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Project Summary

Windrow and Static Pile Composting of Municipal Sewage Sludges

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Several composting research projects were conducted from 1972 to 1978 at the Joint Water Pollution Control Plant (JWPCP) in Carson, California, in response to Federal mandates for sludge treatment. The projects have involved research in both windrow and static pile composting.

The research on windrow composting had three distinct phases because of changes in sludge production and the development of improved composting methods. In the first windrow composting phase (1972 through 1976), the sludge used prior to composting was anaerobically digested and dewatered by nine scroll centrifuges without the use of any conditioning chemicals. Approximately one-third of the solids were removed from the sludge by the scroll centrifuges, resulting in 90 dry metric tons/day (100 short tons/day) of cake containing about 35% total solids. In the second phase, which began in December 1976, sludge solids in the centrate from the scroll centrifuges were recovered by a centrifuge system composed of 44 basket centrifuges. The basket centrifuge system was designed to remove 90% of the solids from the centrate of the scroll centrifuges and produce a digested dewatered sludge cake with 15% to 20% total solids. The two types of centrifuged sludge cakes were mixed in some of the compost tests. The third phase began in June 1978 and studied large windrows for their ability to increase compost productivity and produce more consistent temperature elevations and microorganism kills. Alternative bulking agents, odor and dust control techniques, forced air aeration, and covered (sheltered) windrow experiments were also investigated in the third phase of the research program.

Static pile composting studies began in November 1977 as a potential replacement for the windrow process. Static pile composting, however, was only marginally successful. Windrow composting was found to be the best method for use at JWPCP. The research projects conducted since 1972 have resulted in the establishment of an effective, full-scale windrow composting operation at this facility.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that are fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Composting is a biological process in which organic matter is broken down under aerobic and thermophilic conditions into a humus-type end product with byproducts of carbon dioxide, water, and heat. Unlike many other treatment process schemes for sewage sludge, composting results in a stable product that can be used as a soil conditioner. Many municipalities are therefore considering it as an alternative to other methods of final sewage sludge treatment.

In an effort to comply with Federally mandated sludge treatment at the Joint Water Pollution Control Plant (JWPCP) in Carson, California, the County Sanitation Districts of Los Angeles County have conducted various composting research projects since 1972. The sludge used in these studies was anaerobically digested and dewatered with centrifuges prior to composting. In the early stages of this project, only windrow composting was studied When production of dewatered sludge increased and sludge characteristics changed, more research was conducted not only to improve the windrow composting operation but also to evaluate other composting methods such as aerated static piles. This report describes three phases of research on windrow composting and a study of aerated static piles

Monitoring the Composting Process

Various parameters must be monitored to evaluate the success or failure of the composting process—temperature elevation, drying time, volatile solids reduction, and inactivation of selected microorganisms Odor emissions were also monitored because of special concerns about the proximity of the community to the compost fields

Temperature

The biological aerobic composting process generates large amounts of heat through biodegradation of organic matter. This heat is important, because it inactivates pathogens and aids in the drying of compost material. Temperatures of 55 to 65 °C (132 to 149 °F) should be achieved and maintained in the composting material for extended periods. All compost material should be exposed to these elevated temperatures long enough to inactivate pathogenic and parasitic microorganisms. In the windrow process, this exposure is accomplished by periodic turning of the material. In the static pile process, the elevated temperatures must occur in all sections of the pile.

Microorganisms Inactivation

Most organisms present in raw sewage are concentrated in the sludge produced by standard wastewater treatment processes Thus, many different types of pathogens and parasites are found in the initial composting mixture Because compost is eventually used as a soil conditioner, it is important that pathogenic and parasitic microorganisms be inactivated In fact, inactivation of these microorganisms was the primary goal of the composting research.

Samples were analyzed for indicator microoganisms (total and fecal coliforms), enteric pathogenic bacteria (*Salmonella* sp.), parasites (e.g., *Ascaris* sp.), and enteric viruses. *Ascaris* ova are the most hardy in the natural environment and are used as an indicator of the presence of parasites. If *Ascaris* sp. are destroyed, it was presumed all other parasites were destroyed. Also *Ascaris* sp., as with other parasites, do not regrow when inactivated. Reduction of *Ascaris* ova to low levels therefore indicates a successful compost operation.

