benzene hexachloride is also called lindane.

[d]DDE results from the dehydrochlorination of DDT.

The dilution factor should be taken into account when determining whether the compost product will meet state regulations for heavy metals content. For example, if a sludge contains 15 parts per million (ppm) cadmium and the state limit for cadmium in sludge compost is 12 ppm, a system can probably be designed to produce compost that will meet the state regulation. If the heavy metals content of the sludge is too high, however, either the metals content must be reduced through source controls or an alternative method of sludge management must be considered.

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2. Experiences at Static Pile Composting Operations

Background

This chapter discusses experiences at three static pile composting facilities (Figure 2.1): the Western Branch site in Prince Georges County, Maryland; the Dickerson site in Montgomery County, Maryland; and Site II in Montgomery County, Maryland.

Sewage from the District of Columbia, and parts of sewage from Montgomery and Prince Georges County in Maryland and Fairfax County in Virginia, are sewered into the Blue Plains wastewater treatment plant, a regional facility located in and operated by Washington, D.C. In 1982, the regional facility produced approximately 1,750 wet tons (1,590 wet mt) of sludge per day: approximately 300 wet tons (270 wet mt) from Fairfax, 400 wet tons (360 wet mt) from Montgomery, 350 wet tons (320 wet mt) from Prince Georges County, and 700 wet tons (640 wet mt) from the District of Columbia. These four jurisdictions were thus jointly responsible for utilizing or disposing of sludge from the Blue Plains facility. In 1974, these jurisdictions signed a Regional Sludge Agreement to the effect that each jurisdiction would handle its share of the sludge.

Western Branch Site

Water, wastewater, and sludge from Montgomery and Prince Georges Counties are managed by the Washington Suburban Sanitary Commission (WSSC). The WSSC initially utilized burial in trenches (entrenchment) as an interim disposal method for sludge from these two counties; however, this approach met with mounting opposition, had very expensive land requirements, was subject to permit restrictions that limited future uses, and ultimately required expensive land reclamation efforts. In 1980, the Maryland Health Department discontinued the permitting of sludge trenching. Faced with the need to find an alternative sludge use or disposal method, Prince Georges County decided to conduct static pile composting at a site next to the Western Branch Wastewater Treatment Plant at the eastern border of the county.

Design

The Western Branch site was designed and constructed in 1980 by the Maryland Environmental Service (MES) based on design parameters developed by the U.S. Department of Agriculture's Research Center at Beltsville, Maryland [1]. At the time, these parameters represented state-of-the-art knowledge about static pile composting. Designed to handle up to 1,000 wet tons (910 wet mt) of sludge per day, the site was equipped with four aeration pads, each 600 to 700 feet (180 to 210 meters) long and approximately 120 feet (40 meters) wide. An additional 30 acres (12 hectares [ha]) of paved area were provided for storage, screening, and drying. The aeration system consisted of ⅓-hp blowers spaced 24 feet (7 meters) apart and connected to 4-inch (10-cm) plastic perforated pipe. Each blower aerated 30 dry tons (27 dry mt) of sludge. Ponds were constructed to receive runoff from the site.

Public Relations

The Western Branch site had a minimal public relations program. In fact, many local residents were not even aware that a compost facility was being constructed. Concerns about the local impact of such a facility were minimized because of its location next to a wastewater treatment plant, and no significant public opposition was experienced during construction.

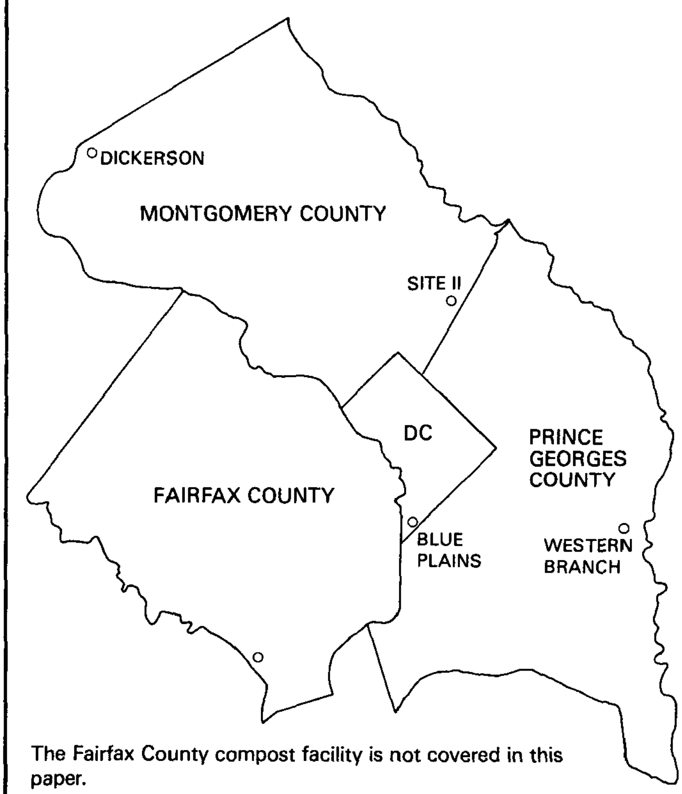


Figure 2.1. Active and Inactive Composting Sites in the Region Served by the Blue Plains, D.C. Wastewater Treatment Plant

Operations

In January, 1981, the Western Branch site was forced to start operation prematurely, when only the four composting pads — about one-third of the total site area — were complete. Despite these limitations, the site operated for four months, composting 350 wet tons (320 wet mt) of sludge per day with few problems or complaints. However, the tonnage to the site tripled to approximately 1,000 wet tons (910 wet mt) per day when the Maryland Health Department banned sludge landspreading at several locations in the county due to public opposition.

Although the site had been designed to handle that capacity, construction was still only partially complete, and the operations suffered as a result. Operations were routinely continued into the night in an attempt to handle the large volume of sludge, resulting in diminished quality control and errors such as inadequate mixing and inadequate aeration due to damaged system components. As a result, the facility began to generate odors, and local residents formed a committee that forced the facility to close until construction was complete. Once construction was completed, the facility reopened to handle 350 wet tons (320 wet mt) of sludge per day. Public sentiment, however, was so negative that the facility was soon closed permanently. One repercussion of that experience is that the committee is now working to close the adjacent wastewater treatment plant.

The Dickerson Site

In 1977, Montgomery County decided to utilize static pile composting as its sludge utilization/disposal method. They designated a site in the eastern part of the county near the Prince Georges County border as the location for their permanent "Site II" composting facility. However, fervent opposition by local residents in this densely populated area resulted in construction delays. Despite a 1978 court order requiring the Washington Suburban Sanitary Commission to build and operate Site II, construction was delayed for two more years until 1980, when the State Health Department decided to discontinue the permit for the sludge trenching sites. At this point, Montgomery County selected a site near Dickerson, at the western end of Montgomery County, as an "interim" facility.

To enhance public relations, the county formed a Citizens Advisory Committee to serve as a vehicle for disseminating information about the facility and as a forum for airing and developing responses to public concerns. This approach was fairly expensive initially, however, it precluded many potential public relations problems later. Nevertheless, when the site was ready for operation in January 1981, a citizens'

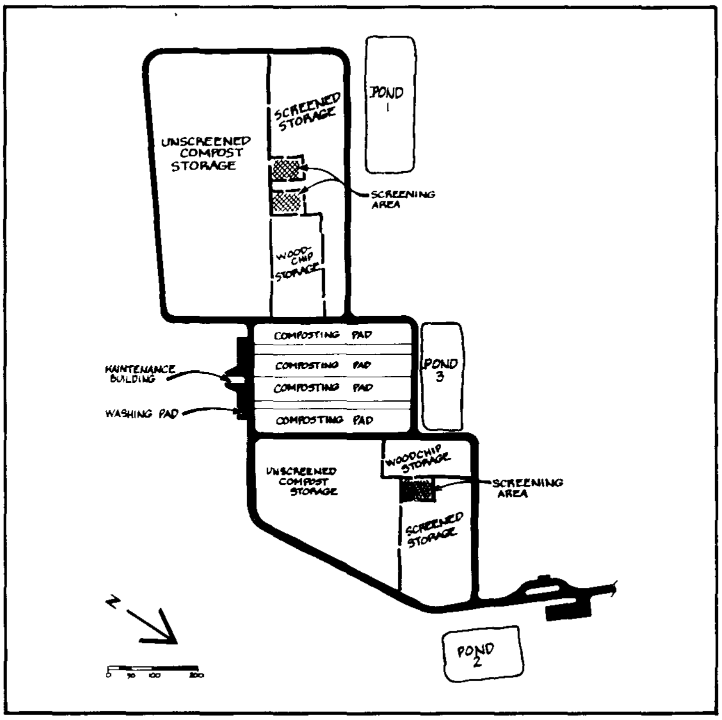


Figure 2.2. Dickerson Compost Facility, Montgomery County, MD

group initiated adjudicatory hearings to delay operations. To end the hearing process, a stipulation was signed that required Dickerson to close when Site II opened. At this point composting commenced at the Dickerson facility and trenching was discontinued.

Design

The Dickerson site is very similar to the Western Branch site. It was designed and constructed in 1980 by the MES based on the design parameters developed at Beltsville. Figure 2.2 shows the site layout. Like Western Branch, Dickerson contained four aeration pads, approximately 700 by 120 feet (215 by 35 meters) in area; an additional 30 acres (75 ha) of paved area for storage, screening, and drying; a series of ⅓-hp blowers spaced 24 feet (7 meters) apart and connected to 4-inch (10-cm) pipes; and runoff ponds.

Public Relations

The experience at the Dickerson site was essentially the opposite of that at Western Branch. The public was totally aware of the site from the beginning. The facility did have some startup problems that resulted in odor production. The public, who were essentially waiting for the facility to make a mistake, reacted immediately through the already-established channel of the Citizens Advisory Committee. These problems were immediately and successfully addressed, and the site continued to operate to the satisfaction of most of its neighbors.

Process Modifications

Although Dickerson was only a temporary site, it provided an opportunity to refine the Beltsville process. Continual efforts were made to improve the process throughout the site life. In this sense, Dickerson was essentially an extension of the Beltsville research.

Mixing Procedures

One of the startup problems was inadequate mixing. To combat this problem, site personnel experimented with various ways of using a Cobey composter and a front-end loader until they discovered a standard procedure that would provide consistent uniform mixing. These methods were then strictly followed. Another change instituted to ensure adequate mixing was increased quality control. The foremen and loader operators were trained so that they could inspect each mix and determine whether the mix was thorough and at a proper moisture content. This visual inspection was double-checked by sampling and laboratory testing.

Sludge: Wood Chip Ratio

Another problem that resulted in odor generation was the high moisture content of the mix. Ideally, the sludge: wood chip mixture should have a moisture content of no greater than 60 percent to facilitate mixing and to provide the proper environment for composting. The initial mixing ratio used at Dickerson was 2.5 to 3 yd^3 of wood chips per wet ton of sludge (2.1 to 2.5 m^3 per wet mt of sludge), based on the experience of MES operations at the pilot plant in Beltsville, Maryland, with a higher solids content sludge. (This ratio is in mixed units, i.e, yd^3 [volume] for wood chips and wet tons [weight] for sludge, because these are the quantities in which wood chips and sludge are delivered.) This ratio resulted in a mixture with a 70 percent moisture content, which created anaerobic conditions and resultant odors. The excessive moisture was a result of the decreased sludge solids (13 to 18 percent at Dickerson versus 20 percent at Beltsville) and the increased moisture content of the wood chips (45 percent at Dickerson compared with 40 percent at Beltsville).

In response to this problem, the Dickerson facility increased the wood chip: sludge ratio to approximately 4.5 to 5 yd^3 of wood chips per wet ton of sludge (3.8 to 4.2 m^3 of wood chips per wet mt) and varied it as needed to maintain a mix moisture content in the 60 to 65 percent range.

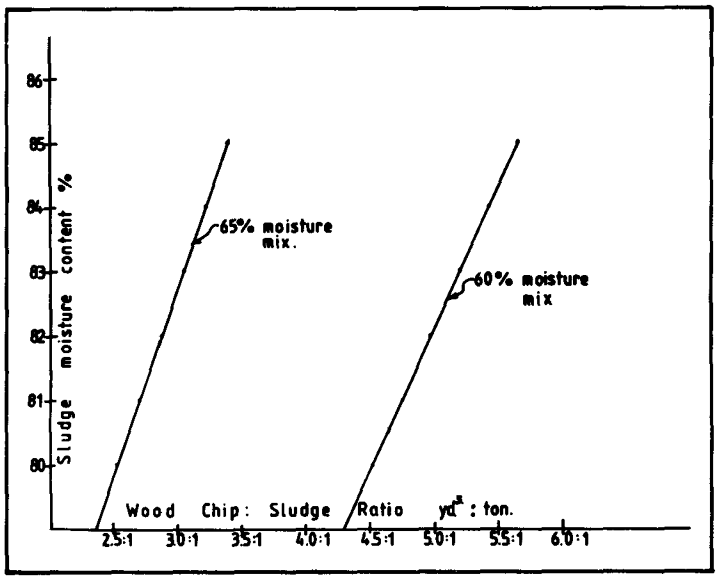


Figure 2.3. Sludge Moisture vs Bulking Ratio
45% Wood Chip Moisture

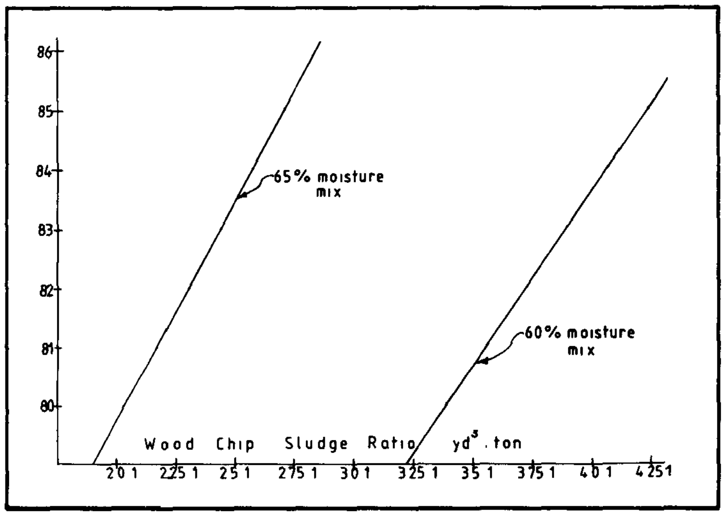


Figure 2.4. Sludge Moisture vs Bulking Ratio
40% Wood Chip Moisture

Figures 2.3 and 2.4 illustrate the wood chip: sludge ratios required to generate mixes with 60 and 65 percent moisture content for sludges of various moisture contents. Comparing Figures 2.3 and 2.4 shows the dramatic difference that a 5 percent change in wood chip moisture content can have on the ratio necessary to achieve a desired mix moisture content.

Leachate and Odor Control

Two additional sources of odors at Dickerson were the leachate and condensate generated during composting. Leachate generation, in particular, can be substantial at a compost facility. Figure 2.5 shows the amount of leachate and condensate generated by a single compost pile containing 29 dry tons (26 dry mt) of sludge. The collected leachate and condensate peaks at almost 900 gallons (gal) (3,400 liters) per day, which is equivalent to 30 gal per dry ton sludge per day (113 liters per dry mt of sludge per day) approximately on the sixth day of composting.

The Dickerson site was originally designed so that all leachate and condensate would drain into channels where it would flow to open ponds and be pumped out and transported to the nearest wastewater treatment plant. (Due to the rural location of the site, a sewer line to the plant was not feasible.) However, as this high strength liquid accumulated in the ponds before pumping, it became a significant odor source. The solution to this problem was to install sump pumps to intercept the liquid as it flowed to the ponds and pump it into waiting tank trucks, which then hauled it to the nearest wastewater treatment plant. With this system, liquid reached the ponds only during periods of peak stormwater flow when the capacity of the sumps was exceeded. This liquid tended to be dilute, with little or no odor.

Stringent housecleaning procedures were also instituted to eliminate any potential for pooling of liquid on the compost pad. Road sweepers and water trucks were used to keep the pad clean. These combined measures basically eliminated the odor problem. Good housekeeping practices had the added benefit of improving public relations. Complainants were invited to visit the site. Its tidy appearance generally mollified their concerns.

The odor control system for the piles originally consisted of piles of screened compost to filter the air that had been drawn through the piles. However, these piles tended to saturate rapidly due to the large amount of moisture in air exiting the system. In response to this problem, a barrel-shaped device that functioned as a heat exchanger and water trap was installed between the blower and the filter pile. As air passed through the device, its velocity decreased, allowing it to cool; the moisture in the air condensed on the inside surface of the barrel. When the blower was switched off, the condensate drained through a check valve into the channels where it was then pumped into tank trucks. This system was able to collect up to about 30 gal (115 liters) per day of condensate (Figure 2.6). Many of the odorous compounds were dissolved in the condensate and never entered the atmosphere. The dehydrated air then passed through the screened compost filter piles, which retained their odor-trapping ability for a much longer period of time.

Other problems encountered early in the operation included poor positioning of the intake pipes from the compost piles to the blowers, which impaired drainage (see photo). This impaired drainage caused condensate to collect in the pipes and block the air flow, again resulting in anaerobic conditions in the pile. The pipes were repositioned to

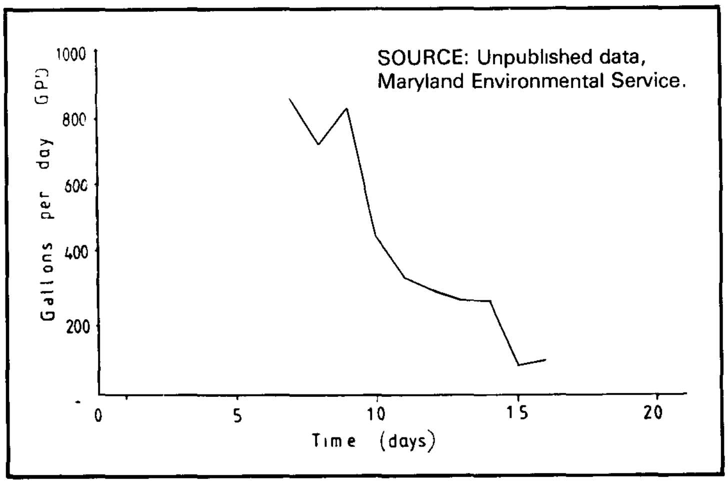


Figure 2.5. Volume of Condensate and Leachate Generated by a Single Compost Pile at the Dickerson Site Containing 29 Dry Tons of Sludge

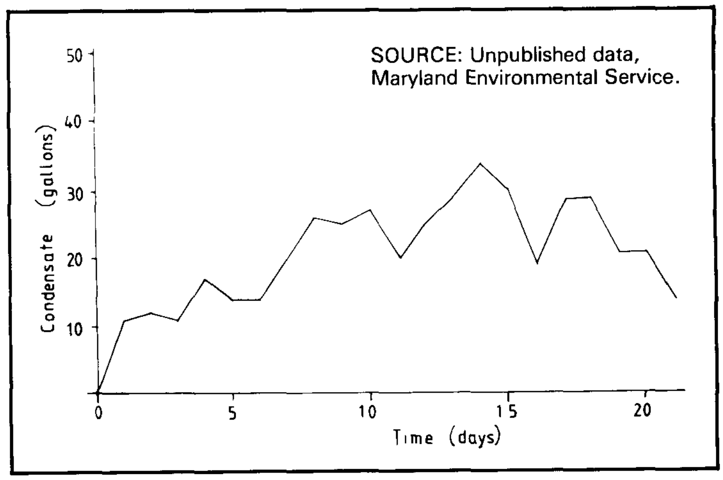
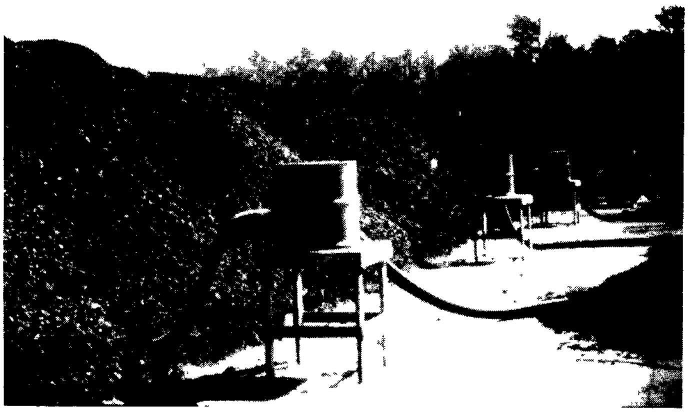
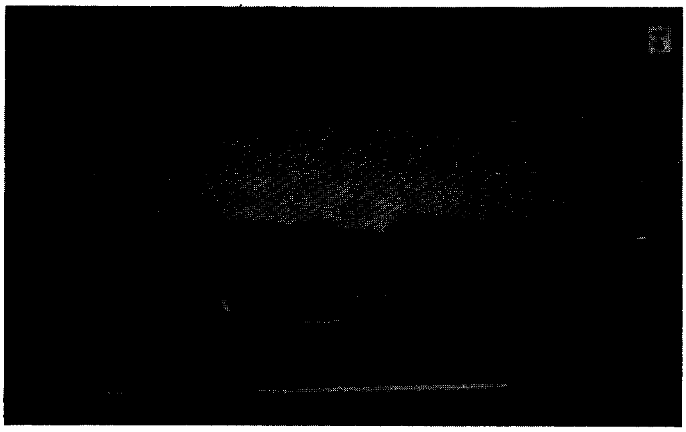


Figure 2.6. Volume of Condensate Collected from a 29-Dry-Ton (of Sludge) Compost Pile by a Two-barrel Condensate Trap System



Sharp dips in the aeration pipes to and from the blower impaired air flow at Dickerson.



Rigid pipes with a drain hole between the pipe and blower helped solve this problem.

correct this problem (see photo). Also, when the plastic pipes became warm, they tended to sag and dam the drainage channels, creating many small pools of leachate and condensate on the site, which contributed significantly to the odor problem. The solution to this odor source was to install rigid piping with drain holes that allowed the pipes to drain when the blowers turned off. This kept the pipes free of liquid and maximized air flow.

Increasing Air Flow

The Dickerson site was originally designed with ⅓-hp blowers based on the Beltsville model with no adjustment for larger pile size. Each blower was connected to three 4-inch (10-cm) lateral pipes via a 4-inch (10-cm) manifold under-

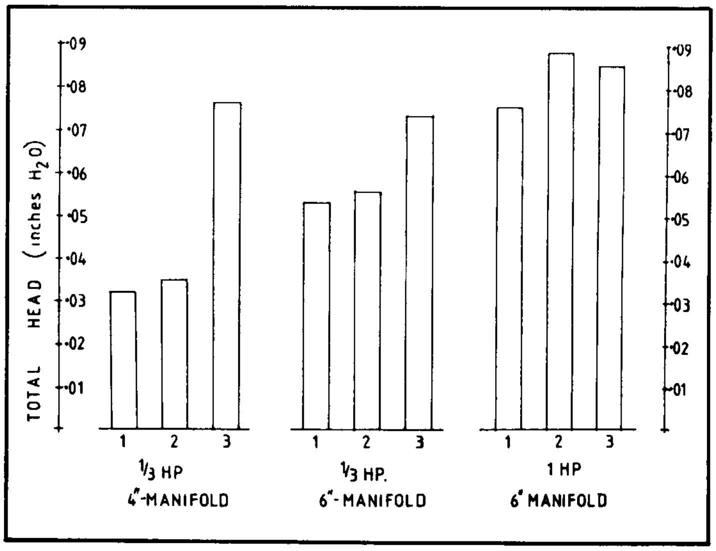


Figure 2.7. Air Flow Distribution between Laterals as a Function of Manifold Size

neath the pile. However, the relatively low oxygen levels in the piles indicated that this system was supplying inadequate aeration to maintain aerobic conditions throughout the pile, so the Dickerson staff began to investigate ways to increase the system's effectiveness. One inexpensive improvement was to replace the 4-inch (10-cm) manifold with a 6-inch (15-cm) manifold. As Figure 2.7 illustrates, the smaller size of the 4-inch (10-cm) manifold tended to cause most of the air to flow through the inlet pipe closest to the blower. Installation of the 6-inch (15-cm) manifold resulted in higher airflow and more even distribution between lateral pipes (laterals). However, the airflow was still insufficient, so the ⅓-hp blowers were replaced with 1-hp blowers, which are the largest blowers that can be operated from the available 110-volt system and that could therefore be installed without requiring expensive electrical power modifications. The 1-hp blowers along with the larger manifold improved both air flow and distribution, resulting in more thorough and consistent pile aeration and decreased odors.

