United States
Environmental Protection
Agency

Office of Water Program
Operations (WH-547)
Washington DC 20460

June 1981
430/9-81-011

EPA

Composting Processes to Stabilize and Disinfect Municipal Sewage Sludge

EPA 430/9-81-011
JULY 1981

TECHNICAL BULLETIN:

COMPOSTING PROCESSES TO STABILIZE AND DISINFECT MUNICIPAL SEWAGE SLUDGES

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF WATER PROGRAM OPERATIONS
WASHINGTON, D.C. 20460

U.S. Environmental Protection Agency
Region V, Library
230 South Dearborn Street
Chicago, Illinois 60604

MCD-79

U.S. Environmental Protection Agency

FOREWORD

This Bulletin was written to provide guidance for the design and operation of sewage sludge composting facilities. It also will serve as an aid in their effective establishment and will help alleviate problems that may arise during everyday normal operation. The guidance consists primarily of recommended operational procedures and performance levels related to the composting facilities. The performance levels, recommended within this Bulletin, are flexible to make allowances for innovation in composting system designs. The recommendations will also help assure that adequate sludge stabilization and disinfection (pathogen reduction) are achieved.

The Agency's main interests lie in the cost-effective design and operation of composting facilities, the adequate reduction of pathogens in the finished compost, and the assurance of aesthetically acceptable and safe working conditions for site employees and nearby residences. To this end, the guidance given in this Bulletin should minimize possible adverse operational, aesthetic and health constraints that are often encountered.

Another very important Agency goal is the proper end-use of the composted sludge product. This guidance will be provided as part of a comprehensive sludge regulation now being prepared by EPA under section 405 of the Clean Water Act. This comprehensive regulation will also be supported by a health assessment. Neither the guidance for proper end-use nor the health assessment is contained in this document.

Aerobic composting is being considered by a number of communities as a method for stabilizing and disinfecting municipal sewage sludge. Two basic methods (windrow and static aerated pile) have been developed and used sufficiently in the United States and Canada, so that they can be relied upon as cost-effective and environmentally acceptable options for processing sludge. A review of eight of these composting facilities supplied the majority of information that is contained in this Technical Bulletin.

While the Bulletin stresses the static aerated pile and windrow methods of composting, it is not intended to indicate an Agency preference for these methods. These two methods have received the most attention because they are the methods that have been operationally proven in the United States in both small and large facilities.

This Technical Bulletin is being issued for immediate use within the construction grants program. It has undergone a number of reviews during the past two years of its development. Recognizing that new developments are rapidly occuring, the guidance and requirements contained in this Bulletin are subject to revision or amendment. Your further comments are welcome. These comments and additional information from future successful projects will be considered in making any possible revisions. Any comments pertaining to this Bulletin should be sent to John M. Walker, (WH-547), Office of Water Program Operations, U.S. Environmental Protection Agency, Washington, D.C. 20460.

Henry L. Longest II, Deputy Assistant
Administrator for Water Program
Operations (WH-546)

DISCUSSION OF REVIEW COMMENTS

The Agency would like to acknowledge the compost plant operators, municipal officials, researchers, engineers and others who willingly discussed their composting program. The information they supplied formed the basis for this document and their assistance is greatly appreciated.

On several occasions in the development of this Technical Bulletin, draft copies were sent out for review to the above mentioned individuals; Federal and State agencies; and other composting facilities, researchers and consultants. The written comments received were in strong support of the document and offered many constructive comments for its improvement. The comments were greatly appreciated and have been carefully considered in revising and producing this final document. We believe that the quality of the document has been significantly improved as a result of these comments.

Many comments have been accepted in the revision of this Technical Bulletin. These comments were incorporated in the text and were used to improve the accuracy and point out limitations of the document. For example, they helped clarify what aspects of a composting operation are eligible for construction grants funding; describe provisions for handling condensate runoff; show the distinction between composted sludge only and a composted sludge/wood chip blend when referring to unscreened compost as a bulking agent; provide further discussion on the reasons for curing the compost; add that drying compost, by spreading it out and disking, facilitates screening; explain how unscreened compost could reduce odors when used as a bulking agent; clarify that separation efficiency during screening, along with the screen's ability to handle high moisture compost, is of major importance when describing the separation of bulking agent from composted sludge; and emphasize the relationships among odor production and the moisture contents of sludge and bulking agent.

The following comments were also used to improve the document; however, they need further discussion since they were not totally accepted.

Several commentors felt the title should directly state that the document applies to the windrow and aerated pile methods. However, since the document provides guidance for all types of methods, we have declined to make the title change. We decided to give the windrow and aerated pile greater discussion because of their proven operational capabilities in this country. Many of the same principles apply to other methods, such as invessel systems, which are rapidly becoming more simple, reliable and flexible due to technological improvements. Also, in the future, high rate-positive aeration systems may offer the potential for faster composting with a dryer end product.

Other commentors suggested that more distinction was needed in the Bulletin to identify when discussions related to the windrow, aerated pile, or both methods. Additional efforts were made to provide these distinctions. More frequent distinction were not made since both these methods are similar in many respects.

One commentor suggested that oxygen monitoring is not necessary for non-aerated windrow operations. The commentor based his belief on the fact that oxygen concentrations usually drop to extremely low levels soon after turning the windrow and that little could be done with oxygen monitoring information. The Agency has not yet resolved the question of monitoring oxygen levels in non-aerated windrows, but strongly agrees that superfluous monitoring is an unneeded burden for municipalities. Presently, the Agency believes that oxygen monitoring for non-aerated windrows is a desirable operator's tool 1) initially, for new and modified operations, to get an idea of the oxygen range for proper composting under the facilities' specific conditions, and 2) when operational problems are suspected or occur.

The previous commentor also felt that the Bulletin should address the merits of using activated carbon and wet scrubbers for odor control, since their studies indicated they were more efficient than compost scrubber piles for controlling odors. The use of some form of odor scrubbing system is necessary. If the composting facility is located close to nearby residences and if odor production is the major stumbling block in gaining public acceptance for the site, the use of activated carbon and wet scrubbers may possibly be advantageous; however, recommending these scrubbers would probably be premature because activated carbon and wet scrubbing systems are relatively expensive and their reliability and cost-effectiveness have not been demonstrated in large-scale sludge composting operations.

Some commentors wanted a discussion on regrowth of Salmonella in finished compost. While there is some uncertainty regarding the potential health risk from Salmonella regrowth, present available data has not indicated a Salmonella health problem from the use of composted sludge.

One commentor asked that the 15 days above 55°C requirement listed in the Bulletin for windrow composting be changed. They supplied results of a series of operational windrow composting trials in support of their request. During these trials, in which anaerobically digested sludge was composted, they closely monitored temperatures, pathogen reduction, and oxygen and moisture content. Their results showed that it was very difficult to maintain windrow compost temperatures above 55°C for 15 days as the Criteria for the Classification of Solid Waste Disposal Facilities and Practices (28) currently require.

Findings of this commentor also suggested that 7 days above 55°C in windrows with a total windrow composting time of 30 days, produced pathogen reductions equivalent to those obtained composting for a total of 30 days, either with 15 days above 55°C in the windrow or 3 days above 55°C in static aerated piles. Presently, the Criteria (28) allows different time/temperature requirements, if the composting facility can show that pathogens are reduced to levels equivalent to the reduction achieved with the approved time and temperature requirements. The Agency recognizes, however, that this can be a very difficult task for a community.

The composting time/temperature provisions of the Criteria are interim final and as such are legally binding. EPA will consider the commentor's data and other data on pathogen reduction by composting during development of the previously mentioned comprehensive sludge regulation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. PURPOSE

This Technical Bulletin has been prepared to assist Environmental Protection Agency (EPA) Regional Offices and delegated State Agencies in reviewing and evaluating grant applications for the planning, design and construction of municipal sewage sludge composting facilities. All municipal sludge management projects involving such processes will be evaluated in consideration of the recommended design principles and operational procedures contained in this Bulletin. In addition, the operational and design information provided should be of interest to engineers, designers, planners, and others as an aid in the development of new composting facilities and to improve the operation of existing facilities. Use of this information should help enhance the cost-effectiveness and reliability of composting alternatives.

II. USE OF THE PERFORMANCE RECOMMENDATIONS

Decisions for Federal financial assistance from EPA will be based on the ability of municipal sewage sludge composting facilities to achieve the recommended performance levels contained in this Technical Bulletin. Facilities which differ in their operational procedures and in their ability to meet the recommended performance levels given in this Bulletin will be considered if assurance can be given to the EPA Regional Administrator that comparable satisfactory performance will be achieved.

This Bulletin is not meant to preclude innovation in composting practices. EPA's policy is to accept and encourage the use of innovative Federal funding as described under section 202(a)(2) of the Clean Water Act of 1977 (PL 95-217). Therefore, EPA Regional Administrators will give equal consideration to innovative technologies that are not included in this Bulletin. To ensure cost-effectiveness and reliability, innovations should be carefully tested before being adopted on a large scale.

III. CURRENT STATUS OF CONSTRUCTION GRANTS FUNDING

Sewage sludge composting is an acceptable method for stabilizing and decreasing the pathogen content of sewage sludge. Composting has been defined as an alternative sludge management system (40 CFR, Part 35, Subpart E) and, thereby, is eligible for 85 percent funding for facility planning, design and construction under the innovative/alternative technology provisions of the Construction Grants Program (section 35.908b, 35.930-5b). Meeting the definition of an "alternative technology", sludge composting has at least a 15 percent advantage in the cost-effectiveness comparisons with the least-cost conventional technologies, and is eligible for 100 percent Federal funding for rehabilitation or replacement if the system fails or breaks down during its first two years of operation. The land needed for composting, curing and temporary storage of sewage sludge compost is also grant eligible (Preamble: land eligibility, Federal Register, September 27, 1978, 44035; 40 CFR, section 35.905 "Treatment Works".) Continuation of these incentives beyond September 30, 1981, will require amendment of the Clean Water Act. Amendments to the Clean Water Act to extend the innovative and alternative technology program are presently being considered by Congress.