Total and Volatile Solids

Proper total and volatile solids contents are important in the formation of windrows and static piles, and they help determine when the composting process is complete. For composting to proceed, moisture content should not be excessive. When using recycled finished compost as the bulking agent, windrows should have an initial total solids content of at least 40%—50% if static piles are used. Lower total solids contents result in a mixture with low porosity, which inhibits oxygen transfer. In this study, the initial volatile solids content (i.e. percent of total solids that are volatile) was between 45% and 50%. The destruction of these volatile solids fuels the composting process. Composting activity decreases markedly and the composting cycle is concluded after the total solids content has increased to between 60% and 65% and the volatile solids content is reduced below 40%.

Windrow Composting

Process Description

Windrow composting was adopted in 1972 at the JWPCP to minimize problems associated with the existing sludge drying beds Spreading anaerobically digested sewage sludge over drying beds required more land area than was available and was a source of offensive odors and vectors to the surrounding community Composting, on the other hand, required less land area, yielded a more uniform and stable product, and produced elevated temperatures that significantly reduced the densities of pathogenic organisms. The full-scale composting process at the JWPCP has been modified intermittently since 1972 to incorporate research findings that have been generated in response to changes in sludge production and characteristics

The current JWPCP windrow composting process typically uses previously composted material as the bulking agent, though rice hulls and wood shavings are occasionally used Windrows are constructed using a tractor-trailer and front-end loader (Figure 1). Dewatered digested sludge cake of a known weight is placed in the trailer, and the loader then places a known volume of bulking agent on top of the sludge. This material is emptied from the trailer and laid in piles up to 120 m (400 ft) long on the compost field. The windrows are turned and mixed by a specially designed machine called a composter. The composter straddles the windrow and has a high-speed rotating drum at ground level. The drum has flails that lift the sludge up and over the drum, depositing it behind the machine in windrow form. Turning serves to mix the sludge cake and finished compost, increases the porosity in the windrow to maintain aerobic conditions, promotes drying of the sludge by exposure to air and sun, and ensures that all of the sludge is exposed to the higher temperatures inside the windrow.

When the total solids level of the compost material reaches 60%, it is considered dry and stable enough to be used by a fertilizer company. During the summer, the windrow composting process is completed in 4 to 5 weeks. Typical winter cycles average 6 to 8 weeks, depending on the Los Angeles weather conditions.

The cost of the composting operation can vary widely depending on the amount of sludge cake that can be composted at any given time. The unit cost per ton of sludge composted is much less from spring through autumn when approximately 450 wet metric tons of sludge cake per day (500 short tons/day) at 23% total solids are processed as compared with the winter application rate of approximately 135 wet metric tons/day (150 short tons/day). These productivities coupled with fixed capital and operating costs result in seasonal costs of approximately $5.50/wet metric ton ($5/short ton) during most of the year and $11/wet metric ton ($10/short ton) during the winter months. These costs are for 1983, and they do not include land and overhead costs.

Study Design

The windrow composting research was conducted with the same basic procedure used in the full-scale operation. The testing involved three distinct phases because of changes in sludge processing and the development of improved composting methods.

Phase I of the composting program at JWPCP took place from the beginning of windrow composting in 1972 through