Another modification to improve air flow was to reorganize the various materials within the pile to take advantage of their different resistances to air flow. Figure 2.8 shows the pressure drop per meter in vertical columns of different composting materials. New wood chips are the least resistant to air flow, followed by used wood chips. Unscreened compost is more resistant, but generally not as resistant as the sludge/wood chips mixture before composting. Screened compost is the most resistant; however, the resistance of both screened and unscreened compost can vary depending on moisture content.

Initially, the entire bed of each compost pile was constructed of new wood chips because they are the least resistant to air flow and produce a manifold effect under the pile. However, this layout short-circuited the air flow through the bed, and most of the air came out around the toe of the pile. To prevent this short-circuiting, the beds were constructed with a 20-foot (6-meter) wide layer of unscreened compost around the circumference with new wood chips in the center (Figure 2.9). The increased resistance of the unscreened compost helped to force more of the air down through the pile. Thus, the aeration through the sludge mix was increased at essentially no increased cost.

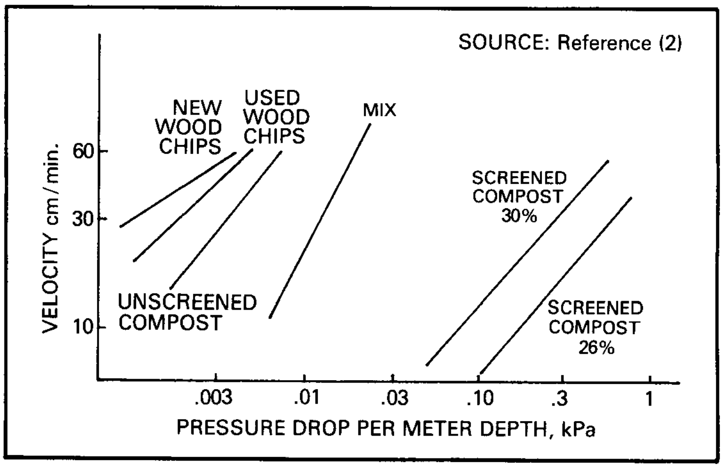


Figure 2.8. Pressure Drop per Meter Depth in Vertical Columns of Different Composting Materials

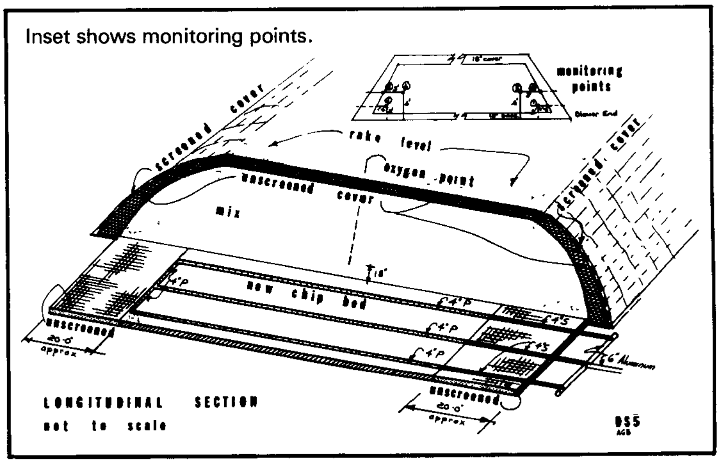


Figure 2.9. Improved Pile Construction at Dickerson

Oxygen and Temperature Monitoring

In static pile composting, temperature should be monitored at the coolest part of the pile, i.e., the toe, due to a lesser degree of insulation there. A temperature of 55°C for three days at the lowest point in the pile indicates that temperatures throughout the pile were high enough to provide for pathogen destruction. Oxygen levels, by contrast, are generally inversely proportional to temperature and should therefore be measured at their low point, which is usually at the center of the pile where temperatures are the highest.

When the Dickerson site opened, both oxygen and temperature were monitored at the ends of the pile within reach of the 6-foot (2-meter) probes (Figure 2.9). Both the oxygen and temperature measuring techniques were subsequently changed. Oxygen was measured through polyethylene tubing, which was placed in the center of the pile during pile construction. Temperature was measured with thermocouple wires, which were able to locate the point of measurement more accurately and provide much more rapid measurements than probes. These monitoring changes increased the overall efficiency of the operation and provided much more useful data on the composting process.

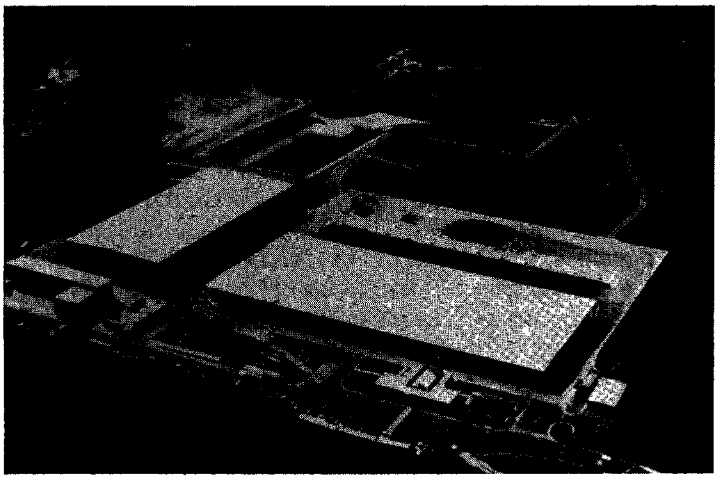
Site II

After 2 years of operation, the Dickerson site was closed on December 31, 1982, in accordance with the agreement with the Citizens Advisory Committee. Site II was nearly complete by that time. Figure 2.10 shows the layout of Site II.

Description

The site encompasses approximately 20 acres (8 ha) — about half the size of the Dickerson and Western Branch facilities. Haul trucks enter the site and unload sludge in the mixing building and wood chips in the wood chip storage facility. Wood chips are mixed with sludge using a Roto-shredder and front-end loaders. The mix is then transported to the two compost pads by dump trucks and formed into piles using a front-end loader. Pile beds are constructed of wood chips in the center and unscreened compost around the circumference. Each pad is about 600 feet (180 meters) long and 110 feet (35 meters) wide.

The aeration system consists of 6-inch (15-cm) flexible pipes that are placed under the compost piles. The pipes are spaced 5 feet (1.5 meters) apart and are connected to 15-horsepower blowers that line the compost pads. A total of 56 blowers are used. The blowers are operated in the suction mode and discharge into an underground header system, which consists of two 30-inch (76-cm) manifolds attached to a 36-inch (0.9-meter) header that discharges to



Site II aerial view.

a central odor filter pile. Water spray nozzles are located in the crown of the header for cooling and to scrub air for odor control. Fifteen-horsepower blowers, as opposed to the 1-hp blowers at Dickerson, were necessary to supply the increased aeration required by the system. The need for greater aeration was due to the central filter pile arrangement. By having all the blowers discharge into one filter pile, substantial back pressure — up to 28 inches (71 cm) of water — is created, and this back pressure increases the power requirements for aeration.

Leachate and condensate flow directly into channels where they are shunted to underground pipes that discharge directly into the local sewer system. Storm water collects in the runoff control pond (see photo) and is metered into the sewer system in offpeak hours. The control pond is made of 8-inch (20-cm) concrete to enable a loader to drive into the

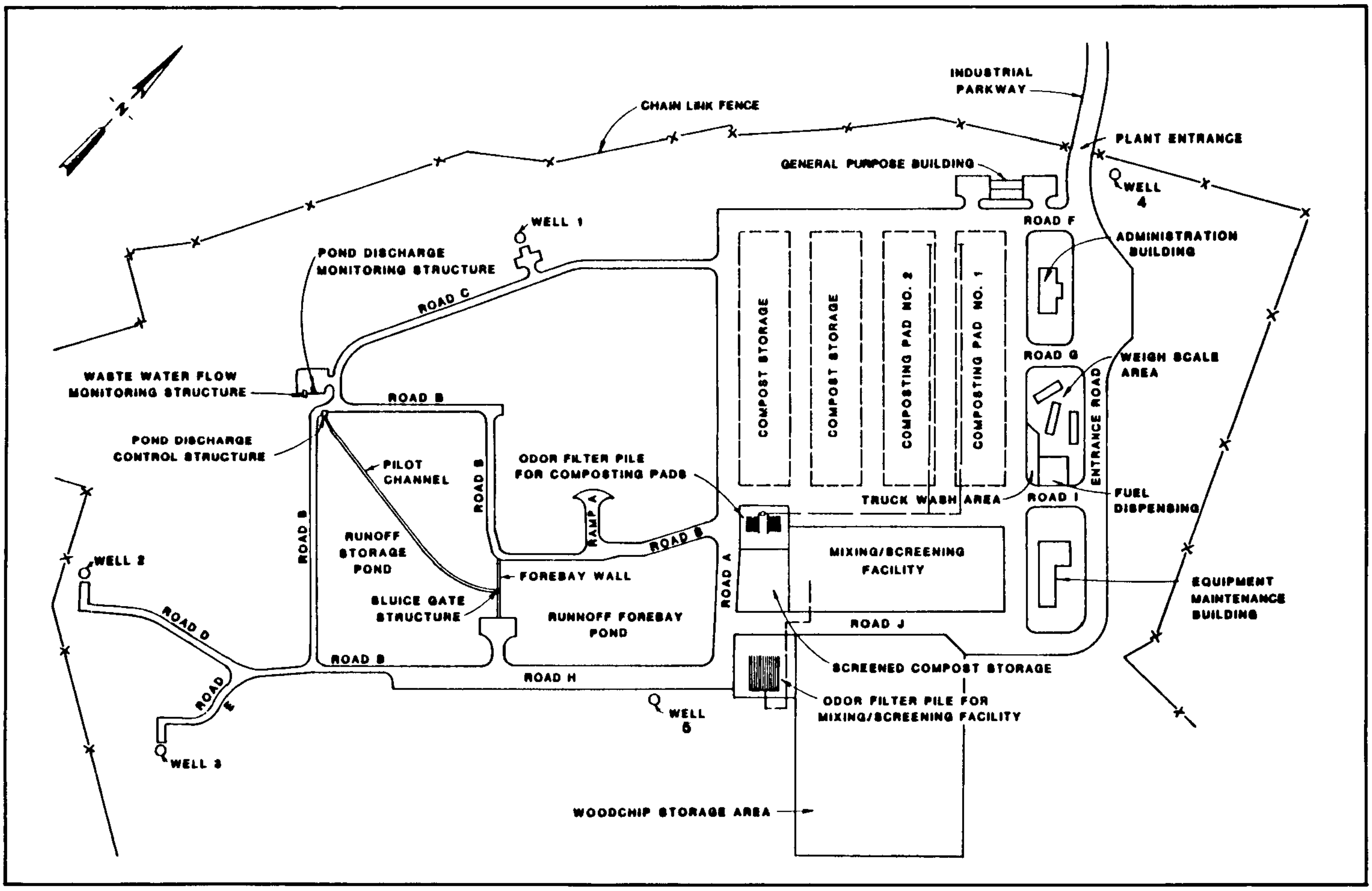


Figure 2.10. Site II Layout

Runoff control pond at Site II, constructed of 8-inch (20-cm) concrete to enable loaders to drive into the pond and clean out any sediment. Runoff that collects in the pond is metered into the sewer.

pond and clean out sediment that may collect there, thereby eliminating the potential for odors.

At Site II, the sludge/wood chip mixture is composted for 21 days. The piles are then torn down and the composted mix is deposited in a hopper that discharges onto conveyor belts. These belts transport the compost to the three Liwell screeners inside a totally enclosed and heated screening facility. Each screener is fitted with a hood to control dust. During screening, air is exhausted through the hoods by three 60-horsepower blowers to an outside filter pile arrangement. The air control system was created in response to public concerns over *Aspergillus fumigatus* and was mandated by court decrees.

Wood chips recovered from the screening process are returned to the mixing area, and the screened compost is taken to the uncovered curing area (labeled "compost storage area" in Figure 2.10), where it is cured for 30 days and then distributed for use.

Other on-site facilities include a laboratory, truck scales and wash area, and an administration building.

The Site II facility is unusual in that the composted mixture is screened before, rather than after, curing. One advantage of this approach is that a greater proportion of the wood chips can be recovered and recycled because they are less decomposed than cured wood chips. This recycling helps to reduce bulking agent costs. Screening before curing also reduces the space required for curing, since screened compost is only 20 percent of the volume of unscreened compost. The reduced land requirements can significantly reduce capital costs.

At Dickerson, attempts to cure screened 21-day-old compost without aeration had resulted in highly odorous material. The original Site II design did not include power to the curing pads; however, in light of the Dickerson data, the Site II curing pads were retrofitted with 1-hp blowers. Subsequent experiments indicated that the oxygen demands during curing were much lower than those during composting and could be supplied by a 1-hp blower in the positive pressure mode. As a result, the curing piles are now aerated continuously at this low level until the compost is marketed. The piles are monitored for oxygen to ensure that adequate aeration is supplied.

Public Relations

The public relations program for Site II was extensive. The site had been opposed from the concept stage, and the experience at Western Branch had provided a valuable lesson about the critical importance of dialogue with the local citizens. One of the first public relations efforts was to create and mail a brochure to approximately 60,000 local residents within a one-mile (1.6 kilometer [km]) radius of the site. The brochure explained the purpose of the site and how it functioned, announced the site opening, and invited local residents to visit.

In January 1983, representatives from each local community met with site officials and formed the Citizens Liaison Committee (CLC). The CLC met biweekly and was kept continually informed about the status of the project by site officials. Long before any sludge arrived, CLC representatives were given a tour of the site and a description of operations. An open house was organized and all local citizens were invited to attend. Events included a ribbon cutting, speeches by local politicians, site tours, and giveaways of compost samples. The open house helped to communicate the attitude that the facility was something to be proud of and that it had nothing to hide. The event was very successful, generated many positive comments, and left most visitors very impressed. Since startup, the CLC has continued to meet, although less frequently, to air any concerns that may arise. Local residents are encouraged to visit the site, and they do so frequently.

Another component of the public relations program was monitoring of *Aspergillus fumigatus* in response to citizens' concerns. High levels of the fungus were found on site, however, levels at the site border and offsite were negligible compared to background levels. There was some initial concern about the health of site workers. However, no incidents of respiratory problems associated with composting were reported, so it was decided that no extraordinary measures were necessary to protect workers.

Further discussion on public relations at Site II can be found in Reference [3].

Process Modifications

Three process modifications — concerning the aeration system, odor control, and compost moisture reduction — are discussed in this section. Information on additional modifications can be found in Reference [4].

Aeration System Modifications

On April 25, 1983, enough sludge was received at Site II to construct five test piles to determine the most appropriate aeration rates and timing sequence. Tests were run to measure aeration rates, back pressures, pile temperatures, and oxygen levels. These tests indicated that back pressure in the manifold varied considerably as the various blowers that discharged into it were turned on and off. The variation in back pressure in turn affected aeration rates. The solution to this problem was to install a temperature controller that caused the blower to stay on until the temperature in the pile center fell below a specific temperature. The aeration rates were thus made independent of the back pressure. It was also hoped that temperature optimization would result in more thorough drying and a more stable material after 21 days. Further tests were run with temperature controllers in place, and on the basis of these results, temperature controllers were permanently installed at Site II.

The temperature controller was wired in parallel with a timer that maintains minimum aeration based on a cycle of 5 minutes on, 15 minutes off. Whenever the pile temperature exceeds the set level, the temperature controller automatically extends the on cycle by up to 15 minutes. Thus, if necessary, the controller can cause the blower to run continuously.

The 5-minute-on, 15-minute-off cycle was based on data like those in Figure 2.11. These oxygen measurements were taken around the fourth day of composting when the initial peak of microbial activity is expected. The blowers were turned off at time = 0. In less than 15 minutes, the oxygen levels had fallen below the critical 5 percent level; within 35 minutes they were close to zero. The blowers were turned back on after 38 minutes, and after 5 minutes aeration the pile oxygen levels were satisfactory. Similar measurements on curing piles indicated that oxygen levels could drop from 20 to 0 percent within 2 hours. For this reason, aeration systems were installed for curing, and a

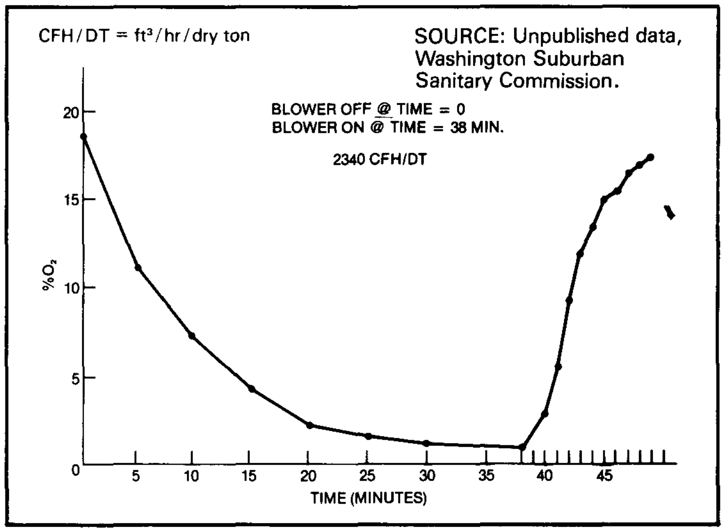


Figure 2.11. Oxygen Depletion in a Compost Pile with Blower Turned Off and On

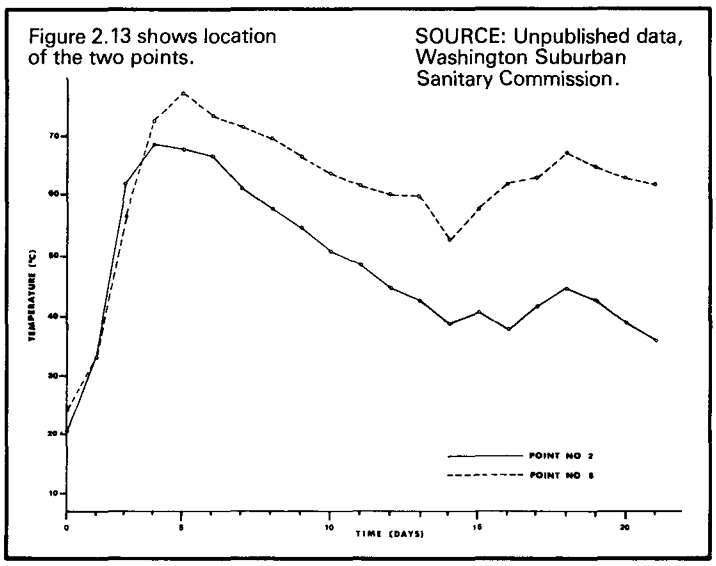


Figure 2.12. Temperature Differences at Two Points in a Site II Compost Pile with Uniform Pipe Layout

backup generator was installed to prevent anaerobic conditions and resultant odors in the event of power failure.

Another startup problem was the differential in air flow from one end of the pipe to the other due in large part to the 15-horsepower blowers. This air flow differential resulted in huge differences in temperature along the length of the pile (Figure 2.12). To solve this problem, Site II engineers used a computer program and trial-and-error to design a piping system that would counteract this effect. To even out the air flow, the number of perforations were varied along the length of the pipe. Several different variations were tested; the optimal system is illustrated in Figure 2.13. The first 16 feet (5 meters) of perforated pipe out of the blower contain 0.44 square inches of open area per linear foot (9.2 square cm per meter [cm^2/m]); the next 16 feet (5 meters) contain double that amount — 0.88 square inches of open area per linear foot (18.4 cm^2/m); the next 31 feet (9 meters) contain 1.7 square inches per linear foot (36 cm^2/m); and, in the remainder of the pipe, the open area is more than doubled to 4.3 square inches per linear foot (90 cm^2/m). Figure 2.14 shows the more uniform temperatures within the pile that resulted from improved air flow with the modified pipe layout.

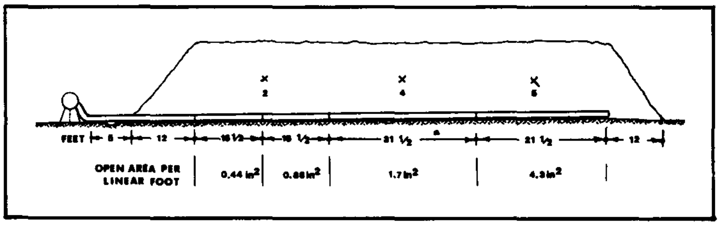


Figure 2.13. Open Area per Linear Foot in Modified Aeration Pipe Along the Length of the Compost Pile at Site II

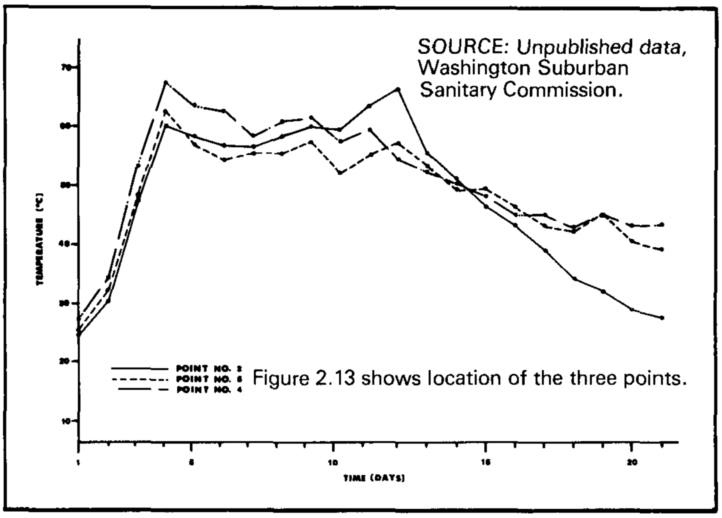


Figure 2.14. Temperature Differences at Three Points in a Site II Compost Pile with Modified Pipe Layout

Odor Control

One major incentive for perfecting the Site II aeration system was to minimize odor generation. A study on odor [5] funded by the Washington Suburban Sanitary Commission identified five compounds that were principally responsible for odor in sewage sludge: hydrogen sulfide, methyl mercaptan, methyl sulfide, dimethyl sulfide, and sulfur dioxide. These are all sulfur compounds with relatively low odor thresholds. Their concentration in a compost pile tends to increase as the temperature rises (Figure 2.15). (Ammonia is also an odor source at composting sites, but has a much higher threshold and dissipates more rapidly.) Thus the major approach to odor control at Site II was to control pile conditions so as not to generate odorous compounds.

Data from Site II indicate that the odor filter piles at the site are essentially cosmetic. A comparison of the concentrations of odorous compounds in the manifold and in gases exiting the filter pile shows that virtually no scrubbing has taken place. These findings concur with laboratory data [6] that show that compost is not an effective odor scrubber at high moisture levels.

Site II engineers have been investigating possible backup odor control systems for use in case of odor generation due to temporary failure of some part of the composting system. The initial backup system investigated was a water-based system using spray nozzles fitted in the crown of the 36-inch (91-cm) header. This system was ineffective. Currently, systems that use chemical oxidizers are being investigated. The first tests with high concentrations of hydrogen peroxide introduced into the manifold system through one of the blowers did result in a detectable reduction of odors from the filter pile. The next step will be to see if atomizing the oxidizer will result in even greater odor reduction.