IV. PERFORMANCE RECOMMENDATIONS

Various composting processes have been developed for the stabilization and disinfection of sewage sludge (see Appendix A) These sludge composting systems include the static aerated pile and windrow configurations, and automated invessel systems. The aerated pile and the windrow configuration have been used for large-scale operations in the United States. Invessel systems have not been used for large-scale sludge composting in this country; however, such systems have been developed and are being used in some European countries. For these reasons, this Bulletin focuses mainly on the aerated pile and windrow methods.

A. Time/Temperature Requirements

In order to minimize possible adverse health impacts that might result from the utilization of composted municipal sludge, adequate stabilization and disinfection via the composting process must be assured. Following the recommended performance levels given in this Bulletin will provide this assurance.

The pathogen content in municipal sewage sludge is reduced by the elevated temperatures that are attained during composting. There are two sets of time/temperature combinations in the Criteria for the Classification of Solid Waste Disposal Facilities and Practices (28) that are required for "significant" and "further" reduction of pathogens. These temperatures should be maintained for the specified length of time to ensure adequate pathogen destruction for the appropriate end-use. The two necessary time and temperature conditions for aerobic sewage sludge composting are summarized in Table 1.

A "significant" reduction of pathogens will be obtained if the temperature is at least 40°C for 5 days and exceeds 55°C for 4 hours (during those 5 days). However, the end-use of a compost that has only undergone "significant" reduction of pathogens is restricted by required waiting periods and access restrictions. In contrast, if the compost meets the requirements for the "further" reduction of pathogens, then waiting periods and access restrictions should not be necessary.

Table 1. PHYSICAL/CHEMICAL CONDITIONS FOR SEWAGE SLUDGE COMPOSTING BY STATIC AERATED PILE AND WINDROW TECHNIQUES (25)

Condition of Sludge/ Bulking Agent Mixture	Levels of Pathogen Reduction	
Requirement	"significant"	"further"
Time/Temperature 1/	40°C/5 days with 4 hrs at 55°C or higher (both methods)	55°C/3 days (aerated pile) 55°C/5 days/5 turnings (windrow)
Conditions Desirable to Achieve Requirement		
Moisture		40-65%
Oxygen 2/		5-15%
pH 3/		5-11
Carbon/Nitrogen (initial) 4/		10-30
Volatile Solids (initial) 5/		35% or greater
Time Composting		21 days, minimum
Time Curing (Stockpiling)		21 days, minimum

1/ Interim Final temperature requirements (28) for sludge composting processes which "significantly" and "further" reduce pathogens.

2/ Readings somewhat less than 5% would be acceptable during the first 10 days of composting especially for non-aerated windrows, and readings above 15% are suitable where high aeration rates are used along with temperature sensitive switches to increase moisture removal.

3/ A mixture of sludge and bulking agent will compost, even if the pH is 12, provided the lime level is sufficiently low, so that the pH is not at 12 more than initially.

4/ Carbon/Nitrogen (C/N) ratio may be misleading if the carbon is in a form making it less available. The carbon contained in the coarse wood chips is not highly reactive and the effective carbon/nitrogen ratio would be lower than for the same wood chips ground into sawdust.

5/ If the volatile solids content of the sludge is less than about 35%, then a bulking agent that provides a source of available carbon may be needed to provide optimum composting conditions.

The following conditions are needed for a "further" reduction of pathogens. For the aerated pile technique, the temperature must be at least 55°C continuously, for 3 days, in the coolest part of the pile (beneath the cover blanket of previously composted sludge). For the windrow technique, the temperature should be at least 55°C in the center of the windrow for at least 15 of the total 21-30 day composting period. Also, there should be a minimum of five turnings of the windrow, distributed throughout the high temperature period. Note that the temperature may temporarily decrease immediately after turning the windrow.

These temperature requirements for pathogen control have been included as interim final in the Criteria (28) and therefore, are legally binding, although subject to change.

Where mobile field composting machines are used, the sludge and bulking agent should be mixed from one to three times to provide a good initial mix. Other periodic turnings of the windrows are necessary for providing aeration, maintaining high temperatures and lowering moisture content. These turnings should be scheduled according to the need that is indicated by monitoring and weather conditions. Since the aerated pile is usually not remixed after establishing the configuration, a good uniform initial mix is particularly important.

Other important factors that should be considered in temperature achievement are also listed in Table 1. Ranges for moisture, oxygen and organic content have been included because these criteria are generally necessary for attainment of these temperatures with optimal performance. To consistently provide high temperatures for pathogen reduction, the proper ranges for moisture, pH and oxygen must be maintained. This requires a facility to be flexible enough to adapt to continually changing sludge and bulking agent characteristics. For example, if a facility doesn't have a flexible design, a change in sludge moisture content could cause anaerobic conditions in the compost pile. Hence, the temperature requirements would not be met.

In general, an active composting period of about 21 days is needed to achieve stabilization of the composting sludge when using either the static pile or windrow method. A 3-4 week period for curing the compost in stockpiles, following the active composting period (either before or after screening), helps ensure completeness of stabilization (reduction of possible odor production) and pathogen reduction.

Other systems for composting municipal sewage sludge should meet the time and temperature requirements and/or otherwise provide for adequate stabilization to be considered as suitable technology. Sludge composting is defined as an alternative technology and may also be considered innovative if it meets the additional requirements in Appendix E of the Construction Grants Regulations. A pilot study is one useful means of demonstrating the suitability of a successfully in the United States (i.e., meets the conditions listed in Table 1).

If a composting design is based on the aerated pile or windrow technique, the need for a pilot study is greatly reduced because these processes have been proven to be efficient methods for sludge stabilization and disinfection. Basic operational and design parameters are given for these two methods in Section V.

B. Monitoring Recommendations

A proper monitoring program should include at a minimum frequent checks on temperature and moisture content and periodic checks on oxygen content. Monitoring will provide information on the progress of each compost pile or windrow and will serve as an indicator that the composting process has proceeded correctly. To obtain monitoring information a facility would need equipment for moisture analysis (laboratory analysis or resistance probe); a temperature indicator with at least a 6 foot probe and a scale reading from 0° to 100°C (32° to 212°F); and a portable 0 to 25%, dry gas oxygen analyzer. In addition to these measurements, the monitoring of heavy metals and pathogens in the sludge and/or finished compost is necessary to insure good quality compost products. A suggested monitoring program is provided in Table 2.

The following is a suggested protocol for locating the temperature and oxygen monitoring probes (see Figure 1 for location of the probes in static piles). Windrows should be probed to measure the temperature in the center of the row, at several points along the row.

The newly created segments of the windrows should be monitored as units for several days until proper composting conditions are assured. Monitoring for oxygen is more important when beginning a totally new composting facility, when changing the operation of the system, or when encountering compost processing problems. As operations become more routine, oxygen measurements may only be necessary on a monthly basis, as a check on operations. Monitoring for oxygen in non-aerated windrows can be misleading. Oxygen levels near zero are often observed within one hour after turning, but the composting process is still proceeding properly.

Table 2. SUGGESTED PARAMETERS AND TIME SEQUENCES FOR MONITORING (36)

Parameter	Size of operation in tons per week (dry solids)		
	25	25 to 250	250
Moisture content 1/	monthly	weekly	daily
Temperature	daily	daily	daily
Oxygen 2/	optional	monthly	weekly
Pathogen survival		as required by local regulations	
Heavy metals 3/		as required by local regulations	
Process odors	daily	daily	daily
Blower operations	daily	daily	daily
pH of sludge 3/	monthly	monthly	monthly

1/ Qualitative "by eye" estimation of moisture of the compost mix should be done daily. Moisture content of sludge should be obtained from sewage plant operator.

2/ Oxygen monitoring is a useful tool under the special conditions described in the text. It is very difficult to specify a prefered frequency for measuring oxygen.

3/ Good communications should be maintained with sewage plant operators, so that the compost plant operator is informed of any process change or condition that will effect the quality of the sludge.