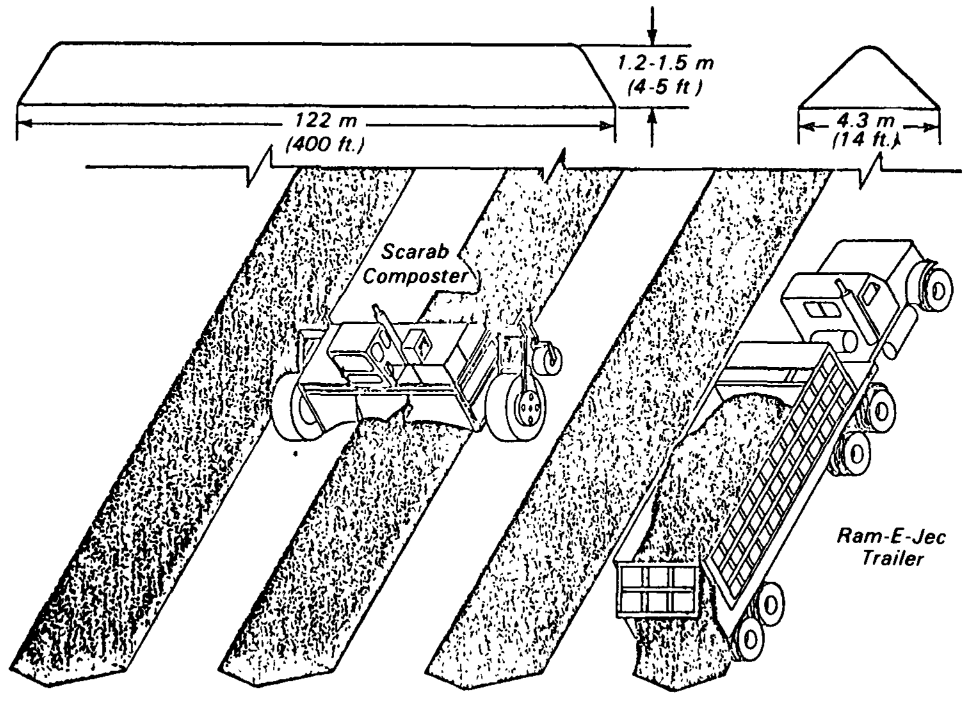


Figure 1. *JWPCP window composting operation*

December 1976. During this phase, anaerobically digested primary sludge was dewatered by nine scroll centrifuges without the use of any conditioning chemicals. These centrifuges removed about a third of the solids from the sludge, resulting in 90 dry metric tons/day (100 short tons/day) of cake containing approximately 35% total solids.

Phase II of the research program began after a second centrifuge system with 44 basket centrifuges became operational in December 1976 These centrifuges were designed to remove 90% of the solids from the centrate of the scroll centrifuges and produced a cake containing from 15% to 20% total solids. After the two-stage centrifuge system began operating, the total amount of dewatered sludge produced increased from 90 to approximately 250 dry metric tons/day (100 to 275 short tons/day) The combined total solids content of the basket and scroll centrifuge cakes was about 22%

Phase III began in June 1978 with the discovery that high windrows 1 2 to 1.5 m (4 to 5 ft) instead of 0.7 to 1 1 m (2.5 to 3.5 ft) increased compost productivity with more consistent temperature elevations and microorganism kills Phase III studies were expanded to include use of alternative bulking agents, odor and dust control techniques, forced aeration, and covered (sheltered) windrow experiments

Results

Phase I

Phase I studies focused on the effects of climate, turning frequency, and volatile solids content for achieving high temperatures in the windrow compost piles. With no rain and no composter breakdowns, temperatures as high as 65 °C (149 °F) were measured inside the windrows when the initial volatile solids contents were about 50% of the dry weight. Low ambient temperatures, rainfall, composter malfunctions, and/or low initial volatile solids contents can contribute to lower temperatures, 50 to 55 °C (122 to 131 °F), in the interior of the compost windrows.

Parasitic ova were monitored, and intact *Ascaris* sp., *Trichuris trichiura*, and hookworm ova were isolated at the beginning of the compost cycles. Viable *Ascaris* ova were rarely found late in the compost cycles, except when maximum windrow temperatures were low. Final coliform most probable number (MPN) concentrations of less than 2 MPN/g were achieved in interior samples of warm weather compost cycles, and final *Salmonella* sp concentrations of less than 0.2 MPN/g were measured in both interior and exterior windrow compost pile samples collected during warm months. Though some coliform regrowth was observed in all cycles (predominantly in samples from windrow exteriors), it was considered insignificant during periods with no rainfall.

Phase II

This phase involved applying the techniques learned from earlier work to the composting of sludge cake from the two-stage centrifuge system. The new dewatering system produced a sludge cake with substantially different properties than a Phase I cake: higher water content, a more dense and less porous consistency, and a higher percentage of fine particles. The new centrifuge cake (at 22% TS) required almost three times the bulking material to raise the initial windrow mixture to 40% total solids. This extra bulking agent increased the amount of land required to compost an equal weight of sludge solids; it also proved detrimental to the composting process because of increased handling problems.

The method of building windrows did not ensure a uniform mixture of wet cake and finished compost at the beginning of the compost cycles. The windrows varied noticeably in moisture content and were uneven in height and width. As a result, all of the material did not experience the same degree of composting, and internal temperatures varied widely throughout the length of the windrow. Average temperatures were lower than in Phase I. During Phase II, final coliform counts averaged 10 to 100 times higher than in Phase I, and *Salmonella* sp. concentrations were also considerably higher. Eventually, adequate bacterial and pathogen inactivation was achieved, but not consistently enough for overall satisfactory composting performance.

Phase III

Phase III began in June 1978 and centered on the composting properties of windrows that were much larger than those used in Phases I and II. These results appear to reflect more accurately the abilities of windrow composting to achieve good temperature elevation and consistent pathogen inactivation. Over a 2-year period of Phase III, 34 windrows were monitored throughout their compost cycle. In addition to the effects of windrow composting and turning frequency, other factors were studied such as the use of alternate bulking agents, forced aeration, enzymes and bacterial additives, and the use of covers to protect to the windrows. Near the end of the study, additional monitoring was performed to measure the odor levels emitted by the windrows so that odor control strategies could be developed.