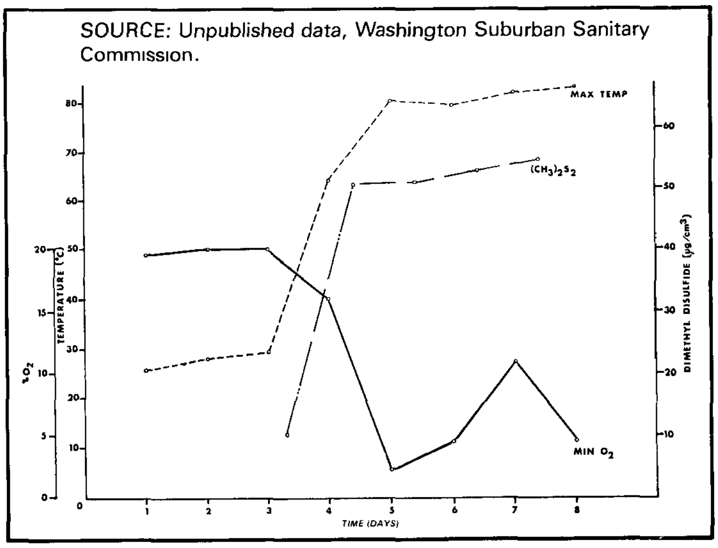


Figure 2.15. Maximum Pile Temperature, Minimum Pile Oxygen Level, and Dimethyl Disulfide Concentration in Exhaust as a Function of Time

Table 2.1 Effect of Positive and Negative Aeration on Initial (Day 0) and Final (Day 21) Moisture Content of a Compost Pile

		Initial Moisture Content (%)	Final Moisture Content (%)
Positive Pressure		62.6	54.2
		64.8	56.4
		64.4	59.5
		64.2	55.2
	Average	64.0	56.3
Negative Pressure		62.6	54.2
		62.7	58.0
		62.4	54.0
		61.3	53.7
	Average	62.3	55.0

SOURCE: Unpublished data, Washington Suburban Sanitary Commission.

Table 2.2 Comparison of Moisture Content of Compost Piles with Two Sludges of Different Volatile Solids Content

	Initial (Day 0) Moisture Content (%)	Final (Day 21) Moisture Content (%)
Blue Plains (30 to 40% volatile solids)	64.7	58.3
	64.3	57.5
	65.9	59.3
	65.1	57.2
	63.4	56.2
Average	64.7	57.7
Western Branch (70% volatile solids)	62.9	51.4
	60.8	53.1
Average	61.9	52.3

SOURCE: Unpublished data, Washington Suburban Sanitary Commission.

Compost Moisture Reduction

To successfully screen compost, its moisture content should not exceed 50 percent. Site II compost had a moisture content of over 50 percent, which necessitated a drying step before screening. Several experiments were tried to reduce the moisture content. Table 2.1 shows the results of tests to compare the effect of positive and negative aeration on moisture content. One study [7] indicates that positive-pressure aeration provides a greater reduction in moisture content than negative aeration, however, at Site II the difference was not substantial.

Another experiment involved tests to determine the effect of sludge volatile solids content on compost moisture levels.

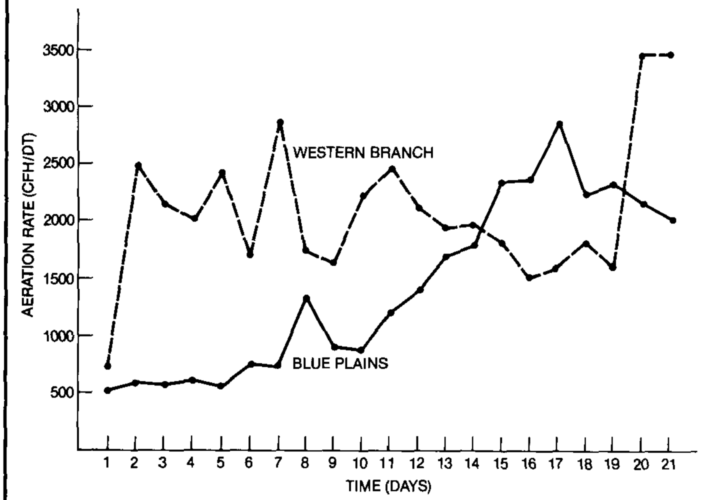


Figure 2.16. Comparison of Aeration Rates Demanded by the Blue Plains and Western Branch Sludge

Using temperature-controlled aeration, Blue Plains sludge, which had a volatile solids content of 30 to 40 percent was composted alongside Western Branch Wastewater Treatment Plant sludge, which had a 70 percent volatile solids content. Figure 2.16 compares aeration rates in the two piles. The Western Branch sludge had a much higher aeration demand than the Blue Plains sludge. The total air flow through the Western Branch sludge was 20.1 million ft^3 (563,000 m^3), compared to 16.7 million ft^3 (468,000 m^3) through the Blue Plains sludge. However, these higher rates did not translate into significantly lower moisture content (Table 2.2).

Another approach to moisture reduction has involved restacking the piles. Each time a pile is torn down and stacked up, moisture is released, largely in the form of steam. Experiments at Site II indicate that tearing the piles down and then restacking them for an additional 2 or 3 days reduces moisture by about 7 percent.

Another modification being considered is to cover more of the pad area. The mixing process is also being analyzed in an effort to improve air distribution, odor control, and moisture control. Preliminary tests indicate that pugmill mixers may provide a better mix than rotoshredder mixers.

Marketing

Marketing of sludge compost was first initiated by Maryland Environmental Services (MES) in 1981. The products being marketed at that time were Dickerson and Western Branch compost. Since the MES, as a statewide utility, was precluded under state law from acting as a retailer, it began its marketing efforts by approaching private fertilizer marketing firms. These firms showed no interest in serving as compost retailers, so the MES created a team consisting of a consultant, an agronomist, and a dispatcher to develop a marketing program. One of the first steps in the program was to develop a product name — "COMPRO" — and an associated logo (Figure 2.17).

A general distribution permit was obtained from the Maryland Department of Health and Mental Hygiene. This permit allowed the compost to be distributed for all uses except on food chain crops. The compost could be used on food chain crops providing an individual permit was first obtained from the same agency. The distribution permit requires that the levels of various heavy metals and organic chemicals in the compost be below specified limits, which are based on the U.S. Department of Agriculture's Agriculture Information Bulletin publication [8]. Levels of heavy metals in COMPRO are generally very low because the Blue Plains Treatment Plant serves a primarily residential community with few industrial dischargers. Site II periodically monitors the compost for these substances and supplies the data to the Maryland Health Department. The compost has never exceeded these limits. In fact, the record has been so good that the Health Department has reduced the frequency of testing for organic chemicals.

COMPRO is sold for \$4 per yd^3 (\$5.20 per m^3) at the production site. Transportation and handling costs increase the retail price of bulk material to \$15 to \$30 per yd^3 (\$19 to \$38 per m^3).

Distribution has not been a problem at Site II. Demand generally exceeds supply. Figure 2.18 shows the volume distribution of 1983 COMPRO sales by user category. At that time, virtually all sales were to bulk users because COMPRO was not available in bag form. The primary users are landscapers and contractors who account for 40 percent of the total sales. Institutions such as universities, schools, and parks use about 25 percent of the material. A network of 50 to 100 retail outlets in Maryland, northern Virginia, and the District of Columbia handles 23 percent. The remainder is sold to nurseries, golf courses, and topsoil dealers. The price is too high for the agricultural market. In the spring of 1984 packaged COMPRO became available, enabling distribution at the retail level to individuals and small-scale users. Bagging is performed by three different concerns. Bagged compost is sold to retailers in bulk quantities. Individuals cannot buy compost at the site as it was felt this would create traffic problems and would put Site II in competition with their retailers.

Figure 2.17. Logo for Maryland Environmental Services Compost Product

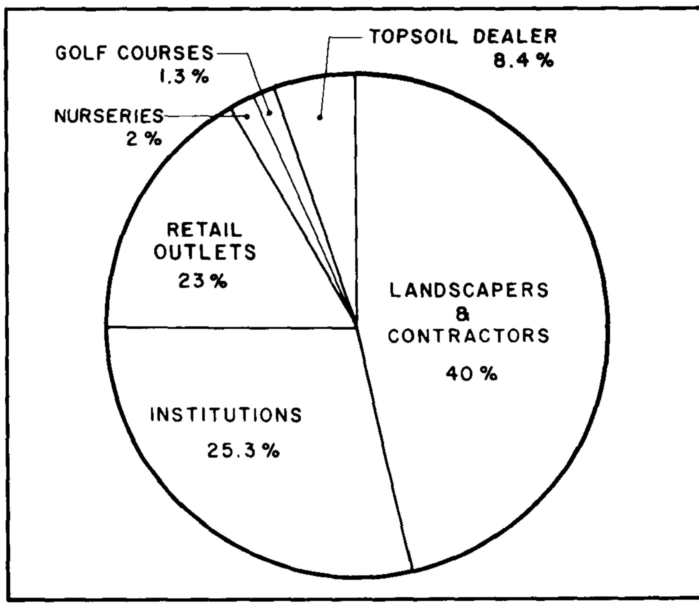


Figure 2.18. Volume Distribution 1983 Compro Sales by User Category

References

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3. Experience at a Windrow Composting Facility: Los Angeles County Site

This chapter presents the experiences of composting operations at the Sanitation Districts of Los Angeles County's Joint Water Pollution Control Plant (JWPCP) in Carson, California. Windrow composting has been performed at this site since the early 1970s. Currently the plant composts 120 dry tons (109 dry metric tons) of sludge per day.

Description of the Los Angeles County Sewage System

The Sanitation Districts of Los Angeles County (Figure 3.1) has provided municipal wastewater collection, treatment, and disposal services for most of urban Los Angeles County since 1928. The system is exceptionally large, serving slightly under 4 million people and treating approximately 475 million gal (1.8 billion liters) of wastewater per day. It consists of a main wastewater treatment plant — the JWPCP in Carson, California — and five upstream water reclamation plants that provide hydraulic relief to the sewage system and high quality reclaimed water for potential reuse applications. These five plants have a combined treatment capacity of 150 million gal (570 million liters) per day. They generate raw (nondigested) primary sludges, waste-activated sludges, and filter backwash sludges, which are returned to the sewer system for conveyance to the JWPCP solids processing facility.

Description of the Joint Water Pollution Control Plant

The main wastewater treatment plant — the JWPCP — treats approximately 350 million gal (1.3 billion liters) per day of municipal wastewater. Current treatment processes include advanced primary treatment for all wastewater flow. In this process, anionic polymers are added to the wastewater to improve the settling characteristics in the primary sedimentation tanks. The JWPCP also further treats some of this wastewater using a pure oxygen-activated sludge secondary treatment system. The JWPCP has the capacity to treat 200 million gal (760 million liters) per day with secondary treatment but is not scheduled to reach that capacity until the summer of 1988 due to the current inability to dispose of all sludge that could be produced. Until that time, approximately 125 million gal (470 million liters) per day of secondary treatment will be employed. The JWPCP has applied to the EPA for an exemption from full secondary treatment requirements through the Section 301(h) provisions of the Clean Water Act. Sludges generated at the plant include primary sludges from the primary tanks and waste-activated sludges from the secondary treatment plant.

Figure 3.2 shows an overall mass balance of the solids disposal plan of the JWPCP in 1984. About 660 dry tons (600 dry mt) of solids arrive at the plant each day. These solids are removed from the wastewater and disposed of through:

- Anaerobic digestion and burning of digester gas.
- Direct landfilling of sludge cake.
- Composting, which accounts for about 19 percent of the solids (solids are reduced to 15 percent during composting due to loss of 4 percent solids in the form of carbon dioxide and water).
- Ocean discharge using a 2-mile (3.2-km) ocean outfall diffuser system. The ocean discharge of solids is in full compliance with Federal NPDES permit provisions and requirements of the State of California for ocean discharge.

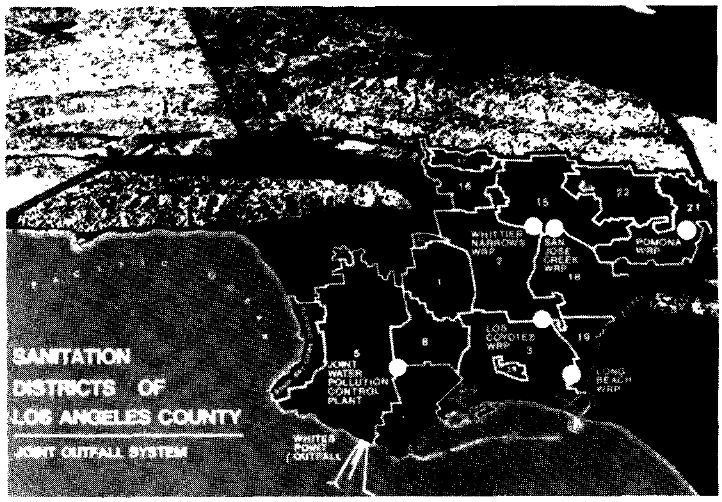


Figure 3.1. Sanitation Districts of Los Angeles County Joint Outfall System

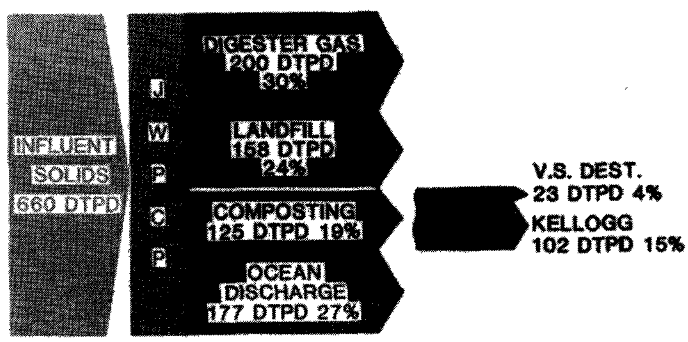


Figure 3.2. Solids Disposal at the JWPCP

Digestion takes place in 37 mesophilic anaerobic digesters, which have a detention time of approximately 17 days. The digesters produce approximately 7 million ft^3 (200,000 m^3) per day of gas, which is used on site to power effluent pumps or to generate electricity.

Solids from the digesters are dewatered using 44 basket centrifuges, which produce sludge cakes of approximately 22 to 23 percent solids. The JWPCP also uses 19 newer, low-speed state-of-the-art scroll centrifuges, which are capable of producing a sludge cake of 25 to 26 percent solids. All sludges from the centrifuges are discharged onto conveyor belts and carried to a storage facility, which consists of 12 storage silos, having a total storage capacity of 6,600 wet tons (6,000 wet mt).

The dewatering operation occurs 24 hours a day, 7 days a week. However, sludge processing can only occur during daylight hours, 6 days per week. During those periods when the sludge cannot be processed, the JWPCP stores it in the 12 silos. During hours when the sludge is handled, the solids are removed from the storage silos and loaded into trucks for conveyance either to a landfill where the solids are codisposed with municipal refuse, or to an adjacent field on the plant site where the solids are composted. The final product of the composting process is sold to a fertilizer manufacturing company, the Kellogg Supply Company.

Composting operations are severely affected by rainfall during winter months due to reduced drying rates and the tendency of young and new windrows to slump and collapse. Since the ability to landfill sludge is also limited during rainy periods, EPA has authorized the JWPCP, through July 1988, to discharge sludge to the ocean during extreme wet periods when the storage silos are filled to maximum capacity. The JWPCP plans to build a new sludge incineration facility and to increase the storage silo capacity by 50 percent, thus providing the capability for onsite disposal of all sludge, including that generated by 200 million gal (760 million liters) per day of secondary treatment, regardless of weather conditions. These new facilities are planned to be operational by July 1988.

Historical Perspective of Sludge Disposal at JWPCP

Air-dried Lagoon Sludge (1928-1950s)

In 1928, when the JWPCP was constructed, essentially no residential development surrounded the plant, so odors from the plant did not create a nuisance. From 1928 through the mid-1950s, sludge was merely air dried in lagoons at the site. By the early 1950s, the plant had expanded considerably, and residential development encroached on the site. At that time, the plant's entire east side consisted of sludge lagoon drying basins that produced considerable odor emissions because of the anaerobic nature of the sludge. This area also attracted large quantities of insects. By the late 1950s, sludge lagoon air drying was no longer tolerable to the surrounding community.

Air-dried Centrifuged Sludge (Mid-1950s to Late 1960s)

In the mid-1950s, the Sanitation Districts began using centrifuges to dewater sludge and return centrate to the treatment plant. The centrifuges produced a sludge cake that was fairly dry — approximately 35 percent solids. However, only about 30 percent of the solids that entered the centrifuges were actually captured. The other 70 percent remained in the centrate and were discharged along with the plant's primary effluent into the Pacific Ocean. The sludge cakes produced by these centrifuges were statically air dried. They were significantly less odorous and initially required less land during drying than the lagooned sludge.

By the mid-1960s, areas very close to the plant had been developed for residential use. By this time, the JWPCP had removed the sludge lagoon beds from service; however, by the late 1960s, even static air drying was no longer acceptable to the community. The population of the JWPCP tributary area had increased by 40 percent between the mid-1950s and the mid-1960s, resulting in increased quantities of sludge cake being placed in deeper piles on larger areas of land. The interior of these piles did not dry, but remained wet and anaerobic for the 1 or 2 years they remained on the field. When the piles were picked up with a front-end loader, significant amounts of hydrogen sulfide were released.

Sludge Marketing (1928 to Present)

From about 1928 to the present, the responsibility for ultimate disposal or utilization of the dried solids from the lagoons, the drying beds, and the present compost field belonged to the Kellogg Supply Company, which has always leased property from the JWPCP on a portion of the site. Up to the mid-1950s, Kellogg sold all the dried sludge material to citrus farmers located in Los Angeles and Orange Counties. These were bulk sales; there were no sales to the residential community. However, in the late 1950s and early 1960s, the citrus area shrank due to expanded residential development in Los Angeles County. Costs to haul the material to the residual citrus groves in distant areas became prohibitive, so starting in the late 1950s, Kellogg began to market the dry sludge material in bags to the residential homeowner market through local nursery supply stores. Today, approximately 90 percent of

Kellogg's sales are to chain store garden shops and independent nurseries that retail the products.

Compost Pilot Studies (Late 1960s)

By the late 1960s, there was considerable debate about the future of the sludge drying and fertilizer manufacturing process due to the odor problem and to the Kellogg products' limited success in competing against cheap, synthetic chemical fertilizers. This competitive disadvantage in turn contributed to the growing piles of drying sludge. The Sanitation Districts' staff debated how the solids should be disposed of in the future, and serious consideration was given to the suggestion that most of the sludge be codisposed with municipal solid waste in a municipal landfill, thereby eliminating the problems posed by the site's proximity to the residential area.

It was also suggested that small-scale composting experiments be conducted to determine whether composting could solve the odor problem. Initially there was much skepticism regarding this idea due to the belief that odors would increase as the rows of anaerobic, drying sludge cake were turned. But, in fact, experiments showed that odor emissions were significantly reduced compared to static air drying, providing that (1) the composting material had an initial solids content of 40 percent (this percentage was achieved by recycling a certain amount of dry sludge and mixing it in with the wet cake) and (2) the mixture was turned daily by a rototiller.

Compared to the current composting process, initial composting methods used at the JWPCP were quite primitive. To construct windrows, a layer of dried sludge was spread, using an earth mover, on the field along the axis of the proposed windrow, and a layer of sludge cake was dumped from end dump trucks on top of the dried sludge cake. A Petibone speed mixer (a large rototiller pulled by a tractor) was then employed to mix together the dry and wet materials. Next, a road grader was used to split the mixed material into several small windrows, which were turned for several weeks, using the speed mixer, until they dried. The small windrows measured only about 1.5 feet (0.5 meters) high, 8 feet (2.4 meters) wide at the base, and 400 to 500 feet (120 to 150 meters) long. This method of windrow construction was very slow and led to pilot studies to evaluate different types of composting equipment and to determine which were best suited for composting wastewater sludge.

During the initial pilot studies, the Sanitation Districts used a Terex-Cobey composting machine to build compost piles. This machine picks up a row of sludge material and deposits it a few feet from the original spot. However, because the JWPCP sludges are heavy, the machine was unsuitable and had a tendency to make wide, sweeping arcs rather than straight rows. The JWPCP evaluated several other machines and found the Cobey Roto-Shredder to be very suitable for the type of windrow composting that the JWPCP conducted. Steam released from the windrows after turning indicated a high temperature within the windrow — evidence of good decomposition, something not achieved with the windrows built with the Petibone speed mixer.

Shortly after it was put into service, the Cobey Roto-Shredder produced smooth, level conditions on the new, lime-stabilized dirt field. With time, however, a number of valleys, hills, and ruts developed in the field and, as a result, windrow sizes varied considerably. During winter conditions, the field was wet and equipment dug holes in the field. These holes affected the ability of the machine to produce level, straight windrows.

First Full-scale Composting (1972-1977)

From about 1972 through 1977, the JWPCP handled 225 wet tons (205 wet mt) per day of 35 percent solids sludge produced by the old centrifuges. Approximately 25 percent of the final product was recycled to bring the initial starting mixture up to 40 percent solids, the value necessary to ensure adequate porosity, and thus aeration, throughout the composting pile.

The operation worked very successfully as evidenced by monitoring data from the early to mid-1970s, which showed good temperature elevations within the windrows, good drying rates, and a reduction of volatile solids indicating that biological reactions were occurring. The JWPCP did not monitor frequently for pathogens because they were not as great a concern as they are today; however, the monitoring that was performed showed fairly good pathogen reduction, particularly of *Salmonellae* and total coliform.

Briefly Expanded Operations (1977)

In the early 1970s, the sludge composted at the JWPCP represented approximately only 30 percent of the solids from the sludge stream. The other 70 percent that could not be removed by the centrifuges was returned to the plant for ocean disposal. In response to orders by the U.S. EPA and the State of California to cease ocean disposal of sludge, the Sanitation Districts designed an advanced sludge dewatering station that would, in theory, produce a 23 percent solids sludge with a 7-fold increase in sludge wet weight. Based on the success of the then-existing composting operation with the smaller amount of sludge, the JWPCP decided to handle the entire increased sludge volume through composting. The JWPCP expanded their composting field from approximately 10 acres (4 ha) to 40 acres (16 ha).

The new centrifuges came on line in mid- to late-1977, and increased sludge generation began to increase from 225 wet tons (205 wet mt) per day up to the anticipated 1,600 wet tons (1,455 wet mt) per day. However, the sludge cake, which was supposed to be 23 percent solids, was frequently 17 to 19 percent solids. With that much water in the cake, there was simply not enough dried compost to bring the material up to 40 percent solids. Consequently, the mixture of materials applied to the compost field was well below 40 percent solids, and anaerobic zones developed within the windrows. Odors were emitted and local residents filed such severe odor complaints, that, after only a few months of operation, when the sludge production reached approximately 700 wet tons (636 wet mt) per day, the JWPCP decided to reduce the volume of sludge composted to whatever level was necessary to eliminate complaints, and to landfill the remaining sludge. The maximum acceptable sludge volume for composting was determined, on a trial-and-error basis over the next several years, to be 500 wet tons (455 wet mt) per day.

When the large-scale composting operation first began in 1977, the JWPCP experienced some equipment startup problems. They tried to use an Athey force-feed loader in conjunction with a specially designed truck to efficiently remove the dried compost from the field once the composting cycle was complete. The plan was for the operator of the Athey loader to drive down the windrow, pick up the dry material, and place it on its conveyor, which was covered to minimize dust generation. The material would rise up the conveyor and fall off the end into the back of a specially designed, enclosed truck, which would follow the force-feed loader down the windrow. The driver of the enclosed truck would back up the equipment to remain coordinated with the end of the force-feed loader. After only a few days of operation, however, it was apparent that the two equipment operators could not coordinate their equipment well enough, and the JWPCP abandoned the specially designed equipment in favor of a front-end loader, which was found to be more versatile.