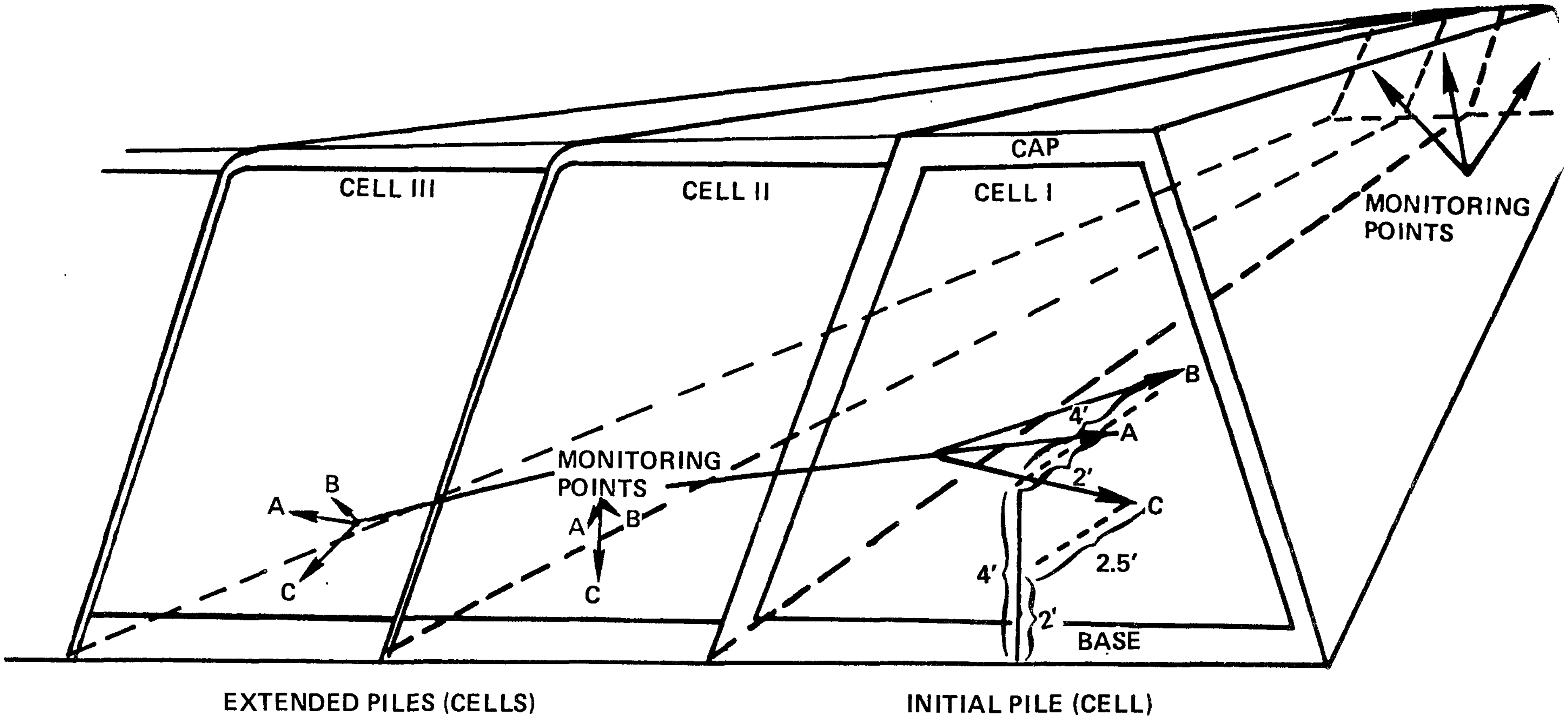


FIGURE 1. MONITORING LOCATIONS FOR TEMPERATURE AND OXYGEN PROBES WITHIN THE STATIC AERATED COMPOSTING PILE. PILE SHOULD BE MONITORED DAILY FOR TEMPERATURE AND LESS FREQUENTLY FOR OXYGEN. OXYGEN SHOULD BE MEASURED AT LOCATION B ONLY.

MEASUREMENTS ARE TAKEN AT THE OPPOSITE ENDS OF EACH CELL NEAR THE BASE MIDPOINT AT:

A- 4' ABOVE GROUND AND APPROXIMATELY 2' HORIZONTALLY INTO THE PILE. (INTERFACE OF BLANKET MATERIAL AND SLUDGE CHIP MIXTURE.)

B- 4' ABOVE GROUND AND APPROXIMATELY 4' HORIZONTALLY INTO THE PILE.

C- 2' ABOVE GROUND AND 2.5' HORIZONTALLY INTO THE PILE.

V. BACKGROUND ON PRESENT PRACTICE IN THE UNITED STATES AND CANADA

Several municipal sewage sludge composting facilities have been operating successfully at different locations throughout the United States and Canada. A total of eight facilities (including both large and small) have been studied in detail, and the results have been used as a basis for the guidelines contained in this Bulletin.

The sizes of these facilities vary greatly. The smallest processed a little over one dry ton of sludge per day and the largest operation composted over 100 dry tons per day, (i.e., currently about 200 dry tons of sludge per day are being composted in Washington, D.C. area facilities). Although the size of these facilities varies widely, there are some general procedures that each facility follows. Their operating procedures have been found to be the most reliable and economical. These procedures, along with problems encountered and an overall recommendation for flexibility, are summarized below. In addition, further information on the concepts and background of composting is contained in Appendix A.

A. General Operating Procedures

A majority of the facilities studied are located at or near the municipal wastewater treatment plant. This greatly reduces the cost for transportation. The smaller facilities may only work with fresh sludge one or two days per week while larger facilities may operate with fresh sludge two shifts per day, 6 or 7 days per week. Several of the facilities contracted for the actual composting operation.

Two of the facilities studied offset part of their operating expenses by selling the finished product for a nominal fee. Others were using sludge as cover material for municipal landfills. A new regulation is being drafted by the Agency that will govern the distribution and marketing of composted sludge (30).

B. Problems Encountered

Various problems have arisen in the development of effective composting practices for the stabilization of sewage sludge. Factors unfavorable to aerobic biological systems, such as too much or too little moisture or very high or low pH, will inhibit composting processes. Moisture content is one of the most important factors in a composting operation. Excess moisture can cause many problems, such as anaerobic conditions, malodors, clogging of screening mechanism, and difficulties in handling the finished product. Fortunately, there are a wide range of conditions under which composting can occur. However, the effectiveness and efficiency of composting practices are much less reliable at the extreme ends of these ranges.

Two universally encountered problems include difficulties in controlling odors and in the recovery, when needed, of bulking materials by screening. High moisture content of the mixture is the major cause of both problems and the usual cause of low temperatures. The control of odor during the composting process is probably the most important factor in gaining public acceptance for a composting facility. Excessive odors from a compost pile or windrow may indicate anaerobic conditions. Composting progresses very slowly under anaerobic conditions and produces malodorous compounds. Anaerobic conditions can result from an improper mixing ratio between sludge and bulking material, excessive moisture content of the mixture, malfunctions in the aeration system or an unclean, muddy composting pad. Hence, odor control is essential not only from an aesthetic point of view, but also from an operational standpoint.

A number of operating facilities have experienced difficulty when screening bulking agents from finished compost because the material placed on the screen was too wet. Compost material with a high moisture content tends to block the mesh openings and impede the separation of finer compost from coarser bulking agent. Once the screens are clogged, they usually have to be cleaned manually. This tends to be a very expensive and time consuming process. Therefore, screening has often been delayed until the weather permitted the screening of a relatively dry compost material. Periods of cold or wet weather can make screening difficult and can lead to a shortage of recycled bulking material.

New equipment has enabled more efficient screening of a relatively high moisture content compost (as high as 50 percent), with relatively few slowdowns resulting from blockage. A discussion of these screens, along with other possible solutions to this problem, are included in the detailed guidance section.

Other problems encountered have been from the establishment of inappropriate pads for the composting operation, poor site and equipment cleanliness, improper blending of bulking agents with the sludge, and the failure to promptly correct imbalances in moisture and aeration. Correcting these problems is essential for maintaining aerobic conditions, proper composting temperature and odor control. Careful management and planning can help minimize these and other common problems associated with municipal sewage sludge composting.

VI. DETAILED GUIDANCE FOR EFFECTIVE OPERATION OF COMPOSTING SYSTEMS

The following ten features (subsections A-J) are very important in developing efficient composting projects.

A. Dewatering

It is important that dewatering activities be carefully coordinated with composting activities. If the content of dewatering chemicals exceeds about 50% (dry weight basis) or if the volatile solids content is less than 35% in the resultant sewage sludge, then composting may be difficult without extra careful selection of bulking materials to provide an additional source of carbon. For the most part, the addition of various chemical agents to improve sludge dewatering has not had an adverse impact upon the composting of the dewatered sludge, except in extreme cases. Sludges dewatered by a number of techniques (Table 3) have been successfully composted.

If the lime content is such that the pH of the sludge remains near 12, the material will either not compost and/or microbial activity and temperature rise will be appreciably delayed. Furthermore, the time required for adequate composting will be lengthened. Most sludges, however, including those with an initial high or low pH, will rapidly equilibrate to pH levels between 6 and 8. Also, wood products that are used as bulking agents will usually contribute to lowering the pH to near neutral.

The capacity and operational reliability of available dewatering equipment must be adequate to prevent the backlogging of sludge. Backlogging often results in sludges turning septic before they are dewatered. Malodor would then be likely for the initial day or two of composting when a batch of this septic sludge is mixed with bulking agents.

In one plant,odorous septic tank pumpings that were added to the locally produced sludge, prior to dewatering, led to odor production at the composting facility. This facility alleviated these odor problems by lime treatment of the septic tank pumpings (adjusting the pH temporarily to near 12), before mixing with the liquid sludge for dewatering.

It is also important to consider the physical nature of the dewatered sludge when planning a particular composting project. Wetter and finer sludges will require an increased amount of bulking agent. There may also be an increased need for bulking agent coarseness with very fine or liquid sludge. Increased sludge fineness may be due to an upgrading of treatment systems to secondary/tertiary treatment or to improvements made in the dewatering process. This change in physical properties of the sludge, if unaccounted for, will result in inadequate penetration of air, a predominance

Table 3. SELECTED CHARACTERISTICS OF SEWAGE SLUDGES AT STUDIED COMPOSTING FACILITIES (33)

City	Sludge 1/	Dewatering Mode	Solids Content		Sludge Composition	
Aerated Pile	Raw		%	VS 2/ %	Lime %	$FeCl_3$ %
H	P+S+CP	Vacuum Filter	17-24	55	25	8
B	P+S+CP	Vacuum Filter	17-24	55	25	8
C	P	Belt Press	24-28	77	0	0
A	P	Vacuum Filter	22-28	60	5	0
E	P	Coil Filter (CF)	20		10	5
D	P	Centrifuge + CF Vacuum Filter	20-25	50	7	8
	Anaerobically Digested					
F	P	Solid Bowl/ Basket Centrifuges	23	50	0	0
G	AWT	Filter Press	40	40	35	5

1/ P = primary; S = secondary; CP = chemical precipitation of phosphate; AWT = P+S+CP + Ion exchange + Filtration + C adsorption

2/ %VS = percent of the total solids present that are volatile.

of anaerobic over aerobic microorganisms, and hence, malodor. If composting of only part of the sludge at a locality is planned, it could be advantageous to keep separate the more easily compostable sludge (e.g., primary from secondary sludge).

A very dry filter press sludge cake (e.g., 35 percent solids content) may require little or no bulking agent, compared with wetter vacuum filtered sludges (e.g., 20 percent solids content) which may require bulking agents, such as wood chips, at the rate of 2 to 2.5 parts bulking agent to 1 part sludge on a volume basis (Figure 2). A dry filter press sludge cake, however, may require some form of crushing before composting to assure thorough mixing and adequate air penetration (17).