Temperature Elevation

A typical plot of the interior temperature of the windrow during an entire compost cycle is shown in Figure 2. Though turning frequency did have a slight effect on internal temperature elevation, three turns per week were adequate and avoided the problems of more frequent turning, which tended to lower temperatures and shorten the period that windrows maintained temperatures above 55°C. Note that a good percentage of the windrow material experiences temperature in excess of 55°C (Figure 3). The periodic turning was effective in moving all the material into zones of elevated temperatures since it resulted in good pathogen inactivation.

Microorganism Levels

The heat generated by the compost process effectively reduces harmful and indicator microorganisms to low levels (Figure 2). By using such data for 20 test windrows over the course of Phase III, it was possible to construct probability plots of expected concentrations of bacterial organisms as a function of internal windrow temperatures (Figure 4). The curves in Figure 4 show the number of consecutive days with internal windrow temperature above 55 °C that were required to reduce bacterial concentrations to low levels. For example, after 7 consecutive days of temperatures above 55°C, 85% of the windrows indicated *Salmonella* sp. levels below the minimum detection limit of 0.2 MPN/g of compost.

The rate of destruction of *Ascaris* ova was not determined because of the cost and complexity of the laboratory procedure. To ensure that adequate destruction of these organisms had been achieved, samples were routinely taken at the beginning and end of select compost cycles, and several of 20 windrows were extensively sampled at locations least likely to have experienced high temperatures (Figure 5). Excellent *Ascaris* destruction was achieved, and a summary of the laboratory results appears in Table 1.

Drying Rates

Six windrows were monitored to determine the effects of turning frequency on drying rates. Evaluations were made of two, three, and five turns per week. Drying rates did increase slightly with greater turning frequency, but not enough to warrant the resulting increase

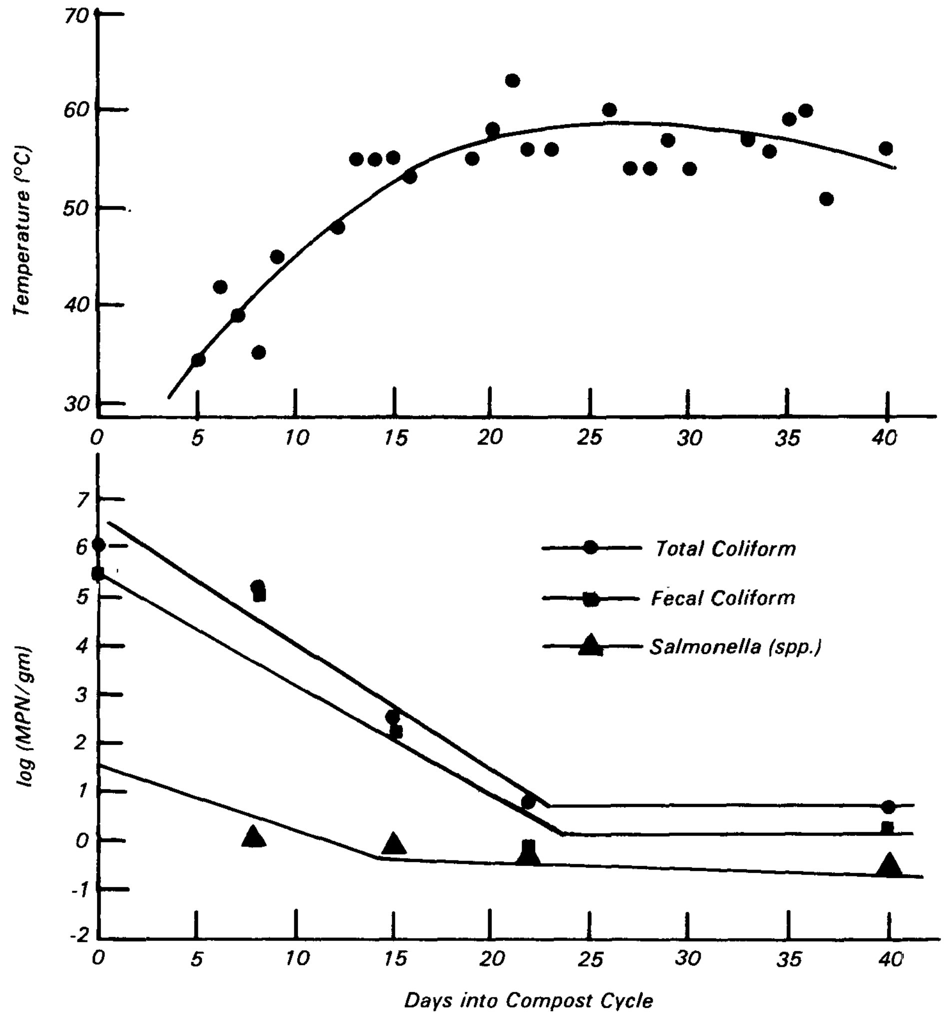
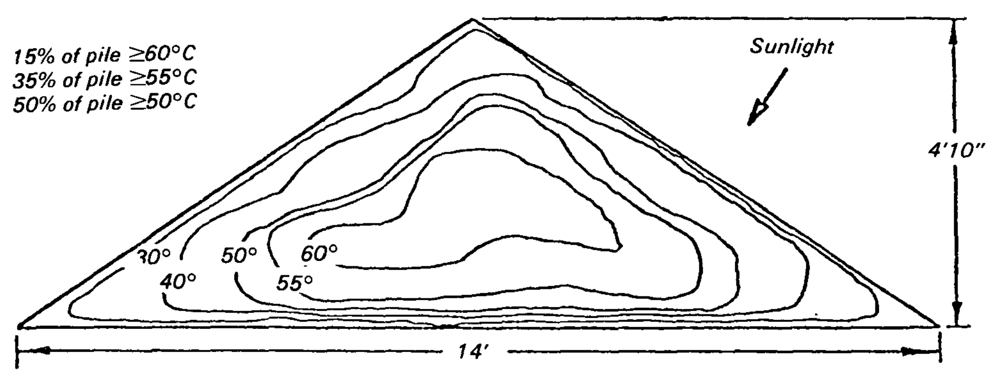
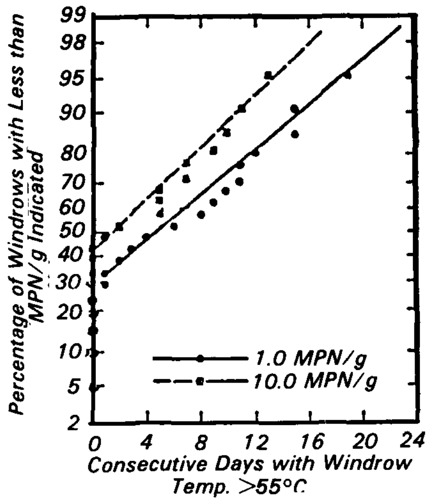