Another equipment problem experienced during startup was with the Flow-Boy truck trailers that were initially used to build windrows. These are trailers on which the sludge-recycle mixture is dropped into a hopper and conveyed onto the field in windrows using a chain-driven conveyor system. These trailers were not designed for the heavy loads imposed on them 10 hours a day, 6 days a week; one trailer collapsed under the weight of the material it was hauling. Another problem was that the movable flight configuration discharged the material out the back of the truck very slowly, so that the cake-recycle mixture would sometimes bridge over the conveyor system, preventing discharge. The JWPCP replaced the Flow-Boy trailers with a 42-yd^3 (33-m^3) end dump truck, and a 42-yd^3 (33-m^3) horizontal-ram pusher truck. Both these trucks are twice as productive as the Flow-Boy trailers.

Process Changes (1980)

From about 1977 through 1980, the revised composting operation, scaled down to minimize odor emissions, appeared to be running smoothly. But in 1980, the JWPCP discovered high levels of coliform and pathogens in the final compost product. Previous data indicated that this was a new phenomena and had not been a longstanding problem.

The problem was apparently largely due to a reduction in sewage discharges by several large paper manufacturing companies. This reduction was the result of an industrial waste user fee system, established in the 1970s, that required industry to pay for using the sewage system based on discharge volume and strength (i.e., the amount of organic material and suspended solids in the wastewater) of the wastewater. Many paper companies with large, high-strength discharges experienced very high user charges. It became more economical for the paper companies to pretreat their wastewater and either landfill the sludge or reuse the paper fibers.

Paper solids are rich in cellulose, which is readily biodegraded in an aerobic composting environment, producing high temperatures that destroy pathogens. The reduction in paper mill wastewater thus reduced the fuel (volatile solids) for composting, and the windrows were unable to achieve adequate temperatures for pathogen destruction. The problem was further increased by the large surface-to-volume ratio of the windrows, which maximized heat loss through the surface.

In addition to the reduction in fuel from the decreased paper solids, the sludge cake had a lower concentration of fibrous materials than before, and the compost tended to form balls or clumps. The grinding action of the Cobey composter's rotating drum, which rotated at approximately 250 revolutions per minute (rpm), was inadequate for breaking up these clumps. The resulting clumps in the final compost appeared anaerobic in the center, suggesting they had not been adequately composted.

The solution to this problem was to eliminate the clumping phenomena and to build larger windrows with lower surface-to-volume ratios that help to conserve heat and maintain high temperatures. The solution was achieved with a new composting machine — the SCARAB I — which was capable of building much larger windrows than the Cobey Roto-Shredder. The 600-rpm speed of the SCARAB's drum — more than twice as fast as the Cobey — was effective in breaking up the clumps. To make the machine work on the heavy sludges at the plant, the JWPCP converted the machine from hydraulic drive to a belt-drive arrangement.

Winter 1984 Experience

From 1980 until the winter of 1983-84, the process worked successfully. However, during a cold spell, with temperatures of 4.5°C in the winter of 1983-84, temperatures within the windrows fell below the 55°C recommended by EPA to ensure pathogen destruction. The cause of this problem appeared to be the significantly increased digester solids detention time, which resulted from placing in service four new, very large anaerobic digesters in the fall of 1983. The increased detention time resulted in increased gas generation during digestion that reduced the fuel value of the resulting sludge for composting. The sludge had decreased volatility, indicating that the extended digestion process had removed some of the readily biodegradable material that had been available previously for composting.

The solution to this problem was to enhance heat conservation by constructing even larger windrows with reduced surface-to-volume ratios. This type of construction required a very large experimental composter. Two years of prior research at the JWPCP had demonstrated that this device could construct much larger windrows than any other composter, but that it worked well only on a paved field. Coincidentally, the Sanitation Districts had just finished paving a 25-acre (10-ha) composting site. These circumstances enabled the JWPCP to make a major revision to its composting operation in March 1984.

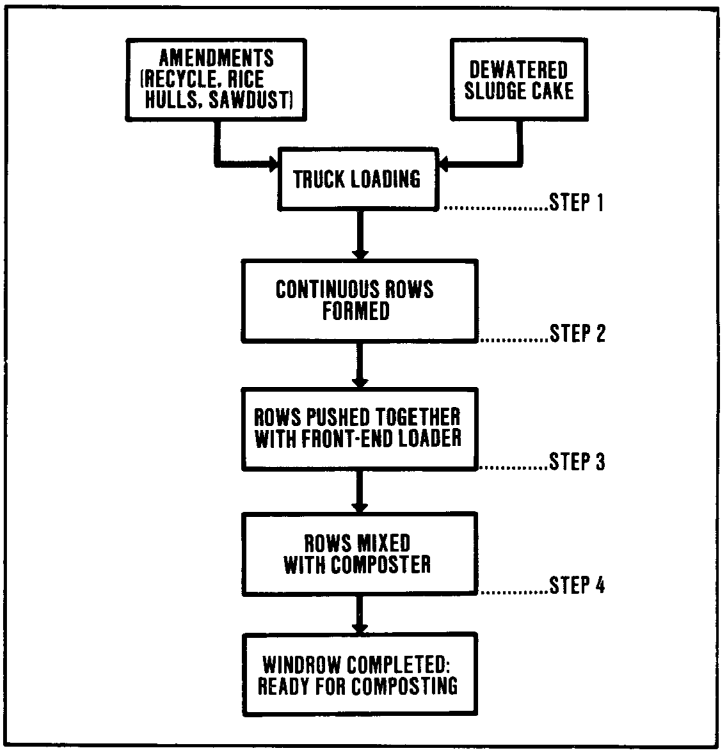


Figure 3.3. Construction of Windrows

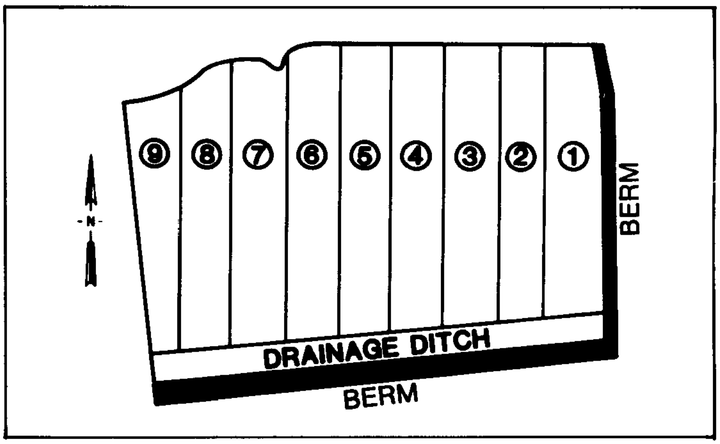
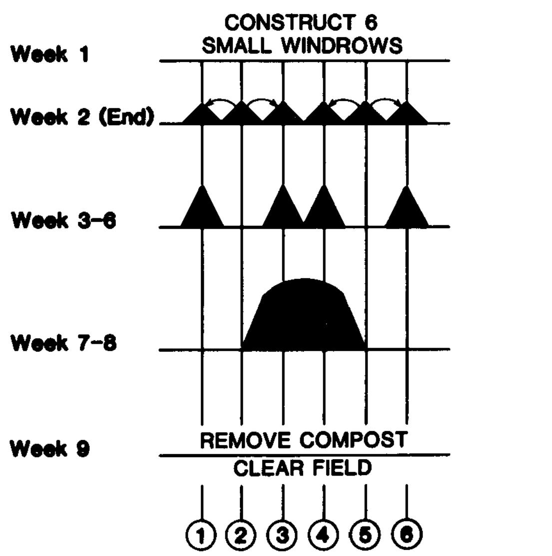


Figure 3.4. Plan of Compost Field

Current Composting Operation

Figure 3.3 shows a block diagram of the windrow composting operation. Dewatered, weighed sludge cake from the storage silos is loaded into trucks. The trucks then travel to the amendment sawdust stockpile area and pick up the appropriate proportion of bulking agent — sawdust, rice hulls, and/or recycled compost. The ratio of sawdust to sludge is varied depending on the needs of the final distributor — the Kellogg Supply Company. Approximately 10,000 yd³ (7,600 m³) of sawdust are on site at any one time. The sludge and sawdust are dumped in the field, formed into rows by front-end loaders, and mixed by the composter. Active composting then proceeds over a period ranging from 4½ weeks in the summer to 13 weeks in the winter, after which the compost is removed from the field.

Figure 3.4 is a schematic of the 25-acre (10-ha) paved field. Note the drainage ditch on the south side and berms on the



(Note. The procedure was recently revised to eliminate the intermediate windrow step. Now, six small windrows are maintained until week 7-8, when they are combined into one large windrow.)

Figure 3.5. Typical Compost Cell Operation

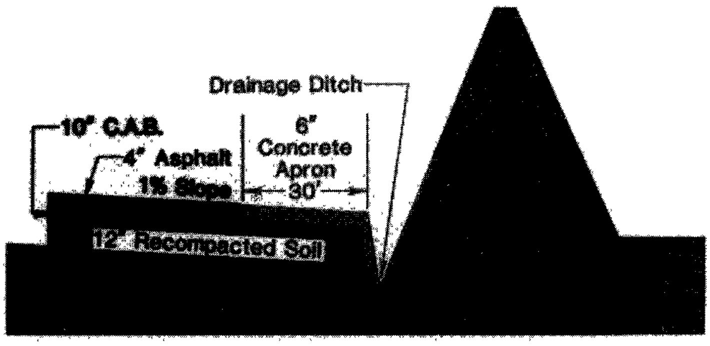


Figure 3.6. Asphalt Compost Field Design

east and south. There are nine separate cells on the site, each with room for six separate windrows. Each cell goes through a typical process as illustrated in Figure 3.5, which shows a 9-week cycle. At the start of a particular cycle, the cell is empty. During the first week, six small windrows are constructed, one per day. Each windrow holds up to 500 to 525 wet tons (455 to 477 wet mt) of sludge cake and the appropriate volume of amendment and is about 800 to 820 feet (244 to 250 meters) long. During cold winter months, the amount of sludge in each windrow is reduced to approximately 300 wet tons (270 wet mt) to reflect the reduced drying rates during winter. During the first week and throughout the second week the windrows are turned daily with the smaller SCARAB I machine to promote rapid evaporation and to increase the porosity of the material.

At the end of the second week, two of the windrows are split; half the material is put into each adjacent windrow, resulting in four intermediate-sized windrows on the field and two blank spaces. For the next 4 weeks (weeks 3 through 6) the intermediate-sized windrows are turned with the smaller SCARAB I machine about three times per week. It is during this period that active composting takes place. Internal windrow temperatures are about 54° to 64°C and organic solids are actively degraded.

At the end of the sixth week, the four intermediate-sized windrows are combined into a very large windrow and turned by the large windrow composting machine at least five times during the next 2 weeks. Very high temperatures are achieved during this stage because of the very low surface-to-volume ratio and the resulting conservation of heat. This procedure satisfies EPA's requirement for pathogen destruction during windrow composting (i.e., maintaining temperatures of 55°C for 15 days, during which time the material is turned five times). It is not uncommon to observe temperatures as high as 71°C being maintained for 7 or more days during this 2-week period.

At the end of the eighth week, the composting cycle is complete, and personnel from Kellogg remove the material from the field and transport it to their site for subsequent processing and bagging.

In recent months, the above procedures have been modified by building two large windrows in each cell during the final 2-week period. Each of these two windrows consists of material from three of the original six small windrows constructed in that cell. This modification was necessary to preserve the large composter, which broke down frequently when attempting to turn the massive windrows. The large composter is a one-of-a-kind machine, and no spare or backup machine is available.

Compost Field

Figure 3.6 shows the current design of the compost field at the JWPCP. The field consists of a 4-inch (10-cm) layer of asphalt (2 inches [5 cm] of type C asphalt atop 2 inches [5 cm] of type B asphalt), which overlies a 10-inch (26-cm) base of crushed aggregate. The field has a 1 percent slope. Precipitation drains into a ditch where it is shunted to a storage pond. The drainage ditch, in conjunction with the pond, has the theoretical capacity to handle the water from a 50-year rainstorm without any overflow (backup) onto the field. In reality, since the JWPCP can discharge some of the pond contents into the sewer system at certain hours every day, the drainage system has essentially unlimited capacity. All stormwater runoff from the compost field is returned to the influent sewers of the JWPCP.

The compost field had originally been covered with lime-stabilized dirt. However, this surface had a tendency to become slippery and to develop holes in wet weather. The field was resurfaced with asphalt a few years ago based on tests that showed that operations during rainy spells were far more productive on an asphalt surface than on dirt. After a couple of years of operation, however, a substantial amount of water had accumulated under the field. The sludge had apparently caused the asphalt field to crack, enabling water to penetrate upslope. According to the Asphalt Institute, this effect commonly occurs on rural roads near cattle crossings where cattle manure accumulates. Based on their recommendations, the JWPCP applied an oil slurry sealer atop the asphalt.

Sludge Conveyor System

The conveyor belts that transport sludge from the centrifuges to the 12 storage silos and to the loading stations are over 1 mile (1.6 km) in length. The system is controlled by one operator from a central control panel. Level indicators show the amount of sludge in each silo. The operator controls the amount of sludge withdrawn from each silo.

Although the conveyors are very reliable, they do have a tendency to spill and require constant cleanup and maintenance. One year ago, the JWPCP investigated an alternative sludge conveying system — a piston pump, which uses a 40-hp hydraulic mover to drive sludge through an enclosed pipe. This system has several advantages over the conveyor system: substantially reduced spillage; no limitations due to incline; and the ability to transport sludge around 90° bends. These capabilities would enable buildings at a facility to be spaced more closely together, thus the system looks extremely promising for large facilities with space limitations.

Research into Other Composting Processes

Forced-aeration and In-vessel Systems

As part of their research over the years to improve the on-site composting process, the JWPCP has examined three alternative composting methods: aerated static pile composting, an in-vessel system, and a partially enclosed forced-aeration system.

Static pile systems traditionally use large wood chips as a bulking agent, which must be screened out and recycled at the end of each composting cycle. In an effort to eliminate the screening step, which was considered to be too dusty, the JWPCP experimented using sawdust or dried compost as a bulking agent during forced aeration. The experiments showed that these materials did not provide sufficient porosity for composting. Their weight compressed the pile and sealed off all air passages; consequently, black anaerobic zones developed, particularly at the pile bottoms.

The JWPCP also examined the Fermentechnik unit — a totally enclosed mechanical composter from West Germany. The unit uses auger screws and paddles to convey and churn the mixture. All composting is done within a vessel, which reduces the possibility for dust. Air is blown into the vessel and exits through odor scrubbers. An auxiliary piece of equipment can be used to dry the final sludge and produce pellets. The JWPCP evaluated the pelletization process as a means of reducing dust emissions during sludge transport.

Finally, the JWPCP examined a partially enclosed, forced-aeration system in which the material is composted in thermally insulated, enclosed bins. Air headers set in a concrete pad provide forced aeration. The material is turned periodically with a front-end loader to enhance aeration.

The three experimental systems were compared to the existing windrow compost process (Figure 3.7). All three systems provided excellent temperature elevations enabling pathogen destruction, but the existing windrow composting process had far superior drying characteristics, producing the driest material in the shortest time (Figures 3.8 and 3.9).

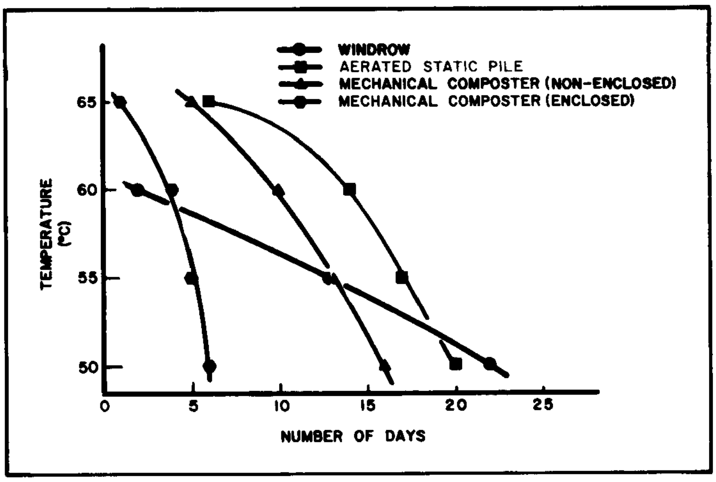


Figure 3.7. Duration of Elevated Temperatures

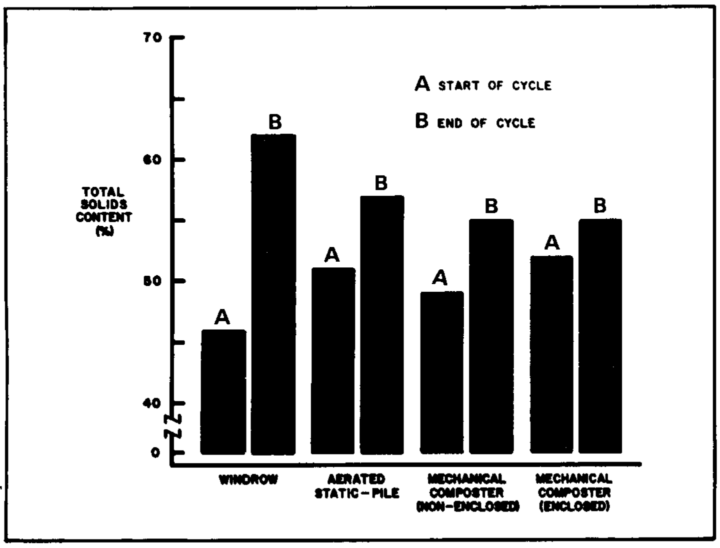


Figure 3.8. Drying Characteristics

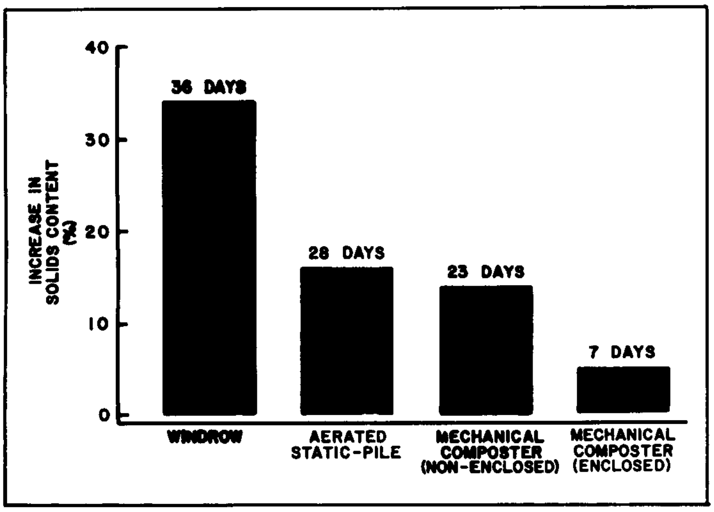


Figure 3.9. Drying Rates for Various Composting Schemes

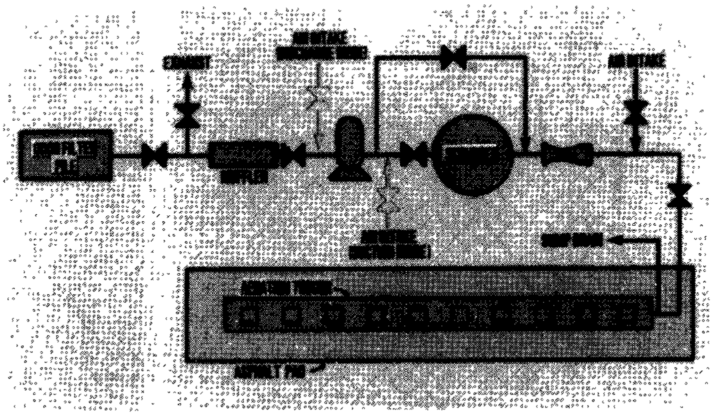


Figure 3.10. Aeration System

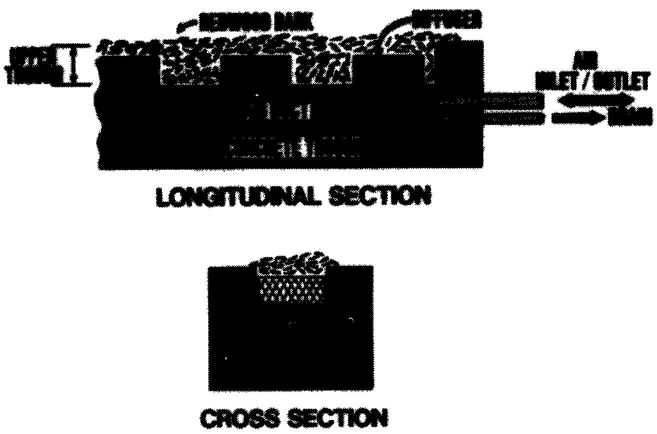


Figure 3.11. Aeration Trough

Combined Forced-aeration/Windrow System

Based on these results, the JWPCP decided to continue with windrow composting. However, for the past 18 months they have been experimenting with a combined forced-aeration/windrow approach to improve their existing process. Figure 3.10 shows a schematic of one such system with an aeration trough beneath the windrow. The aeration trough is shown in Figure 3.11. It consists of a U-shaped steel plate sealed with rubber gaskets and drilled to create orifices. An expanded metal grate is placed around the orifices and covered with large redwood bark chips. Aeration is provided by a 1,000-ft^3/minute (28-m^3/minute) blower that can be operated in a negative or positive mode. An odor scrubber and water sprays are used to reduce any odors generated during negative pressure aeration. The aeration trough also serves as a drainage channel for leachate and condensate. Air distribution is monitored throughout the aeration trough, and thermocouples monitor the temperature of the windrows.

In one experiment with this system, a large windrow containing approximately 60 percent by volume sawdust was constructed. Half the windrow was constructed over the experimental forced-aeration system; the other half was not aerated. All other aspects of the piles, including the turning schedule, were identical. Internal temperatures in the forced-aeration section rose much more rapidly than

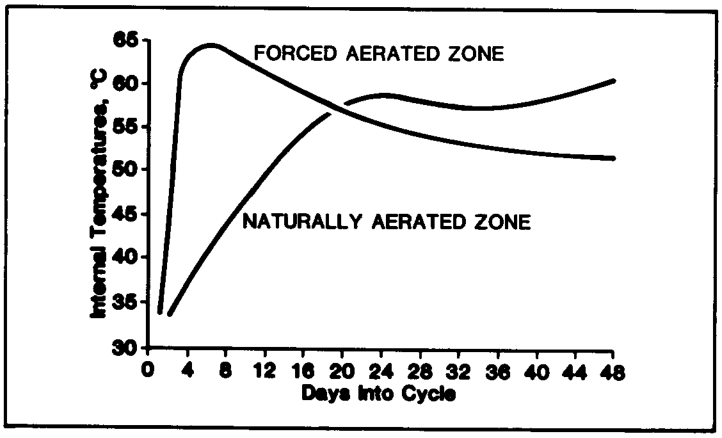


Figure 3.12. Effect of Forced Aeration on Internal Windrow Temperatures (Sawdust Rich)

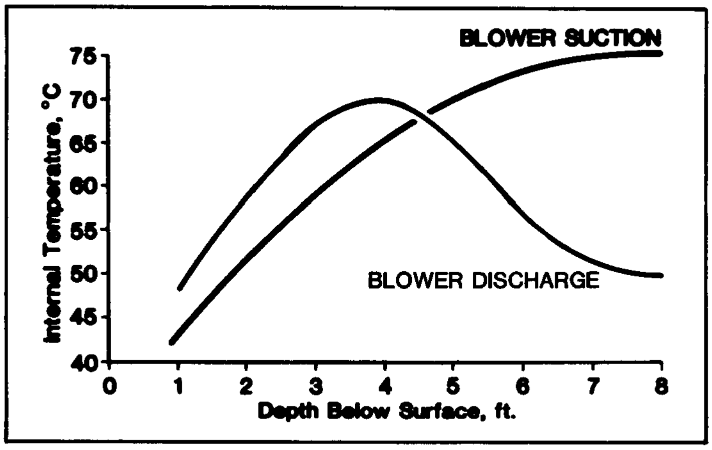


Figure 3.13. Temperature vs. Windrow Depth

those in the naturally aerated zone, but then dropped below 55°C after approximately 3 weeks (Figure 3.12).