The dewatering system chosen also has an important impact upon the usefulness of the final composted sludge product. For example, the use of lime as a dewatering agent may cause excessive lime accumulation in the composted sludge, which may result in a higher sludge pH (high sludge pH can cause ammonia release which in turn can cause corrosion, odor and possibly health problems in indoor facilities). Such a high lime composted sludge has caused reduced growth of some species of plants when they were grown in compost amended soils (7). A second potential problem when using composted sludge to support the growth of plants can arise from the use of high concentrations of ferrous sulfate and/or ferric chloride for dewatering. The salt contained in both the relatively insoluble ferrous sulfate and the soluble ferric chloride can cause phytotoxicity in some species of plants. The soluble ferric chloride, however, can be rather readily leached out. Still another example of a potential problem is dewatering chemicals which may contain excessive levels of unwanted heavy metal contaminants, such as cadmium (2).

B. Bulking Agent

The use of a bulking agent, such as wood chips, compost, straw, etc., has been found to be essential for proper adjustment of the sludge moisture content, to provide an additional source of carbon, and/or to improve the porosity that allows an adequate and uniform penetration of air (3, 35). Various mixture rates of different bulking agents and sewage sludge have been successfully used in presently operating systems. Table 4 illustrates the general relationships between sludge moisture content and bulking agent.

Note, however, that composting operations may require adjustment in the blend and/or type of bulking agent, due to climatic conditions, moisture content and/or fineness of the sludge, the configuration for composting and the availability of bulking agents. If recycled compost (screened or unscreened) is used as a bulking agent, the bulking agent to sludge ratio usually has to be increased to compensate for the increased wetness of the recycled bulking material.

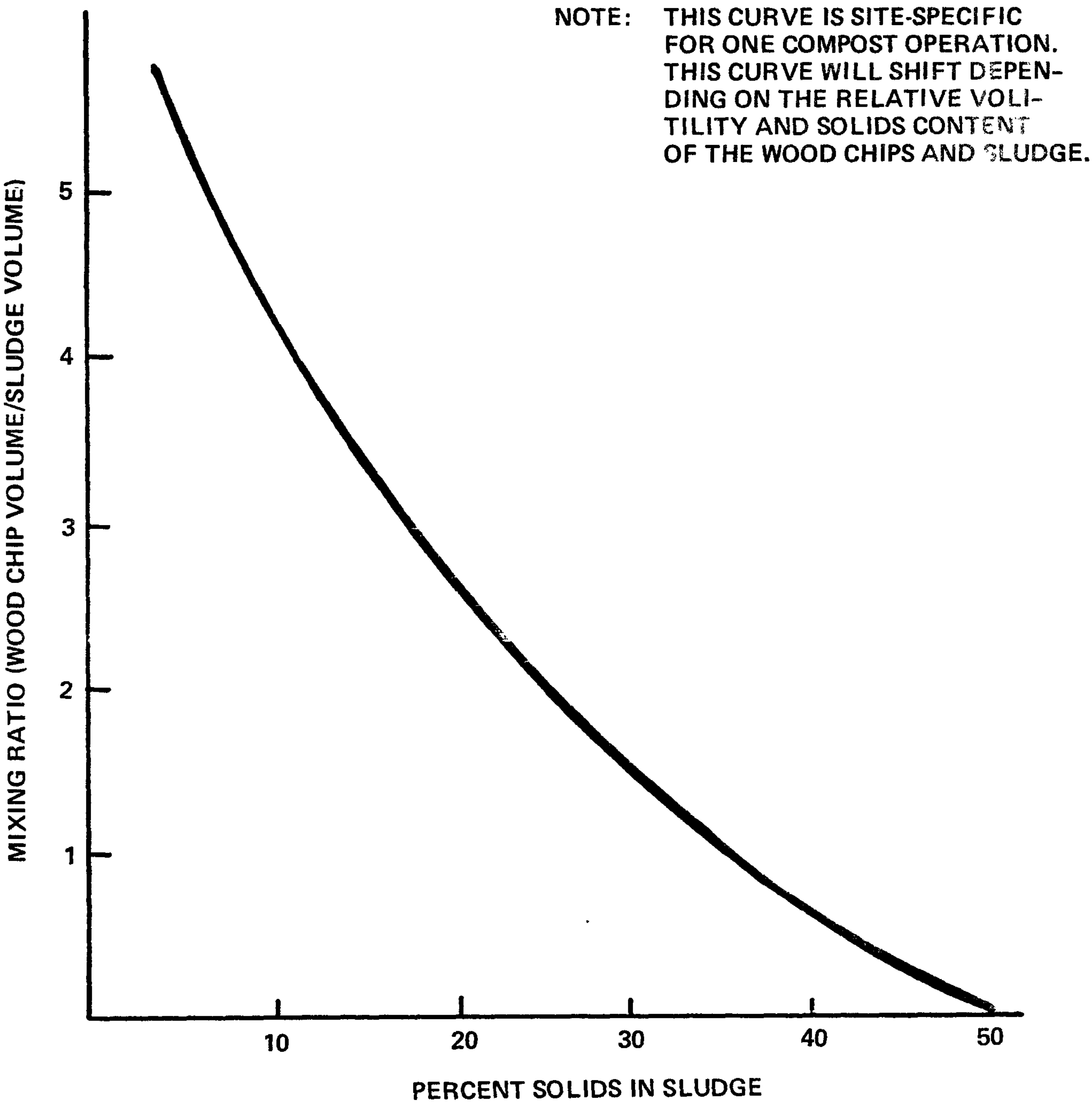


FIGURE 2. EFFECT OF SOLIDS CONTENT ON THE RATIO OF WOOD CHIPS TO SLUDGE BY VOLUME (3).

TABLE 4. RATIO BY VOLUME OF BULKING AGENT TO SEWAGE SLUDGE FOR COMPOSTING BASED ON MOISTURE CONTENT, AERATION, AND PREVIOUS STABILIZATION OF SLUDGE (33)

City	Solids Content	Bulking Agent/Sludge 1/
Aerated Pile	% Raw	Wood Chips 2/
H	17-24	2:1
B	17-24	2-2.5:1
C	24-28	2:1
A	22-28	3:1
E	20	3:1
D	20-25	2.5-3:1
Windrow	Anaerobically Digested	Compost
F	23	1:1
G	40	1:1

1/ The bulking agent to sludge ratios should be increased as the wetness and fineness of the sludge or bulking agent increase.

2/ City A uses shredded bark instead of woodchips. Also, City A alternates using fresh or screened shredded bark with unscreened compost as the bulking agent. City B recycles unscreened compost as the total or part of the bulking agent through many cycles.

Most sewage sludge composting facilities in the United States have used predominantly only one bulking agent, e.g., wood chips or compost. Systems designed specifically for the use of one externally supplied bulking agent may find that adequate supplies are not always available or that the cost for the bulking agent may fluctuate widely. Some systems have tried using the unscreened composted wood chip/sludge blend as a substitute bulking agent in order to help cut the cost of operation. This option has worked for flexibly designed and operated facilities which have the equipment to handle substitute bulking agents and make other necessary adjustments, such as changing the bulking agent to sludge ratio.

Other bulking materials, such as peanut hulls, leaves, refuse, and shredded rubber tires, have been used successfully on a small scale. A rating of the suitability of these materials as bulking agents is given in Table 5. Note that certain of these bulking agents have the added benefit of reducing the potential for odor production.

Equations have been derived as a guidance for determining the proper blend of bulking agent to sludge (9, 27). The simplest equation relates the mass of water in the initial compost mixture, to the mass of organic matter degraded under composting conditions. If the ratio is 10 or less, composting should be adequate.

C. Mixing, Configuration, Aeration and Drainage

1. Mixing

A variety of equipment has been used for mixing. Most of the successful operations have used various forms of mobile mixing equipment (Table 6). Mobile equipment assures flexibility in operation and ease of replacement or repair. The mixer chosen should be able to handle a wide range of 1) textures and types of sludges and 2) moisture contents and densities of bulking materials.

Densities of some types of sludges and bulking agents are given in Table 7. Processing equipment must be able to handle the density, consistency, and weight of the sludge and bulking agent. Machinery designed to handle animal manures will often not be suitable for sewage sludge composting unless suitably modified. This is because manures generally are lighter in weight than sewage sludge, due to the presence of bedding material. Also, the design of facilities for composting animal manures is different, since there is a much greater reduction in the original volume of animal manure than of sewage sludge during composting.

Some facilities have tried stationary mixers in the hope of reducing labor requirements. These fixed mechanical mixers have had difficulty in handling variations in the quality and quantity of sludge and bulking agents. These problems have resulted when

Table 5. CHARACTERISTICS OF MATERIALS USED AS BULKING AGENTS

BULKING AGENT [1]	RATING				
	Effect on Porosity of Mixture	Source of Available Carbon	Recoverability	Overall Suitability	Ability to Control Odors
Woods Chips	good	fair	good	good	slight
Unscreened Compost	fair-good [2]	fair	good	fair-good [2]	moderate
Screened Compost	fair	fair	good	fair-good [3]	moderate
Wood Shavings	good	fair	fair-good	good	slight
Saw Dust	fair	fair	none	fair-good	slight
Peanut Hulls	good	fair	poor-fair	good	slight
Corn Cobs	good	fair	good	good	slight
Leaves	fair	fair	none	fair-good	slight
Garbage	fair-good	fair	fair	fair	slight
Cotton Gin Trash	fair	fair	none	fair	slight
Sugarcane Bagasse	good	good	none	fair	slight
Rice Hulls	fair	fair	none	fair-good	slight
Cereal Straws	good	fair	none	fair-good	slight
Shredded Bark	good	fair	good	good	slight
Corn Stover	fair-good	good	fair	fair-good	slight
Fly Ash	poor	none	none	very poor	none
Shredded Rubber Tires	good	none	good	poor-fair	none
Pelleted Refuse Derived Fuel	good	fair	fair-good	good	slight

1/ Availability of some bulking agents may be effected by seasonal changes (i.e., leaves, stover, etc.) Some bulking agents that perform poorly alone may perform well when mixed with other bulking agents. Some bulking agents, such as unscreened compost help reduce odor production which is especially important in windrow composting. Unscreened compost can be used as the sole bulking agent. However, a coarse and/or drier bulking agent may be needed as a supplement to ensure adequate aeration.