Figure 2. *Bacterial inactivation resulting from elevated temperatures in a typical windrow compost cycle.*

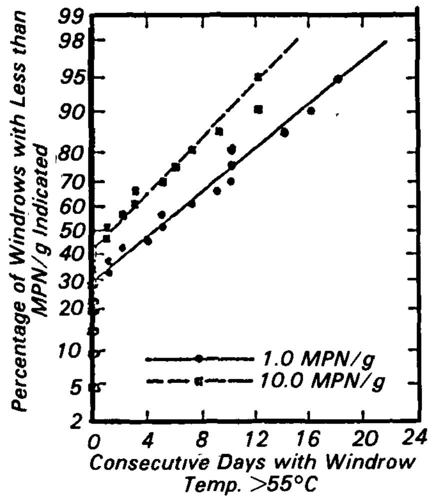


Note: - Windrow turning frequency of 3 times per week..
- Temperatures (°C) recorded on day 29 of cycle.
- Total solids = 58%, Volatile solids = 30%.

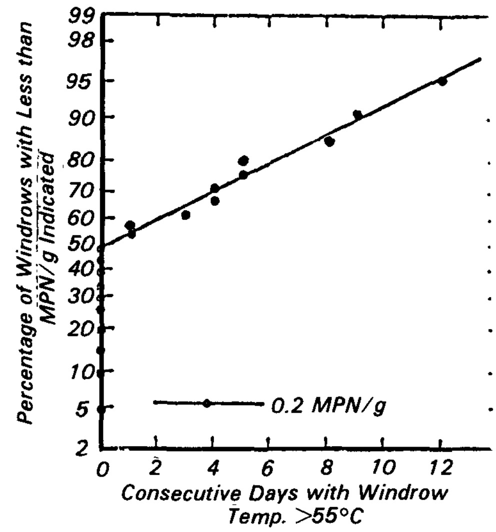
Figure 3. *Temperature (°C) contour diagram for the recommended turning frequency at the JWPCP.*