In another experiment with the forced-aeration system, the JWPCP manipulated the location of the hot zone by alternating negative and positive pressure aeration. The results of this experiment are provided in Figure 3.13. During the first day, the blower was operated in a negative pressure or suction mode. The suction drew the heat generated within the pile downwards so that temperature increased with increasing pile depth, with the hottest temperature found at the base of the pile. (By contrast, a windrow pile that is not mechanically aerated is normally cool at the base due to heat loss to the ground.) The following day, the blower was reversed, sending compressed air into the bottom of the pile and out through the surface. This process concentrated the hot zone in the pile center and warmed the surface. Further research is being conducted to investigate the efficacy of

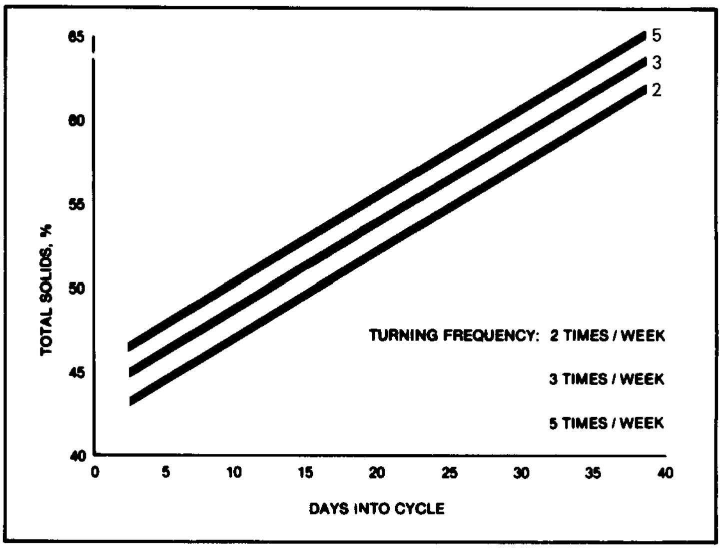


Figure 3.14. Frequency of Windrow Turning vs. Drying Rate

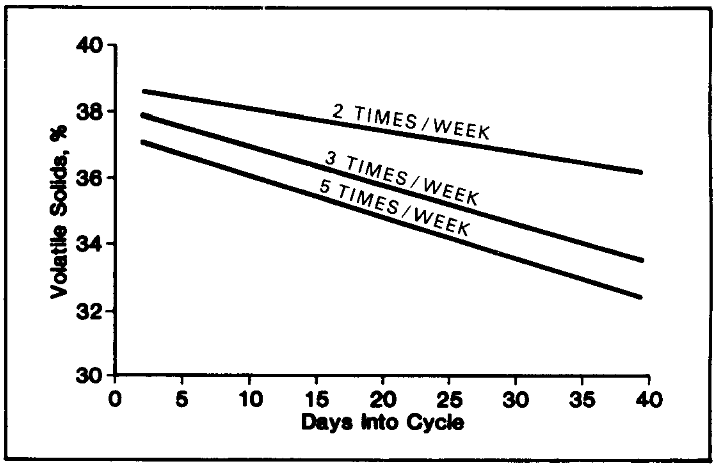


Figure 3.15. Effect of Frequency of Windrow Turning on Volatile Solids Destruction

forced aeration for generating and maintaining high temperatures at all points in the pile. Based on this information, the JWPCP will decide whether to install partial or full aeration at the facility.

Research into Factors Affecting Windrow Composting

Turning Frequency

Many factors affect windrow composting. One factor is the frequency of turning. In a windrow, all evaporation occurs at the surface. Thus, the more frequently a windrow is turned, the faster it dries because wet material from the

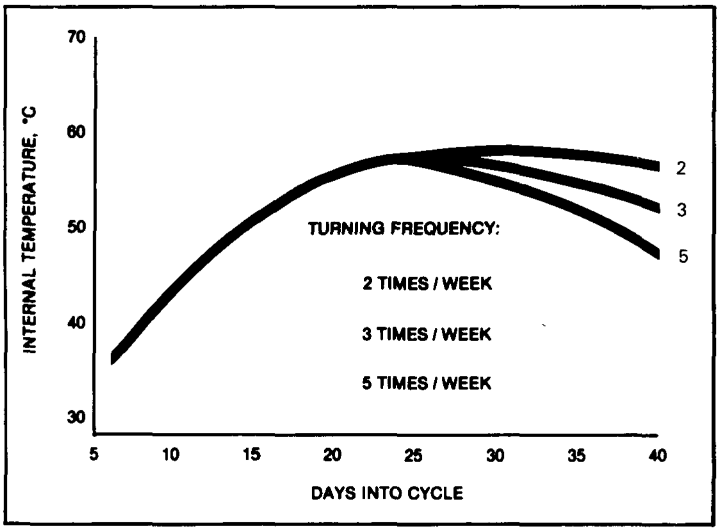


Figure 3.16. Frequency of Windrow Turning vs. Internal Temperature

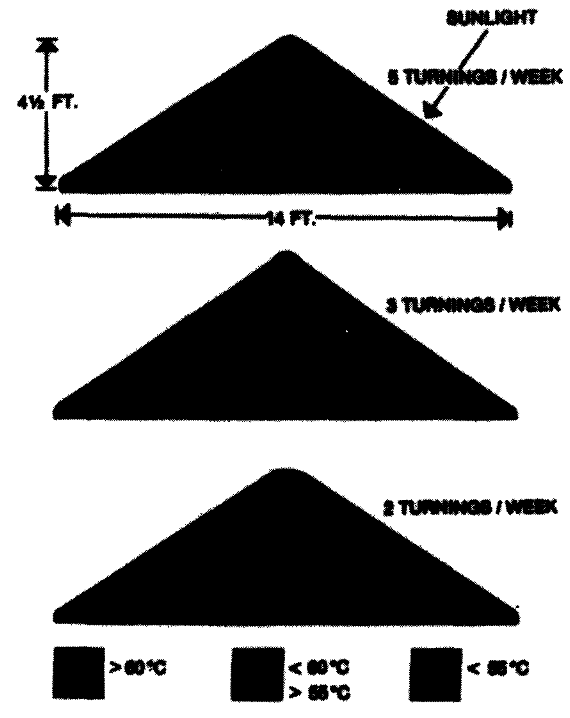


Figure 3.17. Frequency of Windrow Turning vs. Zones of Internal Temperatures

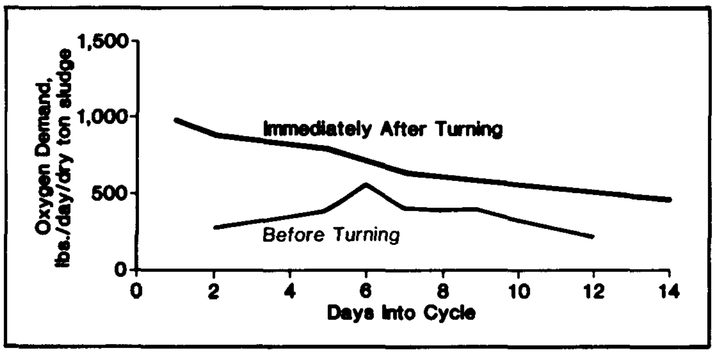


Figure 3.18. Effect of Windrow Turning on Oxygen Demand

center is brought to the surface where the evaporation rate is rapid (Figure 3.14). Volatile solids destruction also occurs more rapidly when a windrow is turned frequently due to the resulting increased aeration (Figure 3.15).

Internal windrow temperatures are also affected by the turning rate (Figure 3.16). Turning breaks up the hot zones in compost piles by bringing cooler surface material into the pile center and hot central material to the pile surface. The more frequently the windrow is turned, the more difficult it is to achieve and maintain a high internal temperature. In one experiment, when the windrow was turned five times per week, a temperature of 55°C was achieved, but was not maintained for as long a period as when the windrow was turned only two or three times per week.

Figure 3.17 shows how the size of the hot zone in a compost pile decreases as the turning rate increases. Note that the hot zone tends to be skewed slightly toward the direction of sunlight.

In one study, the oxygen demand of the sludge material was calculated by operating the aeration system in the suction mode and monitoring the oxygen depletion in the air stream as it passed through the windrow. The study showed that turning stimulates the biodegradation, probably by exposing fresh organic material surfaces to the microorganisms. Oxygen demand readings taken immediately before turning were lower than similar readings taken within minutes after turning (Figure 3.18). This effect occurs throughout the compost cycle life.

The objective in turning is therefore to strike a balance between enough turning to ensure adequate aeration in all sections of the pile, yet not so much turning that heat is lost and high temperatures are not maintained for an adequate period of time.

Effects of Bulking Agents on Pile Temperature and Odor Emissions

The JWPCP uses three bulking agents in their composting operations: dry compost, sawdust, and rice hulls. Dry compost was used exclusively until the late 1970s. At that time, the JWPCP began to add sawdust or rice hulls at the start of the compost cycle to produce different products for the Kellogg Company. Currently, several different blends of bulking agent are used. Figure 3.19 shows the carbon:nitrogen ratios of various bulking agents and sludge/bulking agent combinations. Figure 3.20 shows that the internal windrow temperatures vary with the type of amendment used. Rice hulls and sawdust sustain higher temperatures for a longer period of time than dry compost because of their higher carbon and nutrient levels. The type of bulking agent also has a substantial effect on odor emissions (Figure 3.21).

Effects of Windrow Size and Aeration on Drying Rates

The JWPCP conducted research to examine the effect of windrow size on drying rates in naturally aerated (turned) and forced-aeration windrows (Figures 3.22 and 3.23). Small, naturally aerated windrows dried fastest and achieved the required temperature of 55°C in the shortest period of time. The large, forced-aeration windrow dried faster than the large windrow that was aerated by turning. It achieved almost as high temperatures as the small windrow, whereas the large, turned windrow took a considerable amount of time to reach the required 55°C temperature.

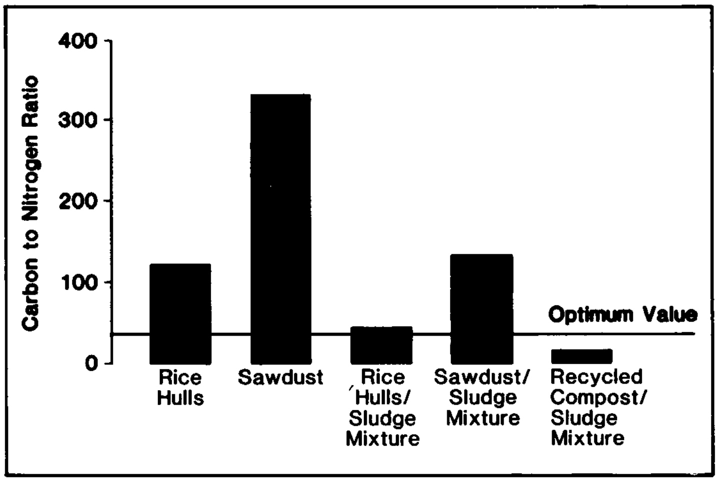


Figure 3.19. C:N Ratios for Various Agents and Mixes

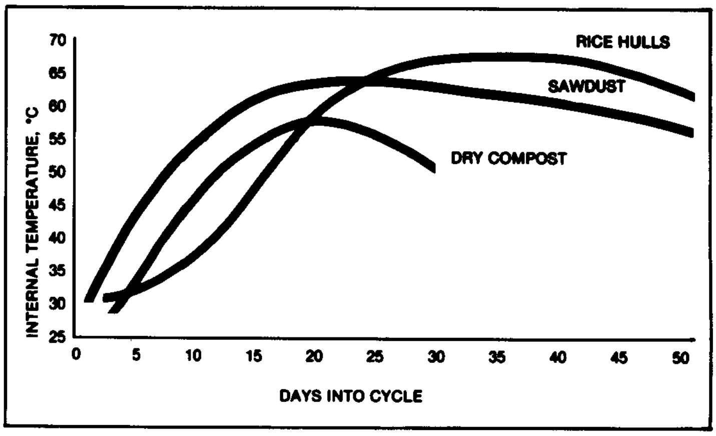


Figure 3.20. Type of Amendment vs. Windrow Internal Temperature

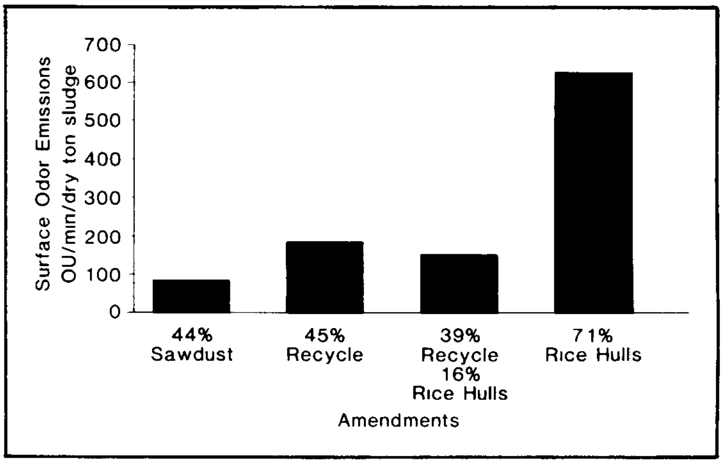


Figure 3.21. Windrow Surface Odor Emissions

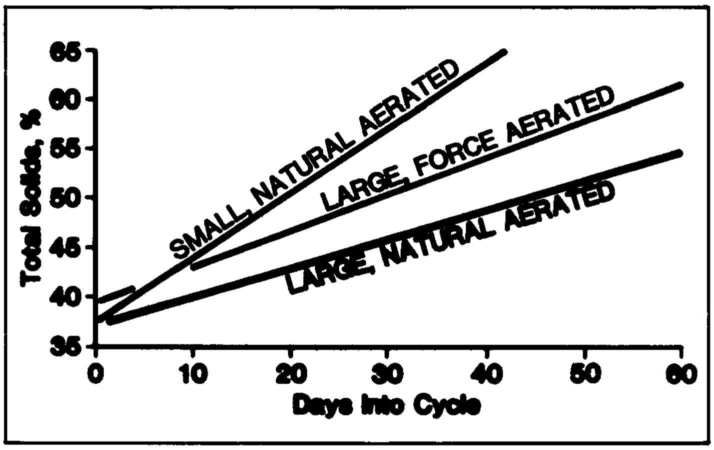


Figure 3.22. Drying Rates of Three Windrow Types

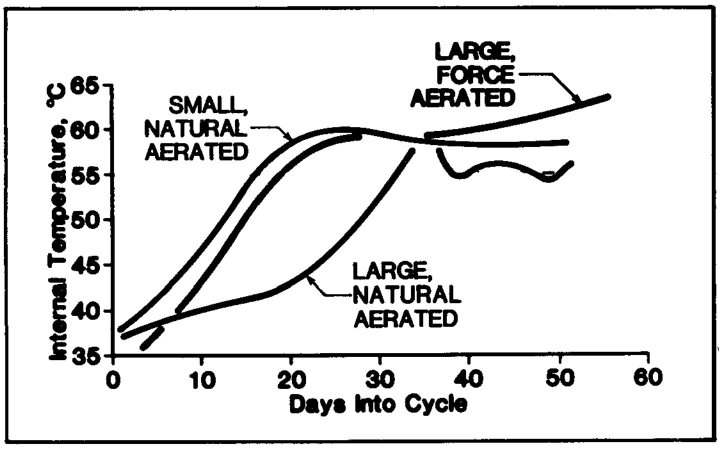


Figure 3.23. Internal Temperatures of Three Windrow Types

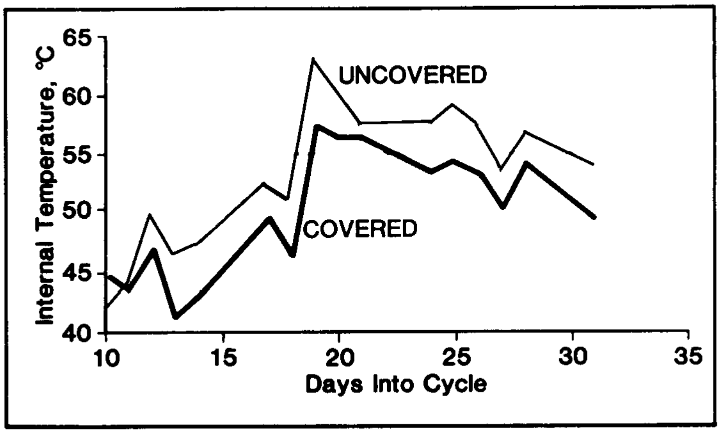


Figure 3.25. Effect of Sunlight on Windrow Internal Temperatures

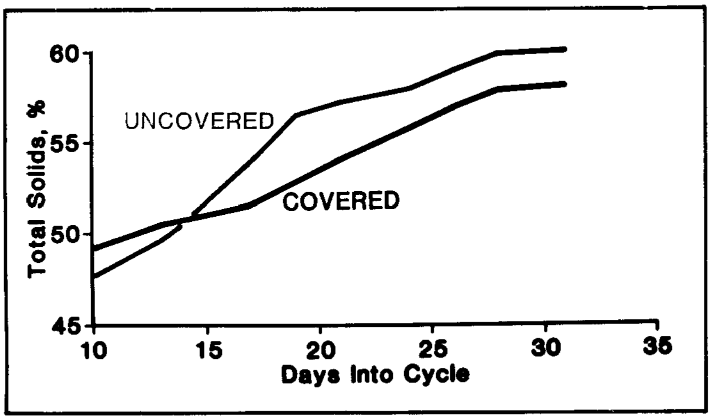


Figure 3.24. Effect of Sunlight on Drying Rate

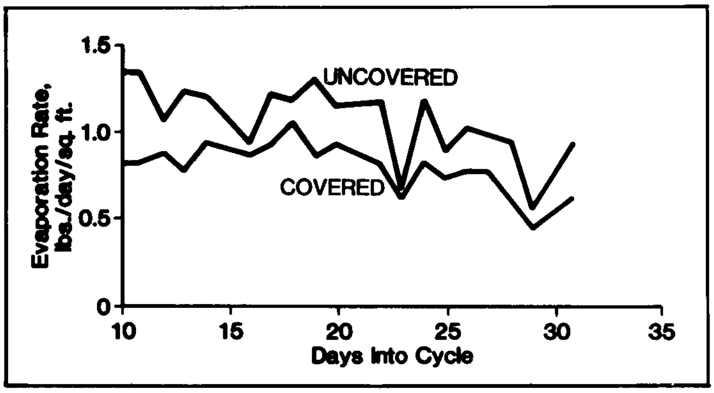


Figure 3.26. Effect of Sunlight on Windrow Surface Evaporation Rate

Benefits of Sunlight

Visitors to the plant frequently ask why the JWPCP does not place the entire operation indoors in a huge aircraft or factory-type building since rain in the winter and odor emissions in summer limit the amount of composting that can take place. One reason that JWPCP does not compost indoors is that sunlight substantially benefits the composting process. In one experiment, the JWPCP covered a 20-foot (6-meter) windrow with black plastic on a wooden frame. The plastic shielded the windrow from the sun but permitted sufficient air penetration. The device was removed only to enable turning. Another, similar windrow was left uncovered and turned with the same frequency.

This experiment showed that the uncovered area, which was exposed to sunlight, dried considerably faster (Figure 3.24), had higher internal temperatures (Figure 3.25), and had a consistently higher surface evaporation rate (Figure 3.26). Based on these findings, the JWPCP determined that placing the entire process indoors would not be beneficial since the number of sunny days far exceed the number of rainy days in the Los Angeles climate even during the winter months.

Important Requirements and Objectives

As a municipal agency, the JWPCP must ensure that both its process and products are acceptable to the public. This task involves continual attention to several key parameters including:

- Odor monitoring and control.
- Pathogen destruction.
- Heavy metals content of compost products.
- Public relations.

Odor Monitoring and Control

Odors are perhaps the greatest constraint to composting at the JWPCP. During the afternoon, prevailing winds carry odors into the heavily populated residential community southeast of the site. Odor complaints are received whenever the amount of sludge composted exceeds the capacity of existing wind conditions to disperse and dilute the odors. This is particularly a problem in the summer and is magnified by the fact that people keep their windows open and are outdoors more at that time of year.

Odor generation at the JWPCP is routinely monitored based on the American Society for Testing and Materials D 1391-57 Odor Panel Evaluation Technique, which involves sniffing of ambient air samples by an odor panel. Samples of ambient air are taken by placing a 1-foot (0.3-meter) square by 0.5-foot (0.15-meter) deep box on the windrow surface. A vacuum pump draws ambient air into an inlet hose on the side of the box and through an activated carbon filter to remove any odors. The air entering the box is thus odor free. Inside the sampling box several baffles force the air to travel a serpentine path along the windrow surface. The air and any odorous compounds that have been picked up then travel through a hose into a bag, which is sealed and returned to a laboratory where a panel of citizen volunteers sniff the odor in this bag. If they cannot detect an odor, the sample is considered to be odor free. If the panel does detect an odor, then an additional sample is taken from the bag and diluted with clean air until the sample is odor free. The number of dilutions required indicates the strength of the odor. The quality of the odor (i.e., whether it smells pleasant or unpleasant) is not considered. This highly subjective test requires many data measurements to develop reliable information on the odor emissions from a particular operation.

Data from several years of odor panel evaluations have shown that 83 percent of the total odor produced during the life of a windrow is emitted between turnings, and the remaining 17 percent is emitted during and immediately after turning (Figure 3.27). Among those odors which occur between turnings, the most repulsive odors occur in the initial days of the cycle (Figure 3.28). After about 10 or 12 days, surface odor emissions drop to a fairly low, constant background level. During turning, odor generation is rapidly elevated, but returns to baseline levels within a few minutes of completion of turning (Figure 3.29). This phenomenon of peak, intense odor emissions that die off very rapidly is the same regardless of when during the compost cycle turning is performed.

Tests with a forced-aeration windrow show that the rate of odor emissions is a function of surface temperature. In the positive-pressure aeration mode, the temperature at the windrow surface increases as air travels through the hot zone on its way to the surface. Odor increases dramatically with increasing surface temperature in windrows containing either sawdust or dried compost as a bulking agent (Figure 3.30).