2/ Assumes the unscreened material contains a coarse fraction, such as wood chips.

3/ Depends upon degree of wetness and fineness of fresh sludge.

Table 6. COMPARISON OF MIXING EQUIPMENT (33)

Equipment	Suitability
Mobile Rotary Drum	Good
Mobile Rotary Belt	Fair to Good
Rototiller (tractor)	Good
Front End Loader	Poor to Fair
Pug Mill	Fair to Good

Table 7. DENSITIES OF VARIOUS SLUDGE COMPOSTING MATERIALS (14,27,34)

Material	Density, lb/cu. yd. 1/
Digested sludge	1,500 to 1,750
Raw sludge	1,300 to 1,700
New wood chips	445 to 560
Recycled wood chips	590 to 620
Finished screened compost 2/	930 to 1,350

1/ 1 lb/cu yd = 0.6 kg/m^3

2/ Varies significantly with % total solids and bulking agent used.

unexpected conditions have occured (e.g., the unavailability of a primary bulking agent and/or a change in the density of the sludge and bulking agent to be mixed). There has not been sufficient experience with these mixers, and their associated feeder hoppers and conveyors, to determine the extent of real labor savings, flexibility and reliability.

Poor composting and odor problems frequently occur when the sludge and bulking agent are mixed in the rain (21). If the sludge/bulking agent mixture becomes very wet, air penetration may likely be impeded. Temporary storage facilities for sludge, alternate methods of disposal, or adequate cover over the mixing area during periods of rain should be provided to avoid these problems.

2. Configuration

Two general configurations have evolved for large-scale outdoor composting of sewage sludge. These are the conical pile/ windrow and the aerated static pile/extended aerated static pile configurations.

(a) Conical Pile/Windrow

The conical pile and the window configurations normally depend upon natural, convective forces to pull air in through the side and bottom and up through the pile, as well as aeration by periodic mixing. One facility has also added the capability of forced aeration for the windrow configuration. The general considerations for forced aeration that are discussed in the aeration section of this Bulletin, apply to the forced aeration variation.

Conical piles are generally limited in use to small sized operations. In this configuration, mixing and turning may be accomplished with a rototiller or front-end loader. To ensure a sufficient mass for self heating, the conical pile should be from 4-6 feet high by 6-14 feet at the base. However, excessive heights of the conical pile may inhibit proper aeration.

Windrows, rather than conical piles, are generally used by larger installations. Mixing of the sludge and bulking agent is usually accomplished with a mobile unit especially designed for mixing and turning compost. The windrows should be from 3-6 feet high by 6-14 feet at the base. Generally, the most desirable dimensions are directly related to the porosity of bulking agent/ sludge mixture. There is no blanket of previously composted sludge either underneath or covering the windrow, (refer to Figure 3) since the entire mass is turned and mixed periodically during the composting period. Also, drying may be more readily accomplished due to increased exposure to sunlight and air; thus, use of recycled compost as the sole bulking agent is more easily accomplished.

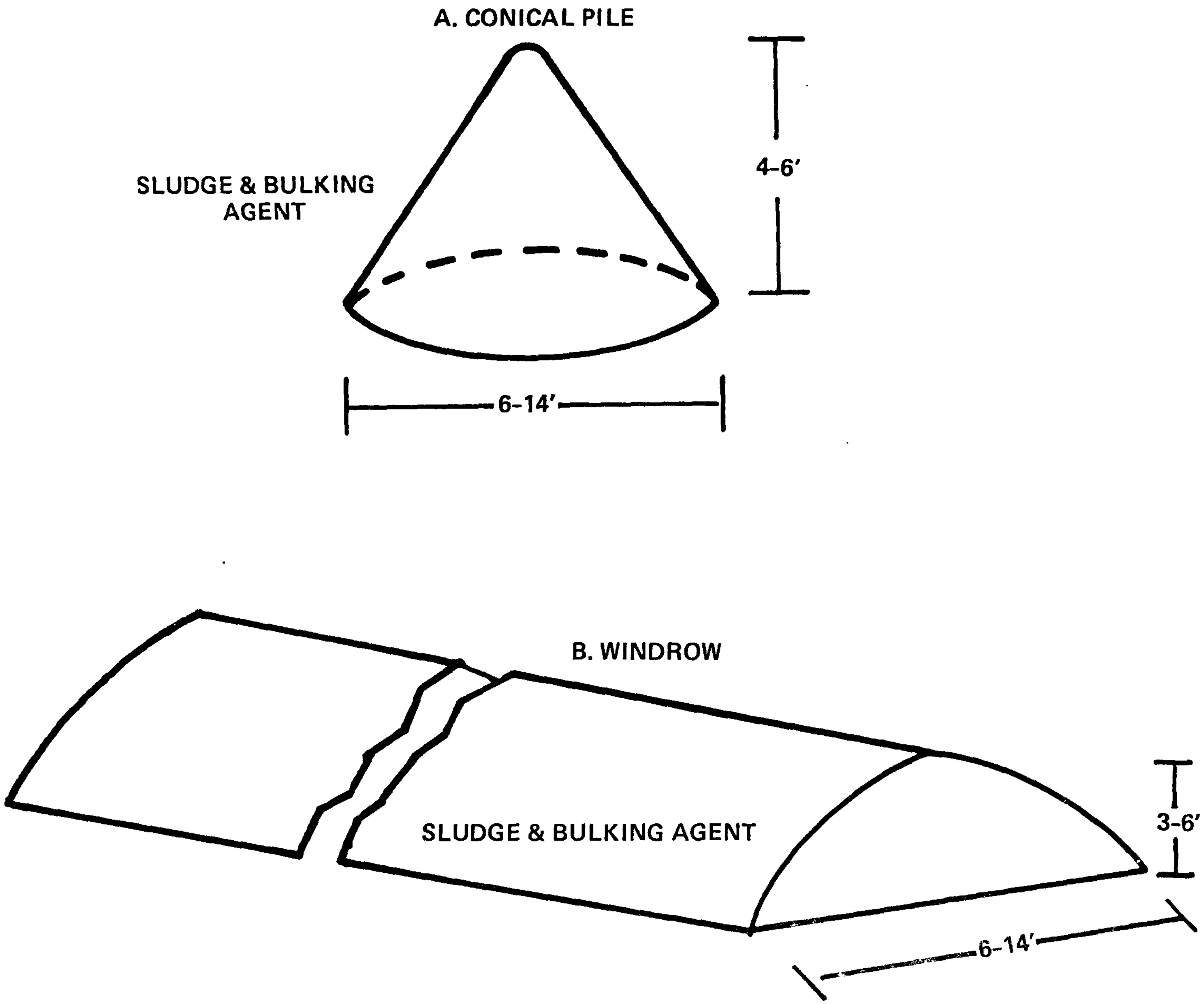


FIGURE 3. CONFIGURATION OF MECHANICALLY TURNED WINDROW PILES

NOTE: WITH FORCED AERATION THESE PILES AND WINDROWS COULD BE HIGHER AND WIDER AT THE BASE

(b) Aerated Static Pile/Extended Aerated Static Pile

The aerated static pile/extended aerated static pile configurations depend upon forced aeration in which the surrounding air is drawn down through the pile by means of air pipes and blowers. The air pipes lie underneath the composting material in a porous base, such as wood chips, and are connected to the blowers. In this configuration, the compost material (the sludge thoroughly mixed with bulking agent) is piled upon the bed of porous base material containing the aeration pipes. The sludge/bulking agent mixture is then covered with a blanket of screened or unscreened composted material, and the pile is not mixed again unless the pile does not adequately compost. A total pile height of not more than 12 feet has helped avoid difficulties with aeration, but usually, pile height is limited by front-end loader capabilities. The aerated static pile configuration is diagrammed in Figure 4-A. The extended configuration reduces the need for cover material by as much as 70% and the need for composting pad space by 50% (shown in Figure 4-B).