A. Total coliform

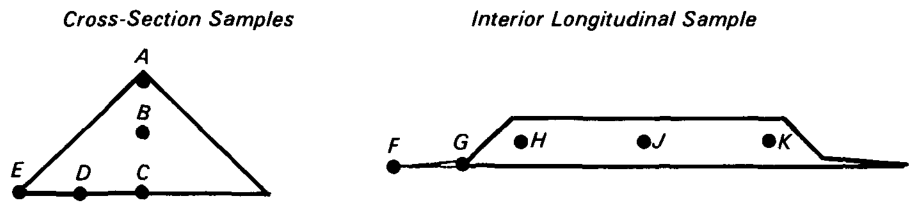


B. Fecal coliform



C. Salmonella *spp.*

Figure 4. *Summary of bacterial inactivation at > 55°C for Phase III windrows.*



Sample	*Description*
A -	*top surface sample*
B- D, E -	*intrior sample*
C,	*ground level samples*

Sample	*Description*
F -	*material thrown from windrow during turning*
G -	*material at toe of windrow*
H, J, K -	*random interior samples*

Figure 5. *Final microbiological sampling locations for windrows.*

Table 1. *Comparison of Total Coliform and* Ascaris *Inactivation*

	Total Coliforms			Ascaris *sp.*	
		Samples with less than			
Compost System	*No. of Samples from Finished Compost*	*10 MPN/g (%)*	*1 MPN/g (%)*	*No. of samples from Finished Compost*	*Samples with no Detectable Viable Ova (%)*
Windrow	*157*	*78*	*56*	*80*	*89*
Aerated static pile	*117*	*43*	*21*	*24*	*58*

in operating time for daily turning. Volatile solids levels were reduced to a greater extent in windrows turned less often.

An optimum turning frequency of three turns per week was chosen based on operational capabilities. This frequency results in a yearly average composting application rate of about 15 metric tons (6 short tons of dry sludge solids/acre) per day when using a dewatered sludge cake of 22% total solids.

Odors

Because the JWPCP composting operation is located near a residential area, odor and dust control on the compost fields are of prime importance. Most odors are emitted during the first 7 to 10 days of the compost cycle and are primarily associated with the surface odor emissions of the windrows in their ambient or unturned states. Turning odors account for approximately 15% of the total emitted, but they are much more concentrated than the ambient odors.

Several methods of odor and dust control were evaluated, including chemical and biological additives. These did not result in improved composting operations or in reduced odor or dust emissions. There are, however, several suggested methods of odor control: (1) halt the turning of windrows during times of adverse meterological conditions or increased odor complaints, (2) design active composting areas so that they provide a maximum buffer zone for the surrounding residential area, and (3) restrict the process of windrow turning to hours of greatest vertical mixing in the atmosphere.

Bulking Agents

Bulking agents are commonly used in the construction of windrows to increase initial percent total solids, improve compost handling characteristics, and to provide proper texture for better air circulation. Recycled, finished compost is frequently used as a bulking agent at the JWPCP, but for comparative purposes a study was conducted using alternate bulking agents such as rice hulls and wood shavings. Good composting performance was achieved for all three bulking agents tested. Rice hulls and wood shavings produced shorter drying times and reduced odor emissions, but their performance was generally similar to that of recycled, finished compost. Cost is the most limiting factor when considering rice hulls or wood shavings as alternative bulking agents.

Forced Aeration

A study was conducted of the composting characteristics of deep windrows that used forced aeration in addition to windrow turning. Forced aeration resulted in more rapid temperature elevation; but when the process was continued throughout the cycle, internal temperatures were lowered. Forced aeration did not appear to be necessary for deep windrow composting when using 1.2- to 1.5-m (4- to 5-ft) high piles, but it may be useful for even larger piles in which drying time would be expected to increase.

Static Pile Composting

Static pile composting studies were initiated in November 1977 based on the success of the U.S. Department of Agriculture in Beltsville, Maryland, who developed this process for dewatered municipal sewage sludge. The Sanitation Districts were interested in the reported advantages of odor control, productivity per acre, and all-weather operations. At the time, initial Phase II results for windrow composting had not been especially encouraging. Thus, if the Beltsville process could have been modified to use recycled, finished compost as the only bulking agent, it would have been a potential replacement for the windrow process. The use of wood chips as a bulking agent (as in the Beltsville process) was not desirable because their recovery and reuse added too much cost and complexity to the overall composting process

Process Description

In a typical aerated static pile, dewatered sludge is combined with the bulking agent and laid into windrows, the material is then mixed by the composter The aerated static piles in this study were constructed using a front-end loader to pile the mixed material on top of the plastic air lines To maintain aerobic conditions in the piles, air was usually drawn through them intermittently Air flow rates and the oxygen contents were monitored The only wood chips used in the process were the few needed to cover the plastic air lines to prevent the lines from being clogged with compost material These chips were not recovered. After the piles were constructed, about 0 3 m (1 ft) of finished compost was added to the surface of each pile for heat and odor insulation.