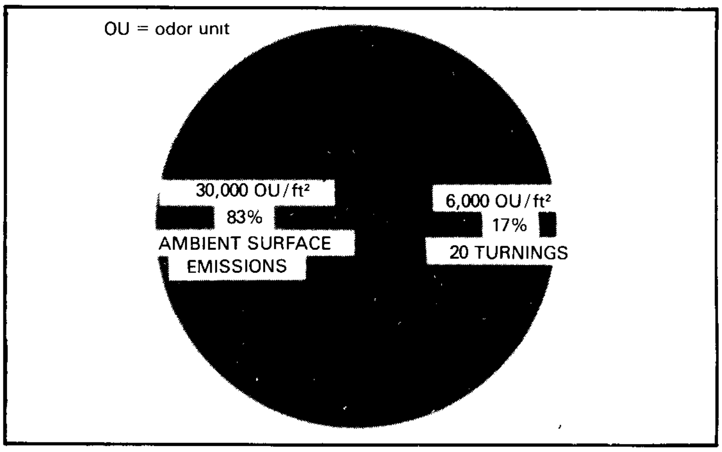


Figure 3.27. Sources of Windrow Surface Odor Emissions

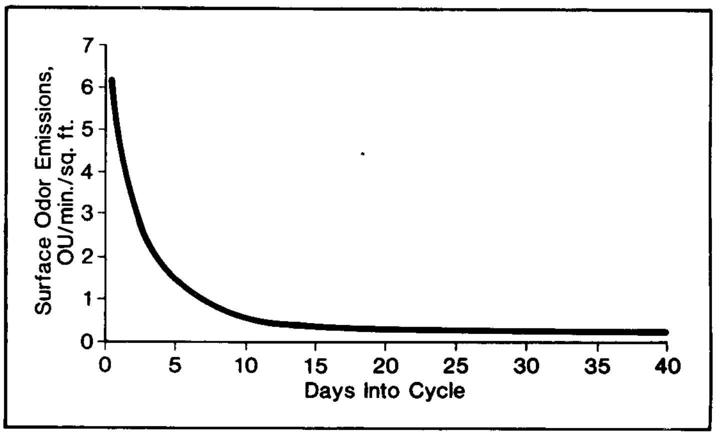


Figure 3.28. Average Windrow Surface Odor Emissions

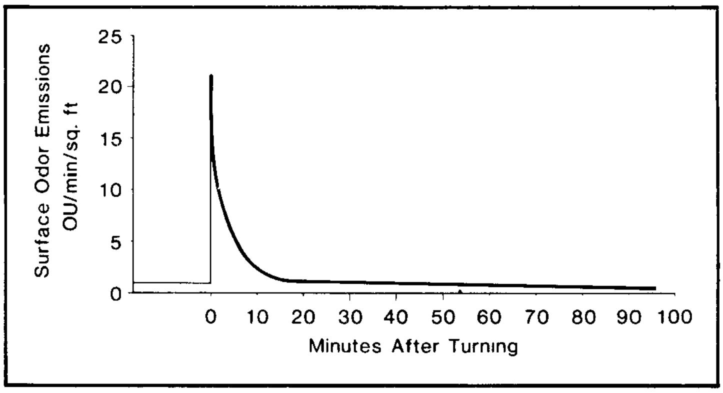


Figure 3.29. Surface Odor Emissions After Windrow Turning

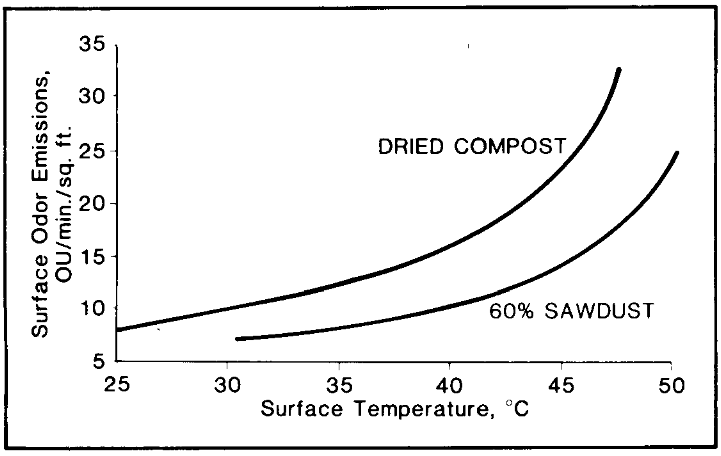


Figure 3.30. Windrow Surface Temperature vs. Surface Odor Emissions

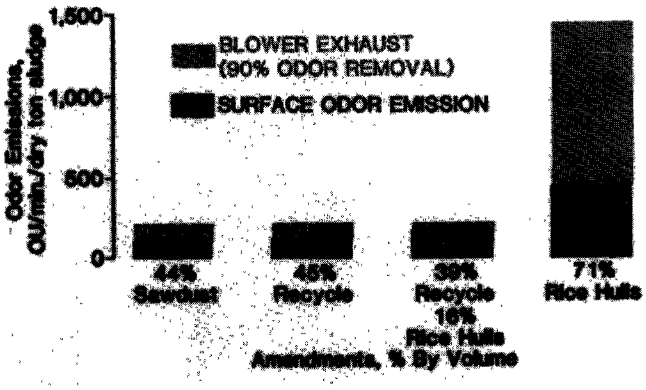


Figure 3.31 Odor Emissions from Forced Aerated Windrows

In the suction or negative-pressure mode, odors are emitted by the exhaust system. Up to 90 percent removal can be achieved with some odor-scrubbing media; however, even at this reduced level, exhaust odors generally equal or exceed surface odors (Figure 3.31).

JWPCP researchers have experimented with several approaches and devices for odor control. One relatively simple approach is the use of water trucks to control odors associated with dust particles. Another approach is the use of a packed tower odor scrubber that can use different scrubbing media: water, permanganate, sulfuric acid, and a 1 percent bleach solution (Figure 3.32). The effectiveness of all these media has been fairly low, ranging from about 43 percent with straight water to 61 percent with permanganate (Table 3.1).

Table 3.1 Scrubber Performance

Scrubbing Agent	Number of Runs	Average Odor Removal (%)
Water	13	43
$KMNO_4$ (0.5 lb/gal)	8	61
H_2SO_4 (0.1N)	4	57
NaOCl (1%)	8	45

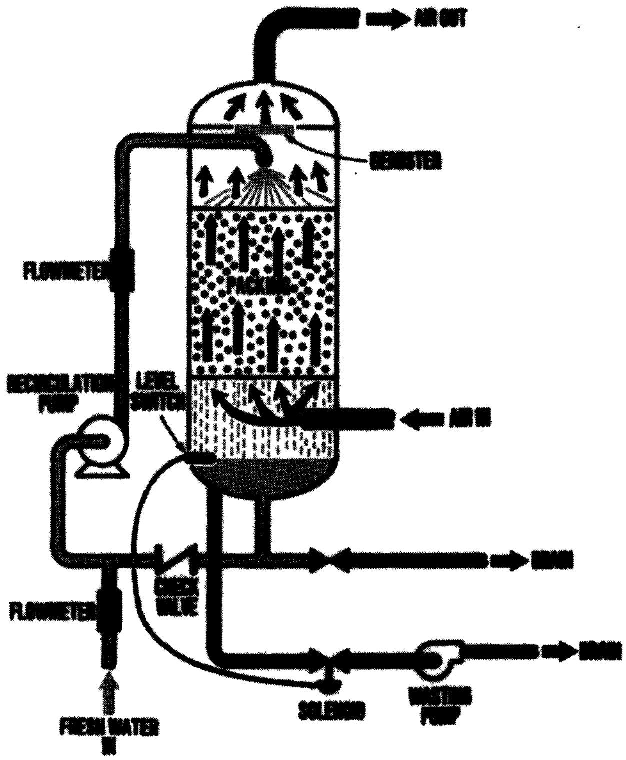


Figure 3.32. Odor Scrubber Assembly

Figure 3.33 shows the results of experiments with different odor-scrubbing devices. The simplest scrubber — a bed of dry compost — was quite ineffective. Wet scrubbers removed 43 percent of odors; activated carbon removed 90 percent; and a wet scrubber with an activated carbon unit gave the best overall performance with 95 percent removal. Unfortunately, the more effective devices are extremely costly.

Over a period of years, the JWPCP has been approached by a number of companies that claim to have novel odor-reduction approaches, such as specialized enzymes or microorganisms, and the extract of the Yucca plant. All these claims have turned out to be false or prohibitively expensive.

Pathogen Destruction

Another very important requirement that the JWPCP, as the operator of a compost facility, must meet is to ensure that neither the process nor the product poses a threat to human health.

Aspergillus monitoring at the JWPCP has shown no evidence of either *Aspergillus* growth during composting or elevated levels of *Aspergillus* around the plant.

The JWPCP routinely monitors compost for total and fecal coliform, *Salmonellae*, viable *Ascaris* ova, and viruses. One important component of monitoring is the standard to which the monitoring data are compared. EPA's time-temperature monitoring requirements (see section on *Pathogens* in Chapter 1) set no standard for actual pathogen levels. The JWPCP has developed its own standard for three types of pathogenic organisms based on their research and a review of the literature (Table 3.2). Ingestion of a quarter teaspoon of compost (believed to be an unlikely event) containing organisms at these levels is estimated to increase a person's risk of disease by about 1 in 200 to 1 in 1,000. Thus, these standards have a wide margin of safety.

These standards do not recognize the very restrictive level of disinfection that certain health experts have advocated for *Salmonellae*. Some of these experts have suggested that no *Salmonellae* should exist in any compost released to the public because of the possibility that *Salmonellae* could regrow. The JWPCP has performed research indicating that *Salmonellae* regrowth does occur occasionally, but very infrequently, at least with the products currently produced from the JWPCP compost. Based on these results, the JWPCP has rejected for the present time the very restrictive "no *Salmonellae* standard" and chosen the 1 MPN (most probable number)/dry gram of compost (MPN/gm) as a reasonable alternative. Should the cause of regrowth become better understood, then the composting process will be changed, if necessary, to ensure that these conditions are avoided.

JWPCP researchers have conducted several studies over the years to examine the relationship between the survival of the various indicator organisms. Figure 3.34 illustrates the relationship between *Salmonellae* and viable *Ascaris* ova at the end of the compost cycle based on data from 142 samples. In the earlier years, the JWPCP had used *Salmonellae* as the overall indicator of pathogen destruction; however, Figure 3.34 illustrates that *Salmonellae* are not a good

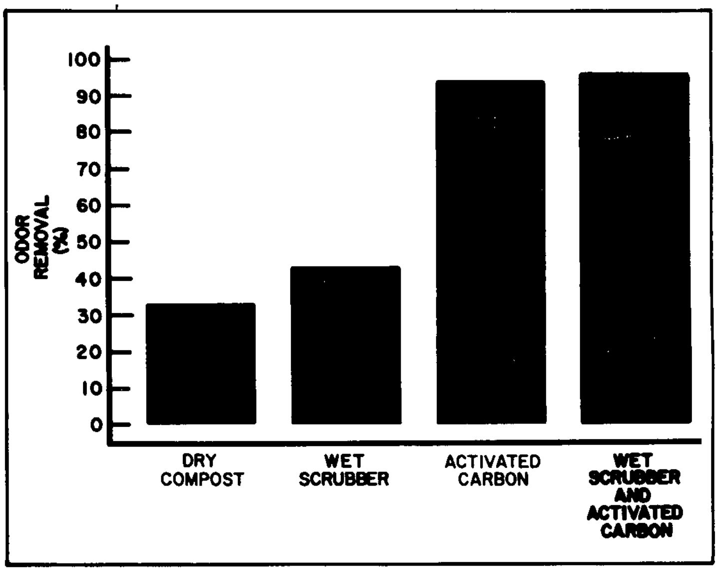


Figure 3.33. Odor Control Study

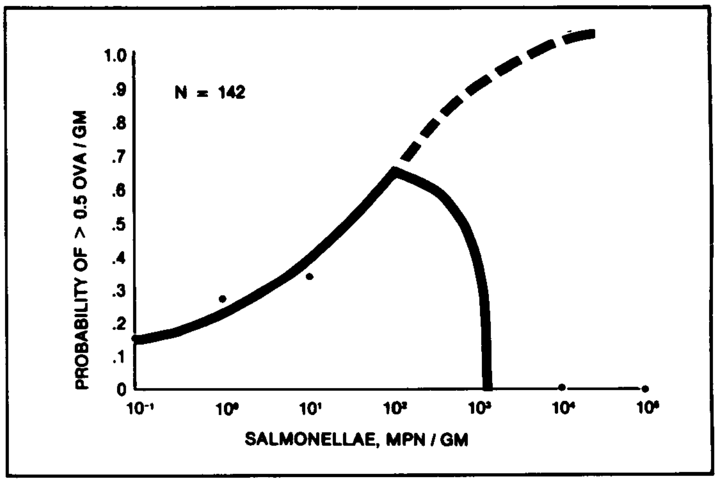


Figure 3.34. Salmonellae as Indicator of Viable Ascaris Ova

Table 3.2 Maximum Population Densities Proposed by JWPCP for Pathogens in Compost

Salmonellae	1	MPN/GM
Viable Ascaris Ova	0.5	OVA/GM
Virus	0.1	PFU/GM

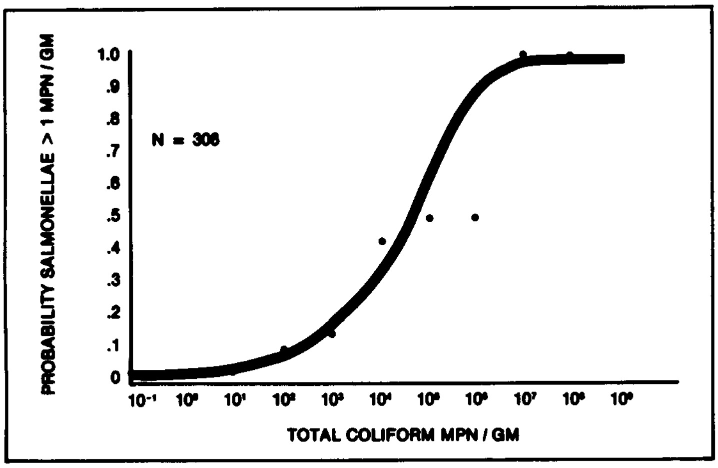


Figure 3.35. Total Coliform as Indicator of Salmonellae

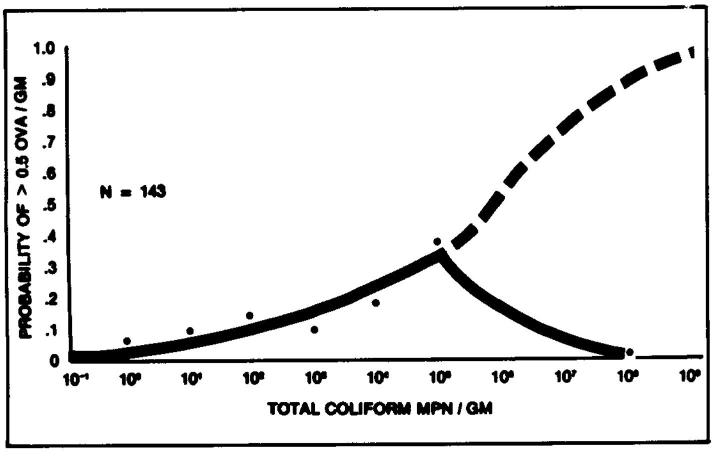


Figure 3.36. Total Coliform as Indicator of Viable Ascaris Ova

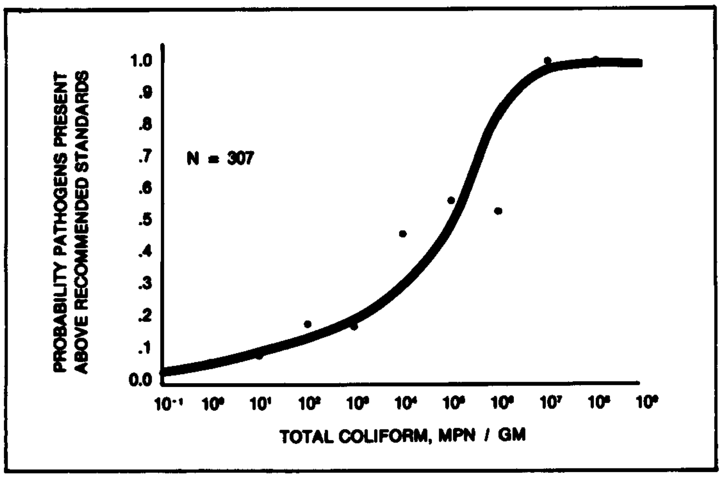


Figure 3.37. Total Coliform as Indicator of Pathogens

indicator organism since, at levels of *Salmonellae* greater than 10^2 MPN/gm, the probability that there may be greater than 0.5 viable *Ascaris* ova per gram actually decreases. At levels of less than 10^2 MPN/gm *Salmonellae*, there is good correlation between *Ascaris* and *Salmonellae* survival. However, even when the *Salmonellae* are reduced to detection limits, there is still a relatively high probability (15 percent) that viable *Ascaris* ova will remain.

In another study, based on analysis of 306 finished compost samples over a 2-year period, the JWPCP examined total coliform as an indicator that *Salmonellae* levels were above the proposed standard of 1 MPN/gm. The data, shown in Figure 3.35, suggest that total coliform is an excellent indicator of *Salmonellae* survival.

Figure 3.36 shows total coliform versus the probability of *Ascaris* ova survival based on 143 samples. The data correlate well at low levels of total coliform, but not at high levels. However, they do show that when all coliform are killed, the probability of viable *Ascaris* ova surviving is extremely low.

The JWPCP then looked at all their data for 307 samples collected over the last few years to examine the relationship between coliform die-off and the destruction of *Salmonellae*, viable *Ascaris* ova, and viruses to the "safe" levels given in Table 3.2.

Figure 3.37 shows the probability that one or more of these three standards was exceeded as a function of total coliform survival at the end of the compost cycle. The data show that when a significant number of coliform survived, there was 100 percent certainty that at least one pathogen standard was exceeded, and therefore the material was not adequately disinfected. But as the total coliform levels were reduced to essentially detection level limits, the probability that any of those standards were violated was only about 2 percent.

These data indicated to the JWPCP that total coliform is a good indicator of overall disinfection, and use of this indicator would allow the compost facility operator to decide whether the material was ready to leave the facility or whether it must remain on the field for a few more days. Total coliform tests are also practical since they are simple to run and provide results in 1 or 2 days. The JWPCP intends to propose total coliform monitoring as an alternative to the time-temperature approach. This proposal is supported by a previous study [1] based on an extensive literature search, which recommended that the reduction of total coliform to a median of 10 MPN/gm be used as an indicator of adequate disinfection.

Figure 3.38 shows the probability of reducing the *Salmonellae* pathogens to 0.2 MPN/gm, — the detection level limit — as a function of time at temperatures exceeding 55°C and 50°C. The data show that *Salmonellae* can be reduced to very low levels at 50°C by extending the composting period slightly. Similarly, a standard for coliform of 10 MPN/gm can be achieved at 50°C by extending the composting period slightly (Figure 3.39).

Figures 3.40 and 3.41 summarize the JWPCP research data concerning coliform die-off as a function of days in the composting cycle. These figures show that at an internal windrow temperature of 50°C, the proposed standard for coliform of 10 MPN/gm can be met after 7 to 25 days of composting. At 55°C, the required period of time is much less — about 17 days.

Another related area of research has been to investigate the conditions that create the temperatures necessary for pathogen destruction. These conditions include the cross-sectional area of the window, turning frequency, and type of bulking agent.

Figure 3.42 illustrates internal temperature as a function of cross section in an irregularly shaped windrow approximately 20 days into a cycle. The data clearly demonstrate that as cross-sectional area increases, the surface-to-volume ratio decreases and the internal temperature increases.

The JWPCP is currently using an intermediate-sized windrow with a cross-sectional area of about 32 square feet (ft^2) (3 square meters [m^2]), and a large windrow with a cross-sectional area of about 90 ft^2 (8 m^2) during the last 2 weeks of the cycle. Routine temperature measurements of up to 71°C, 2 feet (0.6 meters) under the surface of the large windrows, demonstrate that the present operation achieves a very high level of pathogen destruction.

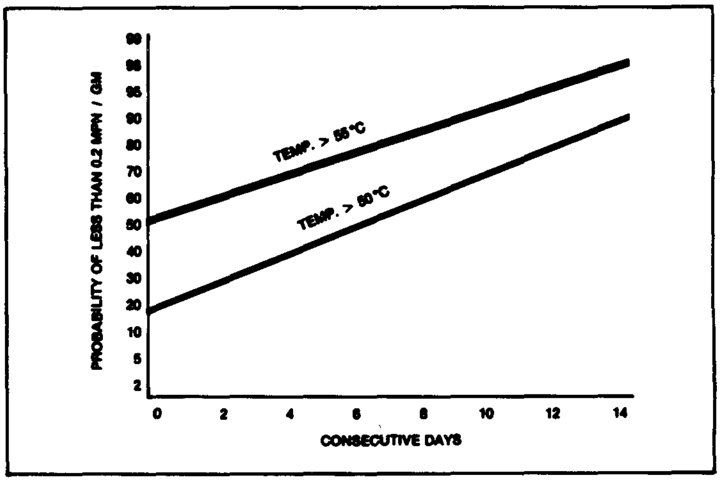


Figure 3.38. Salmonellae Inactivation by Windrow Composting

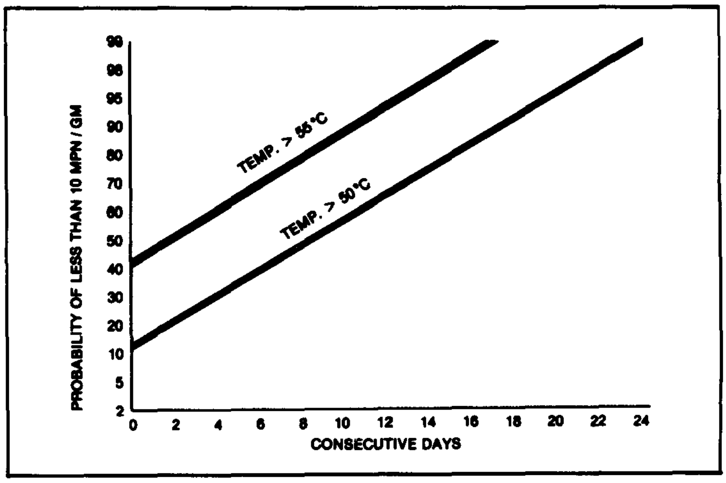


Figure 3.39. Total Coliform Inactivation by Windrow Composting

Heavy Metal Content of Sludge Products

Another important constraint at the JWPCP is to ensure that compost does not exceed the recommended levels for metals (primarily cadmium and lead) and polychlorinated biphenyls (PCBs), a toxic organic constituent. The heavy metal that has received the most attention is cadmium because of its ability to be taken up into the edible portions of certain leafy vegetables. The State of California recommends two levels for cadmium in soil amendment products: 25 milligrams (mg)/kg for direct application to food-chain crops, and 50 mg/kg for the unrestricted use of sludge products marketed to the public.