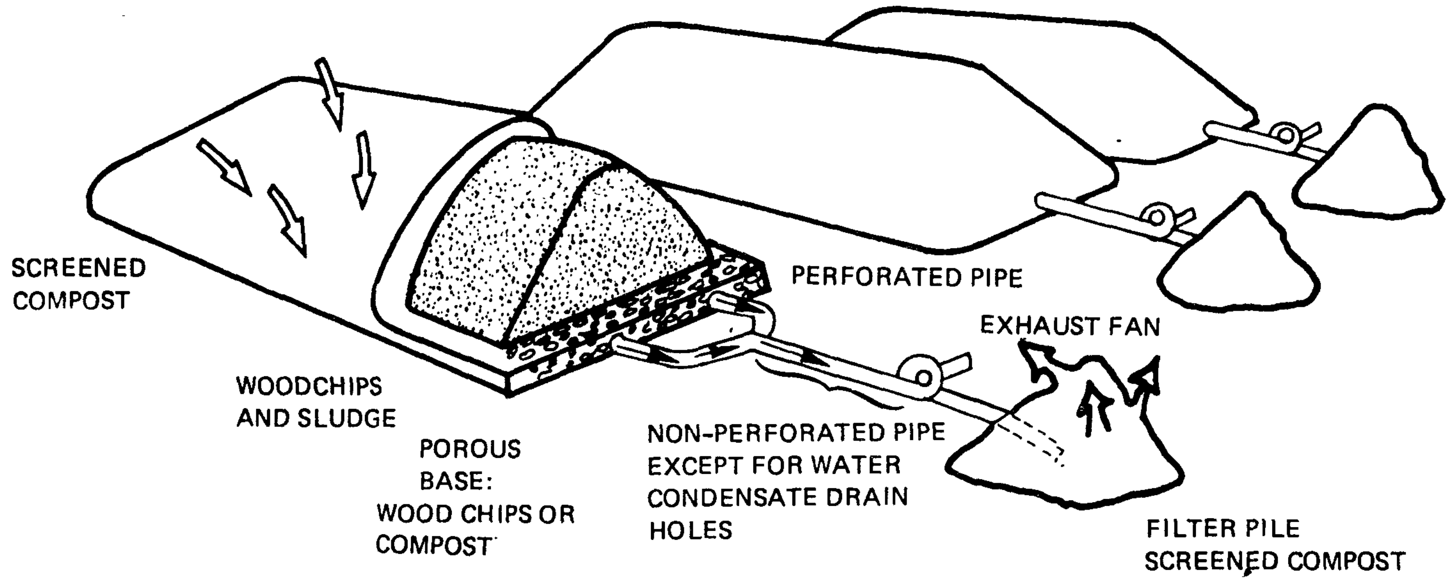
The porous base which surrounds the aeration pipes normally consists of wood chips or unscreened compost and is approximately 12-18 inches thick. The base also has an added benefit of soaking up excess moisture. A blanket of unscreened composted sewage sludge is used to insulate the pile for two reasons: 1) so that the coldest part of the pile attains a temperature of 55°C, for a minimum of 3 days, and 2) so that malodorous volatile compounds that may be released from the pile are screened out. Screened or unscreened compost can be used as a blanket material. However, using unscreened compost is usually more feasible. The use of wood chips as a blanket material is not recommended, since the coarse texture and loose structure of wood chips contributes to heat loss, fly and odor problems.

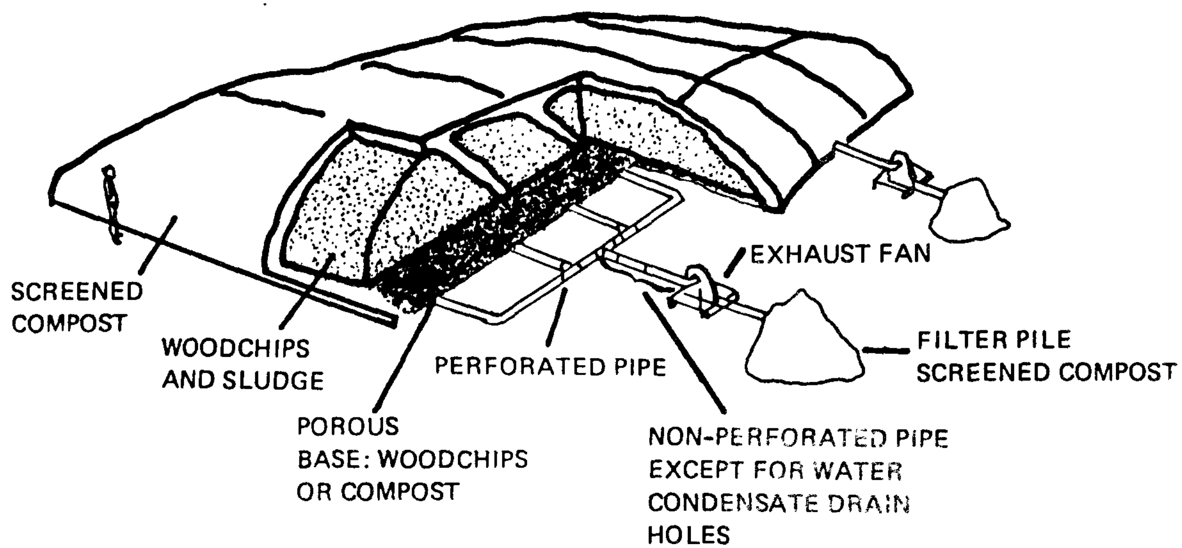
A 16-to-20 inch thick blanket of unscreened compost (or 8 to 12 inches of screened compost) have been found to be sufficient. The thickness of the cover blanket can be usefully increased during cold weather to enhance composting conditions. When the extended pile configuration is used, only a 2-to-3 inch layer of screened or unscreened composted material is applied on the side to which the next layer will be added. This thin layer serves as a temporary overnight screen for trapping odors and retaining heat.

3. Aeration

Forced aeration must be provided in the aerated pile configuration to achieve the oxygen, temperature and moisture levels necessary for complete composting. The form and duration of air flow used by the facilities studied is shown in Table 8. As originally developed, air is pulled down into the pile from a vacuum created by a small radial vane fan which is in line with the porous and non-porous plastic tubing (Figure 4B). The non-porous tubing ends in an odor

COMPOSTING WITH FORCED AERATION





B. EXTENDED AERATED PILE

FIGURE 4. CONFIGURATION OF AERATED PILES SHOWING CONSTRUCTION OF PILE AND THE ARRANGEMENT OF AERATION PIPE. (28)

Table 8. MODE AND DURATION OF AERATION AT SEWAGE SLUDGE COMPOSTING FACILITIES (33)

City	Blower power	No. Piles/ blower	Wet tons Sludge/pile	Air Flow: Vacuum	Air Flow: Positive	Total Scheduled Time for Composting 2/
Aerated Pile	HP			Minutes	Minutes	Days
H	0.33	1	120	12 every 20		21
B	2.0	1	270	15 every 30		21
C	40. 1/	Total Site		30 every 60		21
A	0.33	1	50	Cont. 1 day-5 every 10 3/		21
E	0.33	2	50	10 days-5 every 30	11 days-5 every 30	21
D	0.33	2	125	14 Days-4 every 30	14 Days-4 every 30	28
Windrow						
F	0.0	None				30
G	20. 1/	3		15 every 60		30

1/ Centralized systems

2/ Scheduled times for aeration and composting are shown. These are adjusted according to composting conditions, e.g., total composting time is often extended during cold or wet weather conditions.

3/ Essentially set individually for each pile depending upon operator perception of sludge and ambient climate conditions scrubbing pile of screened or unscreened compost (27, 36). The air flow schedules, i.e., the form and duration of flow, have been set based upon maintaining favorable temperature and oxygen levels in the pile and to drive-off excess moisture (27, 35). The total time required to achieve complete composting is adjusted to compensate for ambient weather conditions relative to air temperatures and moisture levels. For example, during cold climatic conditions, the required composting time may be extended one to three weeks. Also, it has been found helpful in these areas, when the sludge/bulking agent mixture temperature drops below 10°C, to blow warm air from an active composting pile into a newly constructed pile. This speeds up the initiation of the composting process (21). Continuation of this warm air transfer, after the initiation of the composting process, however, results in excessive moisture accumulation.

As an alternative, forced aeration may be provided to a windrow or conical pile configuration. This would provide assurance for attaining an adequate oxygen level, might lessen the need for coarse bulking agent, and should permit greater heights and widths of the piles and windrows.

The perforated aeration pipes in the base of a pile should not be closer than approximately 8 feet from the end or the edge of an aerated pile to prevent channeling of air (i.e., short circuiting of air through the porous base). In addition, short circuiting can be minimized by using a less porous base (e.g., screened or unscreened compost) and/or by surrounding the base with a less porous blanket material (e.g., screened or unscreened compost). The aeration pipe should be from 4-6 inches in diameter. Aeration should be timed at the rate of approximately 500 cubic feet per hour per ton (cfh/ton) of dry sludge for no more than half of every hour, and the time off should not exceed 20 minutes. However, aeration rates varying from 200 to 1,200 cfh/dry ton have been tried without appreciable adverse impact (35).

A pile of screened composted sludge can be used to screen out the odorous gases which have been pulled through the pile by the blower. Approximately one cubic yard of screened composted sludge for every 2.5 dry tons of sludge in the static pile can accomplish this purpose. If the moisture content in the odor screening pile becomes too high from filtering moist air (65-75%), it will not adequately remove odors from the exhausting air. Hence, odor scrubbing compost piles should be replaced when the moisture levels reach 65-75 percent.

As shown in Table 8, two of the composting facilities periodically used positive pressure airflow during the latter part of the composting cycle. This method forces air up through the composting pile. This practice has provided these locations with not only more favorable composting conditions and odor control, but also a more uniform, low moisture compost. The lower moisture content in the compost greatly facilitates screening of the finished product and reduces the production of odor in curing piles.

An alternative method for aeration is also now being tested (5). This method is based upon data which indicate that the optimum temperature range for biological oxidation and drying is 45-60°C. This temperature is maintained using a positive flow of air with an aeration capacity of approximately 10,000 cfh/ton of dry sludge. The air flow is activated with a temperature sensitive switch that is centrally located, well within the pile. This switch is set to start aeration when the temperature rises to about 50°C and to stop aeration when the temperature drops to about 45°C.

The positive rather than negative flow of air apparently may eliminate the need for an odor scrubber pile, relying on the improved aeration and cover blanket for odor control.

The finished compost produced in the positive forced air temperature control mode is drier and moisture is more uniformly distributed. Thereby, greater use of the compost as a bulking agent is possible and screening is greatly facilitated. Additional studies of this mode will determine how well odors are controlled and whether or not the pathogen kill obtained is equivalent to that under the negative aeration, higher temperature rise mode. Included in the testing program will be a disinfection period with temperatures maintained at 55°C or above to kill pathogens. This disinfection period will be tried both at the beginning (before high aeration) and near the end (after high aeration).