The piles remained intact for 3 to 4 weeks. Various data were collected to gauge the performance of the composting process. Little drying occurred during the process, and thus some additional techniques were required. These included air-drying by increasing the air flow to maximum and tearing down the pile and forming a windrow. Both techniques successfully raised the total solids contents of the compost material to the desired level of more than 60%.

Study Design

This study was to determine whether the aerated static pile process could be successfully run without the use of external bulking agents (i.e., wood chips). Odor control was also important. The hope was that static piles would produce less odor than windrows because turning was not required. In addition, most odors would be emanating from a point source (the blower) and thus would be easier to control. Finally, the performance consistency of the static piles was examined because the lack of routine turning or mixing as used in windrow composting might produce anaerobic zones and consequently areas of poor pathogen inactivation.

Results

During the first phase of the aerated static pile research, the use of rice hulls and wood shavings as bulking agents were compared with the standard JWPCP practice of using recycled, finished compost. Wood chips were not used as a bulking agent.

Good temperature elevations occurred rapidly and were maintained throughout the cycles for each of the experimental piles (Figure 6). The static pile using finished compost bulking material produced slightly lower temperatures (63 versus 70 °C), but all of the piles achieved excellent microorganism inactivation.

As expected, odors were concentrated in the blower exhaust, but they did not differ significantly among the piles. In fact, by day 10 of their cycles, virtually no odor emissions were detected from the surface of the static piles.

Several methods were tested for treating exhaust gases from the blowers. Finished compost material was tried as an odor-adsorbing medium but was not adequate. Wet scrubbers using water, potassium permanganate, sulfuric acid, or sodium hypochlorite removed 40% to 60% of the odor from the exhaust gases. A two-stage scrubbing system (water scrubber followed by activated carbon) was the most effective method, removing 96% of the odor.

Further studies were conducted during the second phase of the static pile research to optimize the recycle ratio of finished compost. Results of these studies were not adequate, primarily because of problems with mixing and developing a uniform compost pile. Observations in these and previous studies did show, however, that a proper initial compost mixture of dewatered sludge cake and recycled, finished compost (i.e., mixture ratios of 0.84 to 1.68 m^3 finished compost per metric ton of dewatered sludge cake (1 and 2/yd^3short ton) produced an initial total solids content of about 50% and resulted in the best overall temperature elevations and microorganism inactivation. Too little initial moisture content (> 55% total solids) appeared to cause premature drying of the compost pile and inhibit biological activity. Too much moisture (much less than 50% total solids) tended to prevent oxygen transfer through the pile.

The third phase of the static pile study examined the performance of an extended aerated pile consisting of five piles laid side by side so that one continuous pile resulted. Recycled, finished compost was used as the bulking agent. Construction of a continuous pile was difficult and resulted in a nonuniform mixture of dewatered sludge cake and finished compost. Acceptable microorganism inactivation was achieved, but internal temperatures across the pile varied considerably. This method is not recommended for obtaining uniform results in the final compost material.

Drying was a major problem and consequently had to be investigated to ensure that adequate total solids levels were achieved throughout the pile. Part of the extended pile was removed and formed into individual windrows that were turned regularly. The remainder of the extended pile was allowed to dry by continuous, forced aeration. The windrows dried quickly, reaching 70% total solids levels after 7 days and providing high temperatures for preventing microorganism regrowth. The pile under continuous aeration, on the other hand, dried unevenly (50% to 70% total solids level), and internal temperatures dropped to low levels (30 to 40°C).