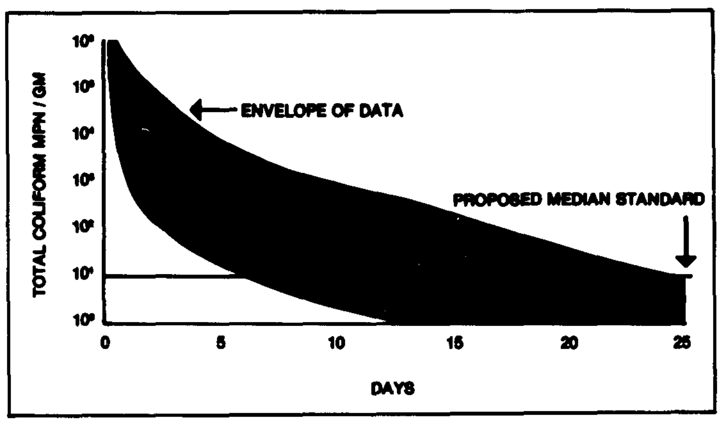


Figure 3.40. Coliforms Remaining After Exposure to Internal Temperatures >50°C

Figure 3.43 shows the cadmium content of three main products marketed by Kellogg during 1983 and 1984: a soil

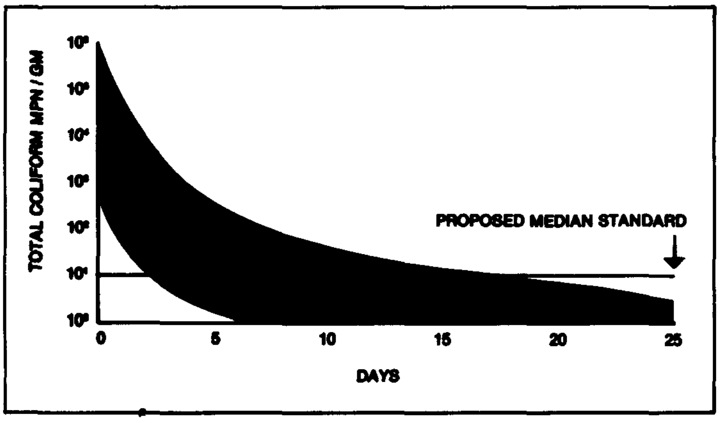


Figure 3.41. Coliforms Remaining After Exposure to Internal Temperatures > 55°C

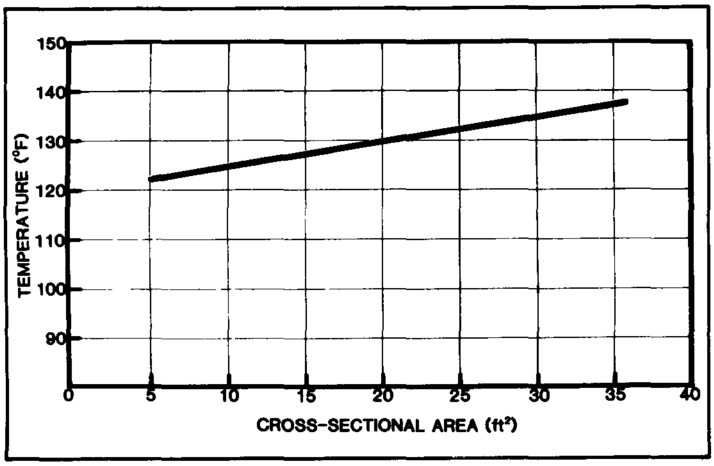


Figure 3.42. Windrow Temperature vs. Cross-sectional Area

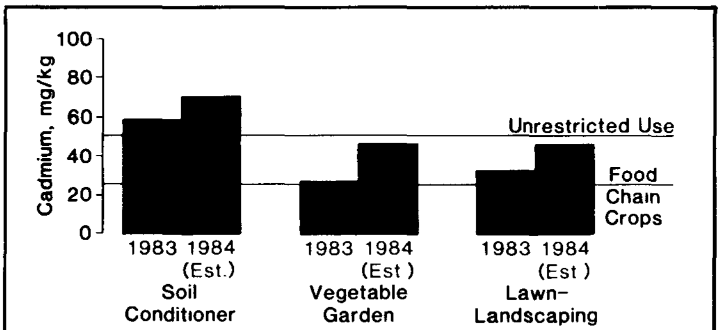


Figure 3.43. Cadmium Content of Soil Amendment Products

conditioner; a product specifically intended for vegetable gardens; and a product marketed as a lawn/landscaping product. The soil conditioner amendment product exceeded the recommended limit of 50 mg/kg. The vegetable garden product, because it contains 75 percent by volume rice hulls, was well below the 50 mg/kg limit and just in compliance with the recommended level for food chain crops. The lawn and landscaping product was well below the recommended limit of 50 mg/kg, but was above the recommended limit for direct application to food-chain crops.

The 1984 values are higher because the full sludge dewatering achieved in 1984 captured a much higher proportion of the very fine sludge particles with which heavy metals are associated. In contrast, no fine sludge particles were ever captured by the old centrifuges used before 1977. Records show that all the JWPCP sludge products, including soil conditioners, contained only about 25 mg/kg cadmium before 1977.

The 50 mg/kg standard is a highly conservative standard designed to protect public health in a worst-case scenario: an individual who amends soil with compost annually, who lives in an area with naturally acidic soils that promote metal uptake by vegetables, and who consumes homegrown vegetables daily for 50 years. This standard is certainly conservative in southern California and Arizona where Kellogg's products are marketed, since these areas have alkaline soils that minimize metals uptake. Thus, the JWPCP feels that current levels of cadmium in its products are well within safe levels for the protection of public health. In addition, cadmium levels are expected to decrease significantly when the EPA categorical industrial pretreatment program is implemented.

Although lead is not taken up by plants, it is a potential health concern because of the propensity of some small children to consume nonfood substances, including soil. Currently, California recommends that lead levels in soil amendment products not exceed 500 mg/kg. Figure 3.44 shows that lead levels of all three soil amendment products were well within this standard in 1983. Additional metals picked up by full dewatering capabilites were estimated to bring one product up to the limit in 1984.

Although the JWPCP has never monitored PCBs in bagged products due to the difficulty of the testing procedure, they did examine the straight compost before dilution with sawdust or rice hulls. The undiluted compost was well within the two California recommended standards (Figure 3.45), and the diluted products would be expected to have an even lower level of PCBs.

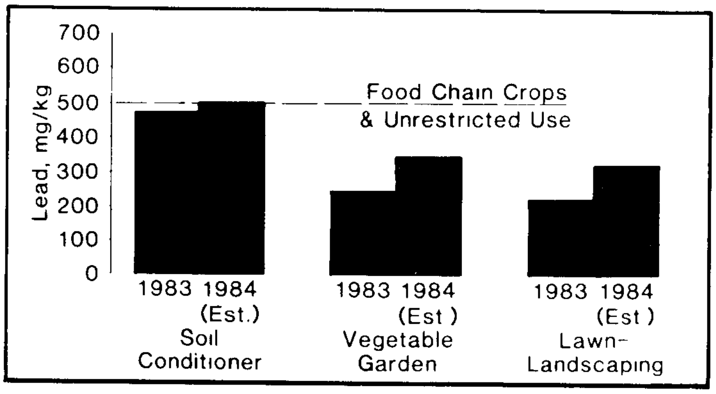


Figure 3.44. Lead Content of Soil Amendment Products

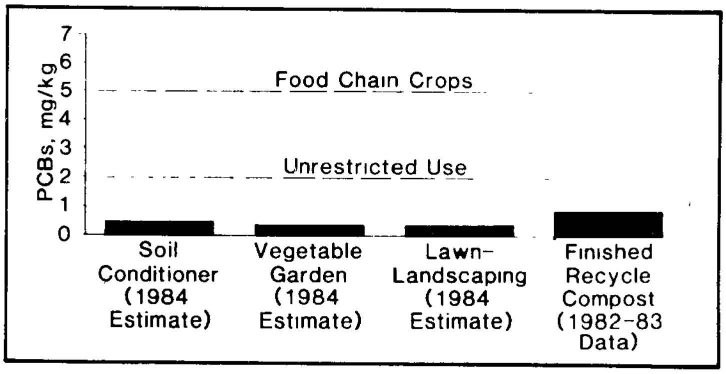


Figure 3.45. PCB Content of Soil Amendment Products

Public Relations

Another objective the JWPCP must meet as an operating compost facility is good public relations. The JWPCP experienced severe public relations problems in 1977 because of odors that were generated when the composting operation was expanded to accomodate the increased volume of wet sludge cake. As a result, a Citizens Advisory Committee was created to work with the JWPCP to identify conditions that lead to odor emissions and to evaluate the effectiveness of the JWPCP's attempts to correct these situations.

Various subcommittees were organized in the surrounding communities. These subcommittees meet individually and elect representatives to the central Citizens Advisory Committee. The central committee meets with the JWPCP on a regular basis to provide feedback on the JWPCP's performance. The JWPCP makes special efforts to ensure that the concerns of the Advisory Committee are addressed in a timely manner and that all complaints are adequately followed up.

As part of the public relations program, a series of meetings and Saturday morning tours were organized to acquaint local citizens with the composting operation. The tours were very successful and have been continued on an annual basis. The plant's weekend staff were trained in how to receive irate complaints from the community. This training included how to avoid taking a complaint as a personal insult, how to record the information in a courteous manner, and how to ensure that the person making the complaint will feel that he or she has reached the proper person and that something will be done about the complaint as soon as possible.

The overall program has greatly enhanced relations between the sanitation districts and the surrounding community.

Marketing of Compost Products

The Kellogg Supply Company has been marketing sewage sludge products from the JWPCP facility since 1928. They process the compost received from the JWPCP by screening it to remove large particles (greater than ⅜ inch [1 cm]) and then bagging it.

Dozens of different products are formulated from the composted sludge. Kellogg's four largest products in terms of volume are:

- *Nitrohumus*, which is a soil amendment consisting of 90 percent sludge and 10 percent sawdust.
- *Topper*, which is used for top dressing of new lawns and for gardens; it consists of 60 percent sawdust and 40 percent sludge.
- *Amend*, which is recommended for vegetable gardens; it consists of 75 percent rice hulls and 25 percent sludge cake. Rice hulls are rich in potash, a necessary nutrient for good vegetable growth.
- *Gromulch*, which is very similar to Topper but contains some proprietary ingredients. It is basically composed of 60 percent sawdust and 40 percent sludge cake.

The materials are primarily marketed in 2-ft^3 bags to home users through 2,000 retail stores in southern, central, and a portion of northern California; throughout Arizona; and in the Las Vegas area of Nevada. Kellogg does not advertise directly to the public. Instead, the firm relies on the nursery supply sales force to recommend the product to local customers. One reason for Kellogg's success in this approach is that all Kellogg sales personnel are previous owners or managers of nursery supply stores and know the business intimately. Also, the Kellogg products work well. They are low in leachable salt content, ammonia, and chlorides. It is almost impossible to ruin a garden by overuse. The nurseries know their customers will not be dissatisfied.

Another factor in Kellogg's success has been the diversity of its product lines. In addition to the soil amendment products, they also sell steer manure, sawdust, redwood chips, lime, sulphur, and numerous blends of fertilizers and herbicide products. Thus nurseries need only make one telephone call to Kellogg to obtain everything they need.

Kellogg maintains a large inventory of products and maintains contracts with a large number of private haulers to offer rapid delivery service — as little as 1-day delivery throughout southern California.

Kellogg also advertises and promotes their products as top-of-the-line materials. Their recommended selling prices are far above all competing fertilizer products. The approach has been very successful. Although Kellogg does not currently sell directly to the public, their products are used so frequently throughout southern California that they have become identified with gardening activity. The Kellogg Supply Company currently employs about 75 people and has annual sales of about $13 million, $9 million of which comes from sewage-sludge-based products from the JWPCP.

The volume of Kellogg's product line is limited by the amount of material they can obtain from the JWPCP. In an effort to generate greater revenues, Kellogg has been investigating the possibility of selling the sludge-based products in much smaller bags at higher prices in supermarkets and grocery stores.

Costs

The actual costs of composting at the JWPCP in 1984 are summarized in Table 3.3. Equipment is the single largest cost component, followed by the wages (including fringe benefits) of the eight operators and one foreman. Total direct operational costs are about $3,000 per operating day (6 operating days per week). In 1984, an average of 104 dry tons (94 dry mt) of sludge cake were composted per operating day, a lower level of productivity than in previous years due to unusually severe odor complaints received in the summer of 1984 and to the slowdown in operations as personnel learned the new composting operation that involved building windrows of three different sizes. Thus, the direct composting cost averaged $28.70 per dry ton ($31.64 per dry mt).

In addition to these direct costs, significant indirect costs were incurred for management, administrative, and clerical support services such as personnel timekeeping, purchasing, labor relations, and handling community complaints regarding odors. When these indirect costs are included, the composting unit costs for 1984 averaged $39.40 per dry ton ($43.44 per dry mt) of sludge composted. The JWPCP received approximately $4 per dry ton ($4.41 per dry mt) from the fertilizer manufacturer for the product sale, so the JWPCP's bottom-line cost was approximately $35.00 per dry ton ($38.59 per dry mt) in 1984. This cost is much lower than the cost of approximately $53.00 per dry ton ($58.43 per dry mt) for landfilling. The JWPCP spends about $300,000 per year in research to improve the composting operation. This cost was not included in the above unit costs.

Table 3.3 1984 Composting Costs

Item	**$/Operating Day**
Direct Costs	
Equipment	1,036
Capital Recovery	
Fuel	473
Maintenance	512
Wages	964
Indirect Costs	1,113
Total Costs	4,098
	$39.40 Per Dry Ton

It should be noted that from late 1984 through mid-1985 operating costs have decreased and productivity has increased, reflecting the experience the operators have gained with the revised composting process. Projecting these latest 7 months of cost and productivity data to an annual average suggests that 120 dry tons (108 dry mt) of sludge will be composted per operating day at a unit cost of $34 per dry ton ($37 per dry mt) of sludge composted. After credit for sale of the product, the bottom line cost is expected to average $30 per dry ton ($33 per dry mt) of sludge composted.

The JWPCP vehicle fleet includes: three tractor trailers devoted exclusively to composting; other tractor trailers for hauling material to the landfill; three large composters and one very large composter; two front-end loaders; and two water trucks. The original composting vehicle fleet cost $1.4 million (Table 3.4). Equipment costs are calculated by amortizing costs over the expected equipment lifetime (Table 3.5). Composters have only a 5-year life because the very heavy wear results in a need for major repairs after 5 years.

Table 3.4 Composting Equipment

Equipment	Cost Each	No.
Tractor-trailer	$95,000	3
Large Composter	$125,000	3
Very Large Composter	$275,000	1
Front-end Loader	$200,000	2
Water Truck	$50,000	2
Total Costs	$1,435,000	

Table 3.5 Expected Life of Composting Equipment

Equipment	Years
Tractor-trailer	10
Large Composter	5
Very Large Composter	5
Front-end Loader	10
Water Truck	15

References

(1) LA/OMA Study Group. 1980. Proposed Sludge Management Program for the Los Angeles/Orange County Metropolitan Area (LA/OMA). Draft Environmental Impact Statement/ Environmental Impact Report (p. VI-72). U.S. EPA, Region IX, San Francisco, California. April 1980.

4. In-vessel Composting

Introduction

In-vessel composting is the biologic stabilization of sludge under controlled aerobic conditions in a closed vessel or an enclosed structure. The structure of the in-vessel system may take many forms (e.g., circular or rectangular towers, horizontal tunnels, bin or box-type vessels, or various structures and configurations within a building). As of early 1985, 4 in-vessel facilities have started up or are operational in the United States, 5 facilities are under construction; and approximately 14 facilities are in the design or negotiation stage (Table 4.1).

The basic steps in in-vessel composting are identical to those in windrow and static pile systems: mixing of sludge with a bulking agent, aeration to promote the biological processes that decompose the material and create 50° to 70°C temperatures that destroy pathogens, and curing to allow further stabilization and to destroy pathogens. The essential difference between in-vessel and other composting systems is that the in-vessel processes are highly mechanized and take place within one or more confining structures. In-vessel systems generally require shorter processing times than static pile and windrow systems because of such factors as better process control, use of sawdust as a bulking agent and, in some dynamic systems, good moisture release through mixing and refluffing.

Figure 4.1 compares the process flow of one type of in-vessel system with a static pile system. In this in-vessel system, the compost and bulking agent (usually sawdust and recycled compost) are mixed in a fixed mixer and then transported by a conveyor system to the reactor, where the mix is composted for about 14 days. The compost is then cured in another reactor for approximately 20 days, during which time composting continues at a slower rate. In cold climates, or for particular compost uses, these retention times may be extended to ensure that the product is suitable for the intended use. For some purposes, the compost can be distributed immediately after curing, and for others, additional curing may be required. Most in-vessel systems that use sawdust as the bulking agent do not require screening of the final product. Frequently, compost is recycled and incorporated into the sludge/bulking agent mix. This recycling increases the residue time of the mixture and reduces the need for new bulking material.

Most of the process parameters for in-vessel composting are identical to those for static pile and windrow processes. For ideal processing, the sludge should contain at least 25 percent volatile organic material, and the sludge/bulking agent mixture should have a moisture content from 50 percent to not more than 65 percent, a carbon-to-nitrogen ratio

Table 4.1 In-Vessel Facilities in the United States, May 1985

Startup or Operational
Cape May, New Jersey
Columbus, Ohio
Portland, Oregon
Wilmington, Delaware
Under Construction
Akron, Ohio
Clinton County, New York
East Richland County, South Carolina
Lancaster, Pennsylvania
Sarasota, Florida
In Design or Negotiation
Baltimore, Maryland
Charlotte, North Carolina
Clayton County, Georgia
Cobb County, Georgia
Endicott, New York
Fort Lauderdale, Florida
Hamilton, Ohio
Henrico County, Virginia
Hickory, North Carolina
Jackson, Mississippi
Juneau, Alaska
Montgomery County, Ohio
Newberg, Oregon
Schenectady, New York
Washington, D.C.

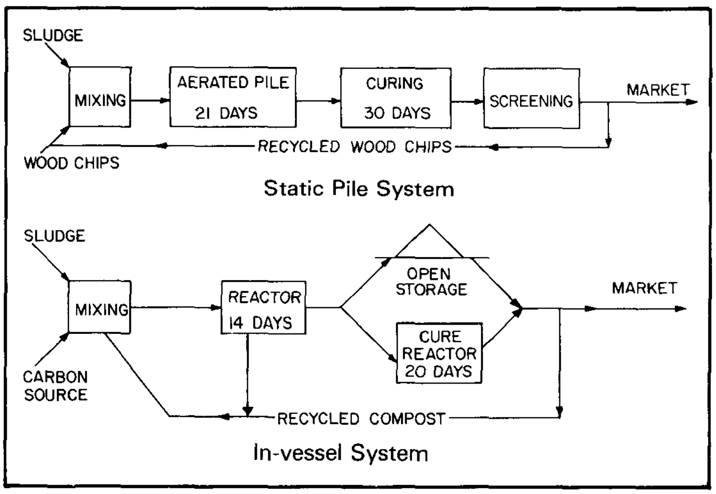


Figure 4.1. Comparison of Process of Static Pile System and One Type of In-vessel System

in the range of 20:1 to 30:1, and a pH between 5 and 8. (Mixtures with an initial pH of 11 or 12 can be successfully composted but may require a few more days to achieve the necessary temperature rise.) However, one major difference is that in-vessel systems generally use a higher ratio of sludge to bulking agent than do windrow and static pile systems. Use of this ratio produces less volume of mix per unit of sludge. The higher ratio is possible due to the greater surface area of sawdust (the bulking agent most commonly used in an in-vessel system) and the enhanced process and odor control of in-vessel systems. According to manufacturers of in-vessel systems, volumetric sludge:bulking agent ratios typically range from 1:0.3 to 1:1, depending on the type of sludge, bulking agent, and moisture content. However, some in-vessel systems have had to use a greater proportion of bulking agent than originally claimed due to greater moisture content of sludge and bulking agents, difficulties in moving a wet mixture through the system, and difficulties in moving air through the wet mix.

In-vessel systems offer several advantages over open static pile and windrow systems:

- Favorable space requirements. In-vessel systems require less land area than open systems.
- Shorter processing time. In-vessel systems generally require about 14 days for composting and 20 days for curing, compared to 14 to 21 days of composting and 30 days of curing in open systems. (However, the adequacy of pathogen destruction is still unknown for the shorter composting time.)
- Lower labor costs. In-vessel systems rely heavily on electric-powered, labor-saving equipment.
- Protection from the effects of weather and climate. Material processed in an in-vessel system is protected from precipitation. The system can be insulated for cold weather.
- Better odor control. Process off gases are more easily contained and treated in an in-vessel system.
- Reduced nuisance potential. Site cleanliness and dust control are easily managed.
- Enhanced process control.
- Better public image. An enclosed "compost factory" is more acceptable to the general public than an open system.

The disadvantages of in-vessel systems are potentially higher capital costs and the lack of operating data on the systems. In particular, the cost of operating the aeration system and the adequacy of pathogen control have not been evaluated on any system operating in the United States. Other potential disadvantages could be higher maintenance costs and less flexibility in adapting to changes in the quality of sludge and bulking agents, and to changes in sludge production rates. Also, some in-vessel systems have had problems with moisture removal.

Types of In-vessel Composting Systems

In-vessel systems can be divided into two major categories: plug flow and dynamic. In plug flow systems, the relationship between particles in the composting mass stays the same throughout the process, and the system operates on the basis of a first-in, first-out principle. In a dynamic system, the composting material is mechanically mixed during the processing. In-vessel systems can be further categorized based on the geometric shape of the vessels or containers used.

- Plug flow:
  - Cylindrical reactors
  - Rectangular reactors
  - Tunnel reactors
- Dynamic:
  - Rectangular tanks
  - Circular tanks

Cylindrical Reactors

Plug flow cylindrical systems of a small size have been operating successfully in Europe for many years. A number are currently under construction in the United States, and one in Portland, Oregon, is operational. Several other U.S. facilities are in the planning stages.

In a typical cylindrical system (Figure 4.2), sludge, recycled compost, and a bulking agent are blended together in fixed mixers and fed into the top of a silo in such a way that the fresh mix is distributed over the top of the existing mix within the reactor. Compost is removed from the bottom of the reactor using a rotary screw. Removing material from the bottom causes the mix within the silo to descend, creating space for new mix to be added at the top. Detention time within the reactor is typically 14 days. The compost mix is aerated by a pipe manifold system that forces air into a plenum in the bottom of the reactor and up through the mix (see photo). Off gases are removed from the top of the reactor and treated for odors.

The cylindrical system includes several process controls. Temperatures in the reactor are measured continuously at different elevations, and the oxygen or carbon dioxide content of the off gas can be continuously monitored. The air flow is adjusted by a microprocessor based on analysis of the temperature and off gases. Process control is geared

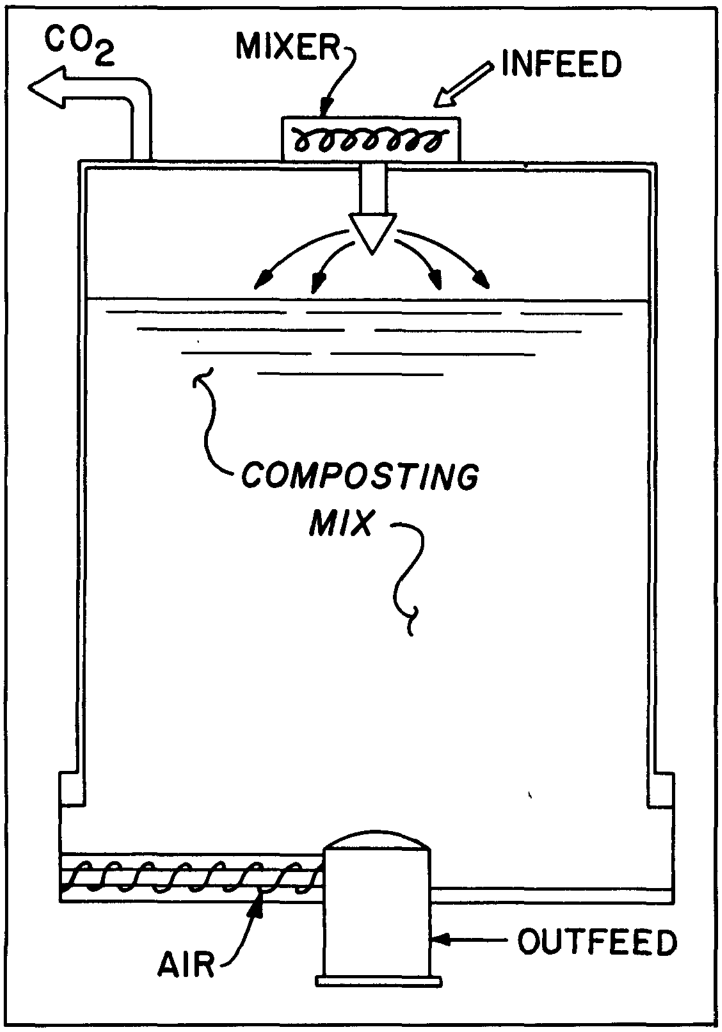
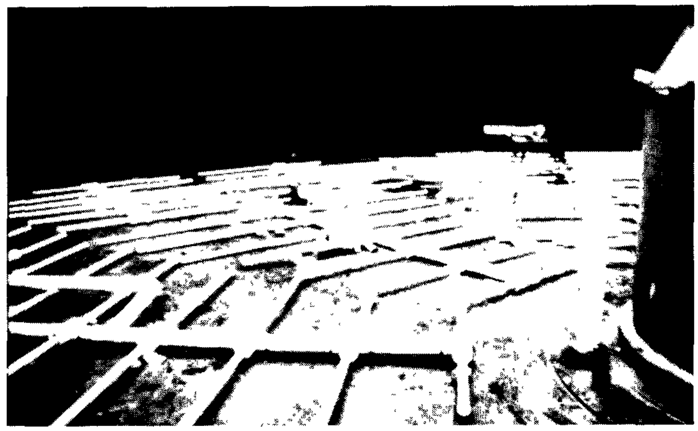


Figure 4.2: Cylinder Tower Reactor



The aeration pipe at the bottom of the cylindrical reactor at the Portland, Oregon, facility. This system distributes air uniformly throughout the bottom of the silo. The air flow cannot be varied with respect to different areas within the silo. Only the total air flow can be varied.