4. Drainage

In negative flow aeration systems, water vapor will condense in the cooler sections of the aeration pipes. Adequate drainage must be provided to remove this condensate from the aeration system. One simple method for removing the water is to place small holes in that portion of the aeration system pipeline where the condensate would normally gather (portion with lowest elevation). These holes should not be very large (about 3/8 inch diameter on the 4 and 5 inch diameter pipes) to avoid causing an air bypass that would result in a drop in vacuum pressure. It is estimated that approximately 6-20 gallons per day of condensate will accumulate during dry weather from a pile containing 50 cubic yards of composting sludge. This liquid must be collected. It then may be discharged through pipes into a sewer system or held onsite, e.g., in an aerobic pond for later recycling or disposal.

A few composting facilities have chosen to use permanent air ducts, which are set in concrete beneath the composting pad surface, rather than disposable pipe. A centralized blower system has also been used for connection to these permanent air ducts. These systems have experienced difficulties with keeping the airflow passageway clear, because condensate water and organic materials have accumulated in the ducts and corrosion has clogged perforations. Thus, full air flow is prohibited pending a clean-up or overhauling of the aeration system. The problem of clogging should be resolved with improved permanent aeration pipe design. In addition, these systems have limited capability for providing separate aeration schedules to specific piles, because of the large central blower, unless control values are provided in the air piping system.

D. Pad

A paved pad is very important to the successful operation of a composting facility, especially in a humid climate. Table 9 lists various types of paving materials that have been used with notes on their suitability. Concrete as a pad material is most suitable while compacted dirt is least suitable, especially in humid climates. A crushed rock pad is marginal to unsuitable.

Some of the locations studied had experienced difficulties with the composting pad due to the high demands placed on the pad material by the movement of heavy equipment and the high temperatures attained by composting. Many of the systems were started as temporary sites using gravel or asphalt pads to reduce capital expenses. The movement of heavy equipment on these sites to handle the initially wet sticky sludges has led to rapid deterioration of pads, and muddy and dirty conditions. This in turn has led to equipment immobility and breakdown, dust, and odor problems.

Certain forms of asphalt appear to be suitable (e.g., rapid cure, coarse aggregate asphalt). However, long-term composting operations, which produce a growth medium for mushrooms in the humid northeastern United States, have chosen concrete over asphalt because of asphalt's tendency to decompose and soften. Where static pile composting is practiced upon an 8-12 inch wood chip base, temperatures on the asphalt may not be so great; therefore, asphalt may be more suitable as a pad for static pile than windrow composting. There is, however, an initial 6 month period when the aspalt pad, especially fine aggregate asphalt, will have soft spots. In contrast, concrete is suitable soon after pouring.

E. Climatic Impacts

Outdoor composting has been successfully operated at the facilities surveyed in air temperatures down to -40°F (21). Composting of sludge has been accomplished in the rain or snow. While mixing of the sludge with bulking agent can occur in the rain, it is most desirable to have sufficient temporary sludge storage capacity so that mixing can be delayed until fair weather. If sludge and bulking agents are mixed in the rain, more bulking agent will be required to compensate for extra water.

Table 9. PAVING MATERIALS

Material	Suitability
Crushed Rock	Marginally suitable. Requires considerable maintenance, hard to clean, serpentene rock has proved to increase nickel in compost. Often has soft spots for 6 months until pad harden.
Fly Ash	Marginally suitable. Dusty, hard to clean. When wet will become very muddy.
Asphalt	Suitable with reservation - Can be kept clean. Asphalt may soften under temperatures produced during composting. Mushroom composters report that asphalt itself may compost.
Concrete	Most suitable - In use 50 years for mushroom composting. Easy to clean. Will not compost.
Dirt	Marginally suitable for dry climate - Can be dusty. Can not clean. Messy in wet periods.

Under very cold ambient conditions, it has been found to be helpful to 1) blow warm air from an existing composting pile into a newly created pile until temperatures reach 20 or 30°C, 2) increase the thickness of the insulating cover blanket of previously composted sludge, and/or 3) operate at a slow rate of aeration. Once a suitable aerated static pile or windrow has been constructed, rain, snow or very cold weather will not adversely affect outdoor sludge composting operations. However, in windrow composting, after a rainfall, allow the surface to dry before turning. Since the rain typically penetrates only the outer surface, drying avoids incorporation of excessive moisture into the windrow mass.

F. Odor Control

The control of odors is one of the most essential steps in maintaining a successful sewage sludge composting operation. Practices that help to minimize odor problems include:

- Having an adequate buffer zone between facility and nearby residents.
- Handling of sludge and opening composting piles only when the meteorological conditions are favorable. Unfavorable conditions are during periods of low wind speed for odor dispersion, excessive precipitation and temperature inversion.
- Monitoring to assure proper temperature, moisture and oxygen levels. Malodor is most often associated with excessive moisture levels.
- Prompt adjustments of bulking agent/sludge mixture whenever sludge or bulking agent is wetter than usual due to wet weather or changes in sludge processing and dewatering. In this manner, the moisture level should be maintained within the range to provide for proper gas exchange.
- Application of a blanket of previously prepared compost over a new aerated pile to screen out malodorous volatile gases arising from the pile.
- Use of a low moisture, screened compost in a separate pile for screening out odors from air that is drawn through a static pile by negative aeration.
- Adequate cleaning of the composting area and equipment.
- Assuring good drainage of surface and condensate water from the composting facility with no puddling of liquids.

- Providing for proper handling and treatment of the drainage water (e.g., in a sewage or an aerobic pond before sprinkling on land). In cases where the composting site is adjacent to the wastewater treatment plant, it is usually expedient to run the drainage back to the head of the plant.

- Providing adequate alternative disposal in landfills or trenches for an occassional bad batch of composted sludge, or provisions for prompt remixing to reestablish composting conditions.

- Regular turning of composting materials in windrow configurations. Turnings should provide aeration, not over cool, and turn the outside surface inward for high temperature decomposition.

- Promptness of all operations.

- Anaerobic digestion of sludge substantially reduces the potential for odor so that windrow composting is generally possible as a stabilization process without odor scrubbing and/or forced aeration. Anaerobic digestion is generally not needed to prevent odors when composting in aerated static pile configurations where compost blanketing and air scrubbing are practiced.

- Recycling cured compost as part of the bulking agent also reduces the production of odor in windrows and aerated piles. This is because fine textured, cured compost can internally coat and scrub odorous surfaces better than coarse wood chips.

- Positive aeration at high rates that is temperature controlled may provide for control of odors in blanketed aerated piles without the need for odor scrubber piles.

- A limited large-scale demonstration of sludge composting has been run in aerated trenches in a building. The study suggests that sludge composting can take place without the need for compost blankets or scrubber piles to control odors. Additional experience will be needed to verify this suggestion and to determine whether scrubbing of the air leaving the building would be needed in controlling odor.

G. Screening and Conveying

Aside from controlling odors, one of the biggest problems in sewage sludge composting is the inability to consistently and adequately screen compost to recover bulking materials.

Screening of compost produced with bulking materials such as wood chips is important for at least three reasons. First, these materials can be one of the most expensive components of a sewage sludge composting system. Proper recovery will permit their reuse as bulking agents with only a minimum make-up with new wood chips. Secondly, a screened composted sludge with its relatively low content of cellulose bulking agent is often easier to utilize and provides a more valuable product for agricultural and horticultural use. However, unscreened sewage sludge compost can be of value for use as a mulch. Third, screening reduces the volume of the finished product that requires transportation to the site where it will be used.

Many types of screens will work in separating the wood chips or other bulking agents from the composted sludge when the moisture content of the composted sludge and bulking agent is less than 45%. Unfortunately, the moisture content of the finished sludge compost is often about 55%, causing frequent plugging of most types of screens. Increasing the mesh sizes of the screens used may help overcome this problem; although it results in a substantial loss of the finer portion of the bulking material. Additional drying of compost may be needed to facilitate more effective screening. If the increase in screening effectiveness outweighs the labor costs involved in additional drying, compost could be spread out temporarily to dry before screening.

Recent developments in screening technology have enabled the efficient screening of wet compost that has a moisture content of up to 50 percent. Modern screens may incorporate a flexing or vibrating motion, along with multiple screens of varying sizes to reduce clogging. The screens may be made of various materials, such as wire, plastic, stainless steel, or rubber.

One recently developed screening mechanism, which employs a vibrating rubber screen with a 7/8 inch mesh opening over a second screen with a 1/4 inch mesh opening, has resulted in excellent separation of the composted sludge from the wood-chip bulking agent. An estimated 85 to 90 percent of the wood chips are recovered with this screen. The capacity for screening the finished compost has been estimated at 1/2 - 1 cubic yards per minute.

Another screen that successfully processes wet compost uses a flexing motion. This unit constantly flexes a rubber screen with 1/2-inch mesh that grades down to 1/4-inch mesh. This flexing action permits self-cleaning of the screen when compost that is greater than 50 percent moisture is processed. Temporarily stopping the flow of compost into the screen facilitates self-cleaning via the flexing action, in lieu of totally ceasing operations for manual cleaning.

Both of these screens, along with many other types, have been used and are currently in use at the major composting facilities in the United States. Operational information on these screens is contained in Table 10.

A maximal percentage recovery of wood chips through screening may not always be desirable or economical. An unscreened sufficiently dry compost, such as obtained from positive rather than negative aeration, could possibly be used more economically as a bulking agent than the screened recycled wood chips.

As a second example, a lower percentage recovery which results in a final product with a larger volume may be desirable if net revenues are increased from its sale. One composting location has completed an interesting study on the cost of screening (24). They have found that their optimal percent recovery of bulking agent depends upon the cost of wood chips versus the cost of screening.

Two important features of any screening system are: 1) capacity and 2) separation effectiveness. Capacity is simply the volume of composted material at a certain moisture content that can be separated in a given time period (e.g., 2.0 cubic yards/hr at a moisture content of 50%). Separation effectiveness is a measure of a screen's ability to closely separate the bulking agent from the fine compost. The most efficient screen would sharply separate the unscreened compost so that the smallest particle of the bulking agent would be just larger than the largest particle in the final compost. In actuality, screens do not produce such a sharp separation (10).