Summary of Static Pile Experiments

In summary, static pile composting was only marginally successful, since good

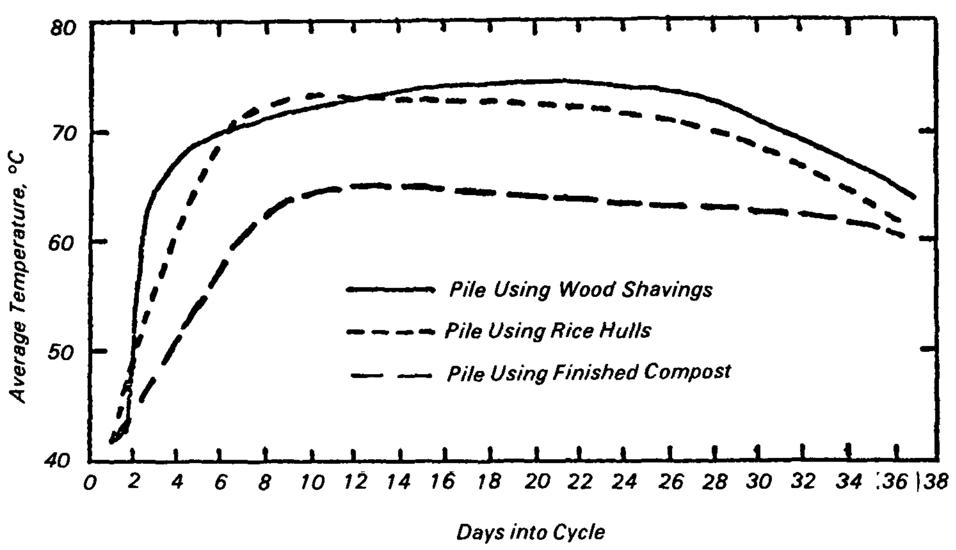


Figure 6. *Average temperatures versus time for static piles.*

performance was unreliable and unpredictible. Alternative bulking agents such as rice hulls and wood shavings imrpoved compost handling and performance slightly. The optimum total solids range for good temperature elevation was 50% to 55%.

Some specific disadvantages of the static pile composting process were nonuniform microoganism kills that allowed regrowth, extended processing time for drying of the piles, the need for scrubbers and carbon filters for treatment of the blower exhaust, and the extreme dependence of process performance on the uniformity and consistency of the initial compost mixture. This process was also labor intensive.

Overall Summary of the Composting Research Study

Sludge composting research conducted since 1972 has helped produce an effective full-scale windrow composting operation at the JWPCP. Research indicated that windrow composting of JWPCP's anaerobically digested centrifuge dewatered primary sludge produced results superior to those of the aerated static pile composting process. This conclusion is based on achieving consistently the temperature elevations needed for microorganism inactivation and sludge drying with simpler operations. The major operational parameters for composting at the JWPCP were the type and quantity of bulking agent used. Windrow size and turn frequency were also significant for windrow composting. Odor control and microorganism regrowth were the controlling output parameters.

Full-scale operation and research studies of windrow composting at JWPCP were very successful from June 1972 until December 1976, when sludge production and characteristics were significantly changed with the addition of basket centrifuges for more complete sludge dewatering. Windrow composting methods used previously to compost the existing scroll centrifuge cake were inadequate for successful composting of this new sludge, which had a much higher moisture content. Research conducted on the windrow and aerated static pile composting processes from January 1977 through November 1977 proved only marginally successful. But in June 1978, the use of larger windrows produced significantly improved process reliability and performance. Early composting studies at JWPCP used shallow windrows 0.7 to 1.1 m (2.5 to 3.5 ft) high. Studies after June 1978 indicated that the use of windrows 1.2 to 1.5 m (4 to 5 ft) high would help assure good temperature elevation and therefore acceptable microorganism destruction. Deep windrow composting became possible because of the development of a new composter (Scarab)* that would adequately process windrows up to 1.5 m (5 ft) high. Deep windrows have the added advantage of requiring less land to compost a given amount of sludge.

Significant findings with respect to other factors influencing windrow composting include: (1) windrow turning frequency of about three times per week results in a well-mixed, aerated pile, (2) mixture ratios of 0.84 to 1.68 m^3 of recycled finished compost per metric ton of dewatered sludge cake (1 and 2 yd^3/short ton) will provide the proper total solids content (40%) and sludge handling properties for successful windrow composting, and (3) the use of alternative bulking agents such as rice hulls and wood shavings improved material handling characteristics for the compost mixture as a result of lower bulk density and indicated possibilities for shorter drying times.

Because the JWPCP composting operation is located near a residential area, odor and dust control are of prime importance. Some possible control methods include stopping windrow turning during times of adverse meteorological conditions or increased odor complaints, using maximum buffer zones around active composting areas, and restricting windrow turning to times of greatest vertical atmospheric mixing.

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*Mention of trade names or commercial products does not constitute endorsement or recommendation for use

*USGPO: 1984-759-102-10682

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***Gerald Stern** is the EPA Project Officer (see below).*
The complete report, entitled "Windrow and Static Pile Composting of Municipal Sewage Sludges," (Order No. PB 84-215 748; Cost: $14.50, subject to change) will be available only from:
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