A cylinder composting facility in the Federal Republic of Germany. Note the insulation around the tower.

toward maintaining the hottest zone near the top of the cylindrical tank to aid in better moisture release.

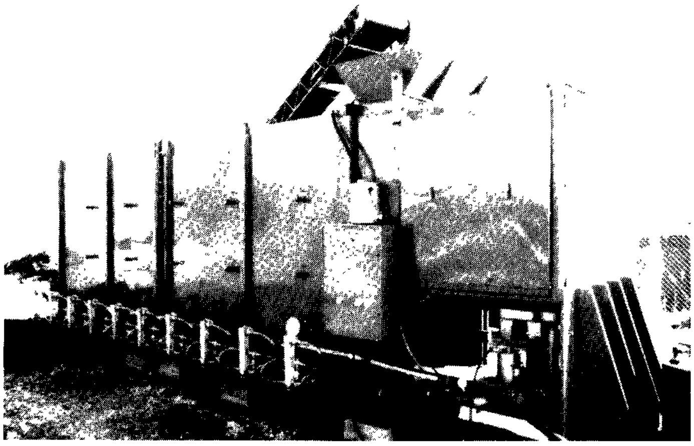
A complete cylindrical composting system consists of a storage silo, one or more reactors in which composting takes place, and curing reactors (see photo). Additional equipment includes mixers, blowers, controls, and materials handling equipment. Reactors are typically 31.5 feet (9.6 meters) high with capacities from 3,500 ft^3 (100 m^3) to 14,000 ft^3 (400 m^3).

Rectangular Reactors

Rectangular reactors were developed to provide large capacity within a single reactor and better process control.

In rectangular reactor systems (see Figure 4.3), premixed material is delivered to the top of the reactor by conveyor belts that evenly distribute the mix over the top of the composting mix already contained within the reactor. Compost is removed at the bottom of the reactor by a screw that runs on tracks along the bottom of the reactor. The length of a reactor is not limited, and capacity can be increased by increasing the length of the reactor. The screw extractor mechanism can be easily moved from under the composting mixture for maintenance and repair.

The mix is aerated by forcing air in at the bottom of the reactor through an air distribution system that can be



Demonstration tunnel reactor in Alabama showing sludge infeed to a hopper; hydraulic ram and door; pump arrangement; and manifolds used to distribute and collect air.

controlled to change the air flow in different sections of the reactor. The nozzles are protected by a layer of granular material such as graded aggregate. Air is forced up through the composting material and removed by an exhaust manifold. The exhaust manifold is located just below the surface of the incoming mix. Heat from the active composting material raises the temperature of the incoming mix. The air exhaust system operates under negative pressure to ensure that no odors leak from the reactor and to help remove moisture from the fresh mix. Temperature, carbon dioxide content, and air pressure are monitored. The air flow is adjusted by a microprocessor based on the monitoring data.

Detention time within the base reactor is 20 to 30 days. The material can be cured either (1) in the same reactor by increasing the detention time, (2) in a second reactor, or (3) in aerated storage piles.

A rectangular reactor is currently under construction in Cape May, New Jersey. The facility includes a bulking agent receiving area, a sludge storage area, a mixing building, a reactor building, and a materials finishing area where the compost can be prepared for distribution. The reactor, which is approximately 30 feet (9 meters) high and 26 feet (8 meters) wide, is designed and operated to maintain the hottest (55° to 60°C) zone in the top half. The reactor is divided into sections sized to accommodate peak sludge production during summer months in this ocean resort community and low sludge production during the winter.

Another type of rectangular reactor system currently being marketed in the United States uses air lances suspended in the composting mixture to provide aeration. Lances supplying positive-pressure aeration are alternated with suction lances to reduce the power required to move the air and to prevent anaerobic areas by distributing the air throughout the mass.

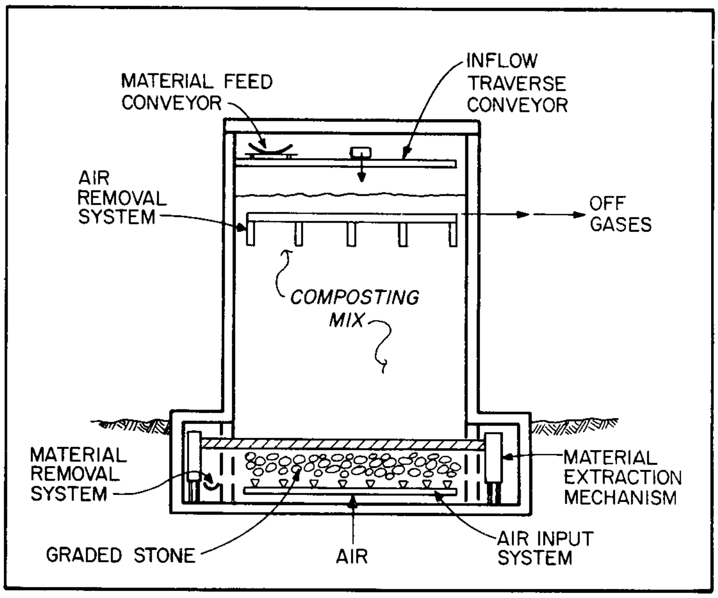


Figure 4.3. Rectangular Reactor

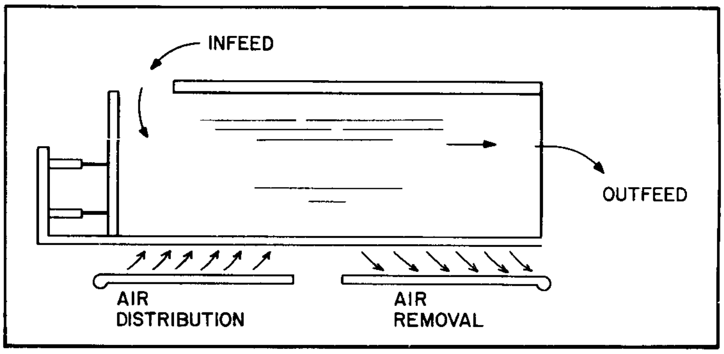


Figure 4.4. Tunnel Reactor

Tunnel Reactors

In tunnel systems, a typical reactor would consist of a 12-foot (4-meter) high by 18-foot (5.5-meter) wide rectangular box (see Figure 4.4 and photo). The length of the reactor can vary depending on the desired capacity. The sludge/bulking agent mix is loaded into the charging end of the

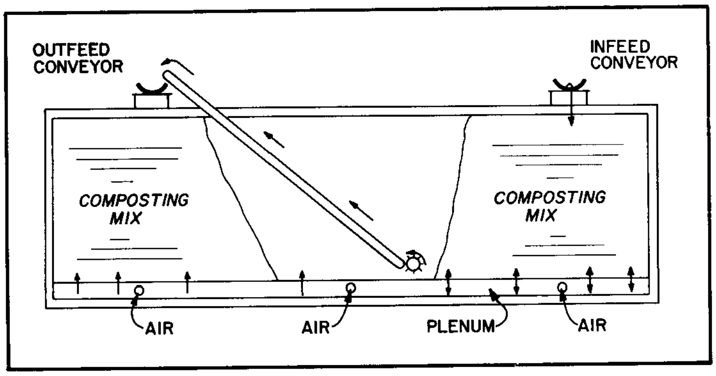


Figure 4.5. Cross-section of a Tank Dynamic System

tunnel by conveyor. The material is loaded into the reactor by hydraulic rams to a uniform density to enhance even air distribution. The entire contents are then moved horizontally toward the discharge end of the reactor. As material is loaded into the reactor, a corresponding finished charge of material is displaced down a discharge chute to a conveyor. Composting takes place within the tunnel, with a total detention time of about 14 days. At the end of the tunnel, the material is discharged by gravity to a conveyor. Additional curing may be required after discharge from the reactor. All moving parts are located outside the tunnel, so maintenance can be performed without interrupting the process.

The aeration system consists of two air manifolds — one positive and one negative — that run along the base of the reactor parallel to the direction of material flow. The manifolds feed a network of floor-mounted air headers that are controlled by modulating valves interlocked with temperature sensors in four zones. Air is distributed through a series of openings in the floor. The aeration rate and location can be adjusted to meet specific requirements. The process is automatically controlled by adjusting the air flow based on temperature. Data indicate that the process provides uniform aerobic conditions.

Four tunnel reactors for composting solid waste are operating in Europe. The only tunnel reactor in the United States is a small demonstration reactor that is currently operational in Alabama.

Rectangular Tanks

Rectangular tanks are dynamic composting bins in which premixed (usually with a pugmill) sludge and bulking agent are aerated and periodically mixed, moved, and fluffed. The dimensions of the bin are typically 10 feet (3 meters) deep and 20 feet (6 meters) wide. Length depends on the volume of the sludge to be composted. The bottom of the bin contains a sealed plenum, which is divided into compartments so that the air flow can be varied according to the processing needs of particular mixes. The mix is supported above the plenum by a perforated steel plate covered with coarse limestone pieces. Individually controlled blowers provide a negative or positive flow of air to each compartment. Because of the porosity of the mix and the depth of the bed, less power is required for aeration, which makes this system less energy intensive than some other in-vessel systems.

The sludge/bulking agent material is delivered to the bin by a central conveyor that discharges onto a second conveyor, which fills the bin using an automatic leveling device. Within the bin, the material is periodically remixed and removed by a device called an Extractoveyor, consisting of a rotary breaker, which penetrates, remixes, and fluffs the mass; a chain and flight conveyor, which lifts the material from the bottom of the reactor bin; and a trailing conveyor, which transfers the material onto a central conveyor. Figure 4.5 shows a schematic drawing of the tank dynamic system with an Extractoveyer.

Material within the bin is mixed and moved at least twice during the composting period. This process creates a fluffier mixture than that produced by static in-vessel systems, and releases moisture. The system also mixes material from the top and sides into the interior. The remixing also exposes all the material to the higher temperatures in the middle of the mass and to ensure pathogen destruction. By using the trailing conveyor, the Extractoveyor can move material onto the central conveyor for relocation within the bins or movement outside the bins.

With this system, material can be composted in about 14 days. In extremely cold climates, 21 days may be required. According to the manufacturer, curing is not required. The system is controlled by monitoring temperature, moisture, and air flow data.

A dynamic composting system in South Charlestown, Ohio, has been used for over 10 years to compost feedlot manure and bark. Part of this system was used successfully to compost sludge. Based on the results of these studies, similar systems are under construction at several locations around the United States and are expected to be operational soon.

Circular Tanks

The dynamic circular composting tank consists of a completely enclosed circular reactor 20 to 120 feet (6 to

36 meters) in diameter and 6 to 10 feet (1.8 to 3 meters) high. Sludge and bulking agent are fed into the center of the tank at the top by an overhead conveyor (Figure 4.6). Mixing normally takes place outside the reactor, but also can occur during input. The mix is moved by a conveyor built on a radial arm. The conveyor transports the material to the perimeter of the tank and places it evenly beside the wall.

The mixture is agitated and relocated by a series of augers mounted on a radial arm. The augers are staggered at a skew angle and rotate on a track atop the perimeter of the tank. As the augers rotate, material moves in a serpentine flow pattern toward the center, where it is discharged into an opening and removed by conveyor belt. The aeration system is located in the floor of the tank, and the air diffusers are covered with a layer of aggregate. According to the manufacturer, retention time in the tank is 10 days and curing is not required. However, it is very likely that external stockpiling (curing) would be necessary for some uses.

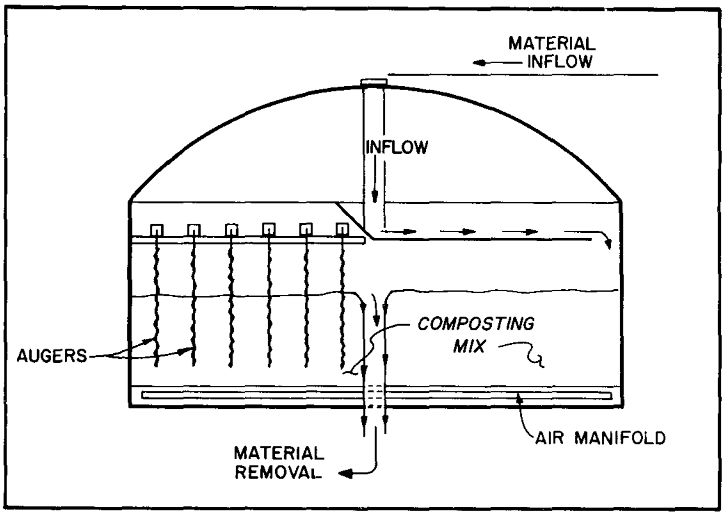


Figure 4.6. Circular Dynamic Reactor

Process control is based on temperatures achieved in the mix and the permeability of the composting mix as measured by the head loss of the blowers. The material can be remixed or fluffed by the augers, and air flows can be controlled.

Performance

Compost Quality and Quantity

The characteristics of the input sludge and bulking agents directly affect the characteristics of the finished compost. During composting, nitrogen and carbon are used for microbial growth, which reduces the volatile solids content of the sludge by 40 to 55 percent. To ensure pathogen destruction, a temperature of at least 55°C must be maintained within each part of the composting mass for 3 days. Complete destruction of weed seeds may require a higher temperature for a few hours. As in all composting systems, levels of trace organics and metals will be reduced in the final product by the dilution effect of the bulking agent.

The volume and mass reduction achieved by an in-vessel system depends on the bulking agent and on the solids content of the sludge. Generally, the compost produced will be approximately 30 percent lower in volume than the initial mix, and the compost will be about half as dense as the incoming sludge.

Reliability and Availability

Experience with in-vessel systems in the United States is limited. Five systems are under construction, and four are operational as of early 1985. In-vessel systems (mostly cylindrical systems) have, however, been operating in Europe for over a decade. The earliest European cylindrical systems experienced problems with aeration and mechanical deficiencies, particularly with the material extraction systems. Both types of problems caused the systems to be filled to less than capacity. Much effort was spent redesigning and modifying the equipment, and recent systems have proved more reliable. Performance has also improved with increasing operational experience. One problem that has been experienced at some facilities is condensation of moisture on the inside of the vessel, particularly during cold weather. Condensation prevents moisture release and inhibits the composting process. Insulation of in-vessel facilities in cold climates and installation of adequate aeration systems are important factors for all facilities.

Programmed maintenance of in-vessel systems generally requires about 1 week of downtime per year. However, it may take several weeks for the biological system to return to steady state. It is therefore important to incorporate provisions for handling maintenance and system loading variations into system design. Many European suppliers provide their customers with a maintenance service contract in which the supplier refurbishes the system once a year.

Sludge received during maintenance periods can be handled by storage, converting cure reactors to main reactors, curing in open piles, sharing capacity with other facilities, or using alternative methods of disposal.

The recent increase in use of in-vessel systems reflects the technical communities' growing acceptance of the process, which seems to offer several important aesthetic, process control, and space-saving features. However, it is important to continually evaluate and improve these various forms of in-vessel systems as they come on line. Key areas for further process enhancement include optimization of temperature and oxygen levels to control odor production, decompose volatile organic matter, remove excess moisture, and destroy pathogens.

5. Federal and State Regulation

The following information provides general guidance on Federal and state regulation. The specific requirements concerning the composting process and product use must be determined by contacting the appropriate state and local authorities.

Current Federal Regulation

At present (May 1985), no Federal regulations deal specifically with the distribution and marketing of sludge products. Until more specific regulations are promulgated, distribution and marketing of sludge compost are covered under the same regulations that apply to land application, i.e., 40 CFR Part 257: *Criteria for Classification of Solid Waste Disposal Facilities and Practices.* These criteria include requirements to protect the environment and public health. Requirements for sludge and sludge products containing high levels of metals or PCBs are found in 40 CFR Part 761 and in hazardous waste rules under the Resource Conservation and Recovery Act (RCRA).

Environmental Criteria

Under 40 CFR Part 257, land application of sludge and sludge products is considered to be a form of solid waste disposal. Any "facility" or land where sludge or sludge products is applied must comply with the following requirements:

- *Floodplains.* Application sites may be located in a floodplain; however, they must not "restrict the flow of the base flood, reduce the temporary water storage capacity of the floodplain, or result in washout of solid waste, so as to pose a hazard to human life, wildlife, or land or water resources." (A base flood is a 100-year flood.)
- *Surface Waters.* Discharges from the application site that would violate Sections 402, 404, or 208 of the Clean Water Act are prohibited.
- *Groundwater.* Application sites must not "contaminate an underground drinking water source beyond the solid waste boundary." (EPA is currently examining more stringent controls on land application to protect particularly vulnerable and valuable groundwater resources such as irreplaceable aquifers.)

In general, application of sludge compost at reasonable rates in accordance with state or U.S. Department of Agriculture (USDA) guidelines would not be expected to cause problems within floodplains or to pollute groundwater or surface waters.

Public Health Criteria

To protect public health, Federal regulations define requirements and limitations for application of sludge and sludge products that contain pathogens, cadmium and other metals, and PCBs.

Pathogens

Federal regulations in 40 CFR Part 257 define two levels of pathogen reduction in sludge — Processes to Significantly Reduce Pathogens (PSRP) and Processes to Further Reduce Pathogens (PFRP) — with different use restrictions for each resultant product. To "significantly" reduce pathogens through composting, pile temperatures during static pile, windrow, or in-vessel composting must be maintained at 40°C for at least 5 days, with a temperature exceeding 55°C for at least 4 hours of that period. The resulting product can be applied to land; however, public access to the land must be controlled for at least 12 months, and grazing by animals whose products are consumed by humans must be prevented for at least 1 month. In addition, food-chain crops for direct human consumption cannot be grown on the land for 18 months after application if the edible portion of the crop might contact the sludge.

To achieve the next level of pathogen reduction (PRFP), the composting process must meet the following conditions:

- In-vessel composting and aerated static pile composting must maintain internal temperatures at 55°C or greater for 3 days.
- Windrow composting must maintain pile temperatures of 55°C or greater for at least 15 days, with a minimum of five turnings during this period.

Compost resulting from these processes can be applied to land used for food-chain crops, and crops can be grown immediately after application.

Cadmium

The total cadmium in compost applied to a site used for growing tobacco, root crops, and leafy vegetables must not exceed 0.5 kg/ha/year. Cumulative annual cadmium application to sites growing other crops is limited to 1.25 kg/ha/year until 1987, when the limit will drop to 0.5 kg/ha/year. The cumulative application of cadmium over the lifetime of the site is also limited to a total of 5 to 20 kg/ha depending on soil pH and soil cation exchange capacity. In general, soil pH must be 6.5 or greater at the time of planting, and EPA recommends that pH be permanently maintained at or above 6.2. Alternatively, if the crop is exclusively used for animal feed, cadmium applications need not be limited, but pH must be consistently maintained at or above 6.5; the facility must have an operating plan that shows how the animal feed will be distributed to preclude ingestion by humans; and future property owners must be notified by a stipulation in the land record or property deed that states that the property received high concentrations of cadmium and that food-chain crops should not be grown.

Other Metals

Sludges and sludge products that contain high concentrations of metals and thus qualify as hazardous wastes are controlled under provisions of RCRA. Thus far, very few municipal sludges have been classified as hazardous wastes.

Polychlorinated Biphenyls (PCBs)

Compost containing greater than 10 mg/kg but not more than 50 mg/kg of PCBs must ordinarily be incorporated into the soil when applied to land used for producing animal feed, including pasture crops for animals raised for milk. Compost containing greater than 50 mg/kg of PCBs must be treated under the strict requirements of 40 CFR Part 761.60, which allows only incineration (in compliance with Part 761.70) or disposal in a chemical waste landfill (defined under Part 761.65). These requirements are separate from hazardous waste requirements specified under RCRA. Substitute methods of disposal may be approved by EPA Regional Offices.

Future Federal Regulation

In 1983 the EPA formed a Sludge Task Force to examine current regulations and guidance and to explore improvements and alternative approaches. The Task Force recommended that a comprehensive technical regulatory program be developed under the legislative authority of Section 405 of the Clean Water Act, which requires EPA to develop regulations that:

- Identify sludge use and disposal options.
- Specify factors to be taken into account in determining the measures and practices applicable for each use or disposal (including costs).
- Identify concentrations of pollutants that interfere with each use or disposal.

In addition, the Task Force issued a policy statement, signed by the EPA Administrator in May 1984, that provides general guidelines for future Federal and state regulations. This statement promotes "sludge management practices that provide for the beneficial use of sludge while maintaining or improving environmental quality and protecting public health." It also recognizes, to a greater extent than before, the site-specific nature of sludge management, and requires states to take a prominent role in managing sludge, provided that local management options are consistent with state and Federal regulations.

Based on the Task Force recommendations, new Federal regulations that cover all the different sludge use and disposal options (distribution and marketing, land application, incineration, landfilling, and ocean disposal) are expected to be issued in 1986. Developing these regulations will require a comparison of risks, benefits, and costs across several media. The health and multimedia environmental effects of contaminants in sludge will be profiled to determine which substances need to be regulated and the appropriate limits. In addition, EPA plans to establish management practices that will protect human health and the environment. These practices will take into account site-specific factors such as soil conditions and climatic variability. The new regulations will also specify requirements for compliance monitoring.

State Regulation

As of December 1984, ten states regulate sludge distribution and marketing: Florida, Illinois, Kentucky, Maryland, North Carolina, Ohio (in draft), Pennsylvania, Rhode Island, South Dakota, and Wyoming. Tennessee and New Hampshire provide guidelines. Several states also regulate sludge land application. Some state regulations exceed Federal standards; therefore, it is particularly important when considering composting to check with the appropriate state agency.

Federal regulations concerning the responsibility of states in sludge management are expected to be proposed sometime in 1985. They will include a requirement that each state describe its plan for managing sludge and ensure that the plan implements Federal requirements. Each state plan would describe the site-specific evaluation process and provide for compliance monitoring and enforcement, contingency planning, and assurance that facilities have adequate capacity to manage the sludge. The Federal regulations are expected to encourage technical assistance and research and development by the states to the extent possible.

Abbreviations

°C	=	degrees Celsius
CLC	=	Citizens Liaison Committee
cm	=	centimeters
cm^2/m	=	square centimeters per meter
C:N	=	carbon-to-nitrogen
ft^2	=	square feet
ft^3	=	cubic feet
gal	=	gallon
gm	=	grams
ha	=	hectare
hp	=	horsepower
JWPCP	=	Joint Water Pollution Control Plant
kg	=	kilogram
km	=	kilometer
lb	=	pounds
m^2	=	square meters
m^3	=	cubic meters
MES	=	Maryland Environmental Services
mg	=	milligrams
mgd	=	million gallons per day
MPN	=	most probable number
mt	=	metric ton
O&M	=	operation and maintenance
OU	=	odor unit
PCBs	=	polychlorinated biphenyls
PFRP	=	Processes to Further Reduce Pathogens
PFU	=	plaque-forming units
ppm	=	parts per million
PSRP	=	Processes to Significantly Reduce Pathogens
RCRA	=	Resource Conservation and Recovery Act
rpm	=	revolutions per minute
yd^3	=	cubic yards

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