The rating and review of the effectiveness of screens given in Table 10 was based upon wood chip recovery and did not really address separation effectiveness. We refer the reader to Higgins, et.al. (10) for the results of a detailed study on separation effectiveness of screens.

H. Curing (Stockpiling)

An active composting period of approximately 21 days is needed to achieve stabilization of the composting sludge when using either the static pile or windrow method. As an additional safeguard, a 3-4 week period for curing the compost, following the active composting period (either before or after screening), helps ensure completeness of stabilization (reduction of possible odor production) and pathogen reduction. However, if the compost is too wet and has a high volatile solids content, it should be composted again to avoid anaerobic conditions and, hence, malodors. The size of curing piles will usually depend on the capabilities of available front end loaders; although, factors such as texture and density of compost should be accounted for to avoid compaction. Also, the curing

Table 10. SLUDGE COMPOST SCREENING FACILITIES FOR RECOVERY OF BULKING AGENT (33)

City	Screen Form	Screen Fabric	Mesh	Moisture Limit	Ease of Cleaning 1/	Flow Through	Bulking Agent Recovery
Aerated Pile			Inch	%		Cu yd/min	%
H	Rotating Cylinder	Stainless	3/8	45	3	1	65
B	Flexing	Plastic	1/2-1/4 2/	50	1	1-2	80
C	Harmonic Vibrating	Wire			4	0.5	60
A	Vibrating Drum	Steel	1/2	60	3	1	50
E	Rotating Cyclinder	Steel	3/4	50	2	1	45
D	2-Stage Vibrating	Rubber	7/8 over 1/4	45	3	0.5-1	85

1/ Index of cleaning ease: 1 easiest, 5 most difficult.

2/ Compost first falls on that part of the screen with a larger mesh. The material retained on the screen is shaken down toward the second half of the screen with the smaller mesh.

pile should be rounded on top, so that water buildup can be minimized.

I. Disposition/Use

A great variety of beneficial uses are potentially available for properly composted sludge. The application of sludge compost to marginal soils at rates that supply the fertilizer (e.g., nitrogen and phosphorus) requirements of crops can produce significantly higher crop yields than commercial fertilizers applied alone, especially for soils with low organic matter. Higher yields are attributed to an improvement in soil physical properties by the compost. Sludge compost is known to enhance aggregation, increase soil aeration, lower bulk density, lessen surface crusting, and improve permeability, infiltration, and/or water retention. Sludge compost added to sandy soils will increase the moisture available to plants and will reduce the need for irrigation. In heavy-textured clay soils the added organic matter will increase the soil's permeability to water and air, and increase water infiltration into the profile; thereby, surface water runoff is minimized and water storage capacity is increased. Addition of sludge compost to clay soils has also been shown to reduce compaction (i.e., lower the bulk density) and to increase root development (12).

The USDA concluded that sludge compost, like composted manure, is hygienically and environmentally safe if used and stored properly. They advised that compost not be stored near children's play areas, surface water, wells and other water supplies. They also recommend that all fruits and vegetables should be washed, before they are consumed, to remove any residual compost that may be present (12).

Composted sludge has proven to be an acceptable substitute for peat as a soil conditioner. A commercial potting mixture of one-part composted sludge, one-part sand or soil and one-part vermiculite has been shown to be an excellent medium for growing and propagating ornamental plants (6, 12).

Composted sludge has been used with great success in the reclamation and revegetation of strip mined areas, acid mine spoils and other barren or disturbed poor soils. Large scale field demonstrations in the coal mining areas of central Pennsylvania have enabled Philadelphia to proceed with mine spoil reclamation and revegetation as one of their primary sludge disposal options (23).

Sludge compost is an excellent soil amendment for use in tree nurseries. An application of 100 dry tons per acre to a sandy nursery soil has resulted in taller, more densely rooted and more winter-hardy deciduous and conifer tree seedlings. This improvement is noted when compared with conventional green manure/chemical fertilizer practices (6, 8).

A one-or two-inch layer of composted sludge placed over the surface of soil has successfully produced high grade sod on irrigated commercial turf farms in 6 to 7 months rather than the normal 12 to 18 months (12). Composted sludge also has been used successfully as a top dressing for established lawns and for amending soils used for growing flowers and vegetables (6, 12, 20). USDA has identified composted sludges that when added to soils have resulted in very little increase in heavy metal content (including cadmium) in the compost grown food crops, compared with control plants grown in soils that were not treated with composted sludge (11).

The contents of heavy metals and other toxic organic compounds present in the sludge may limit the usefulness of the compost product. Guidance and regulations are currently being developed to govern the distribution and marketing to the public of composted sludge derived products. A preproposal draft regulation was circulated for comment on May 6, 1980 (30). The Criteria for Solid Waste Disposal Facilities (28), the Sludge Technical Bulletin (25) and other recent publications (29, 31) provide guidance that is applicable to the utilization of composted sludge for both agricultural and non-agricultural uses. Note compost that has only met the requirements for a "significant" reduction of pathogens has greater limitations on the end use than compost that has received "further" reduction of pathogens (see p. 3).

J. Employee Safety (33)

The following recommendations and provisions are advisable to ensure the health and safety of employees:

1) Rules pertaining to personal cleanliness should be posted in appropriate areas. For example, the following items should be emphasized:

   (a) Wash hands before eating, drinking, and smoking.
   (b) Wash hands before returning home after work.
   (c) Avoid storing food in close proximity to sludge or compost samples taken for analysis.

2) Showers and lockers should be provided at the composting facility.

3) The municipality should provide onsite clothing, e.g., coveralls and safety shoes for all workers.

4) Workers should change from this onsite clothing to street clothes at the end of each day. The onsite clothing should not be worn home.

5) As necessary, the municipality should provide for cleaning the onsite clothing.

6) Site employees should wear hard hats, if appropriate for the tasks they are performing.

7) During periods of dry weather, the area should be sprinkled periodically to minimize worker's inhalation of dust. During such dusty conditions, workers should be encouraged to wear face masks.

Recent studies have not indicated that Aspergillus fumigatus poses a significant health threat. A possible exception would be susceptible individuals working at the compost facility (16, 19, 22). A susceptible individual would be a person weakened by a primary infection or by some physical disturbance such as surgery or immunosuppresive therapy. (see Appendix B). Nevertheless, it might be advisable to locate the composting facility away from large populations of susceptible individuals (i.e., hospitals or nursing homes) to minimize any possible adverse impacts. The minimum separation distance will, however, depend on topography, climate, and velocity and direction of wind. Milner, et.al. (18) has presented a methodology for determining siting to minimize Aspergillus dispersal. In addition, compost site workers should be selected from the large majority of people who are not sensitive to A. fumigatus or other respiratory allergens. Finally, increased use of finished compost as a bulking agent, with fewer woodchips, has resulted in a decreased level of A. Fumigatus (19).

VII. REFERENCES

(1) Burge, W. D. Colacicco, and W. Cramer. Control of Pathogens During Sewage Sludge Composting. 1979. In Proc. National Conference on Municipal and Industrial Sludge Composting, New Carrollton, MD. Information Transfer, Silver Spring, MD, pp. 105-111.

(2) Daniels, S.L. and E.S. Conyers. 1975. Land Disposal of Chemically Treated Waters and Sludges. In Proc. 2nd National Conference on Complete Water Reuse. Chicago, IL, pp. 697-704.

(3) Epstein, E. 1979. Bulking Materials. In Proc. National Conference on Municipal and Industrial Sludge Composting, New Carrollton, MD. Information Transfer, Silver Spring, MD, pp. 30-34.

(4) Eralp, A. (ed.). 1981. Proc. on National Conference on Enclosed Municipal Sludge Composting. Cincinnati, Ohio (unpublished).

(5) Finstein, M.S., J. Cirello, S.T. MacGregor, F.C. Miller, and K.M. Psarianos. 1980. Sludge Composting and Utilization: Rational Approach to Process Control. Final Report. Rutgers University, New Brunswick, NJ, 211 pages.

(6) Gouin, F.R., Chairman. 1979. American Society Hort Science Working Group Indexed Bibliography of Municipal and Industrial Waste Utilization in Horticulture (341 references).

(7) Gouin, F. 1981. Utilization of Compost on Nursery Crops. Hort. Science (in press).

(8) Gouin, F.R. and J.M. Walker. 1977. Deciduous Tree Seedling Response to Nursery Soil Amended with Compost Sewage Sludge. Hort. Science 12:45-47.

(9) Haug, R.T., and L.A. Haug. 1977, 1978. Sludge Composting: A Discussion of Engineering Principles (Parts 1 and 2). Compost Science 18#6:6-11 and 19#1:10-14.

(10) Higgins, A.J., V. Kasper, Jr., D.A. Derr, M.E. Singley and A. Singh. 1981. Evaluation of Screens for Sludge Composting. Biocycle 22#3, pp. 22-26.

(11) Hornick, S.B., J.J. Murray and R.L. Chaney. 1979. Overview on Utilization of Composted Municipal Sludges. In Proc. of National Conference on Municipal and Industrial Sludge Composting, New Carrollton, MD. Information Transfer, Silver Spring MD, pp. 15-22.

(12) Hornick, S.B., J.J. Murray, R.L. Chaney, L.J. Sikora, J.F. Parr, W.D. Burge, G.B. Willson, and C.F. Tester. 1979. Use of Sewage Sludge Compost for Soil Improvement and Plant Growth. USDA, Science and Education Administration. Agricultural Reviews and Manuals, ARM-NE-6. 10 pages.

(13) Horvath, R. 1978. Operating and Design Criteria for Windrow Composting of Sludge. In Proc. National Conference on Municipal and Industrial Sludge Composting, Silver Spring, MD. Information Transfer, Silver Spring, MD, pp. 88-95.

(14) Iacoboni, M.D., T.J. LeBrum and J.R. Livingston. 1980. Deep Windrow Composting of Dewatered Sewage Sludge. In Proc. National Conference on Municipal and Industrial Sludge Composting, Philadelphia, PA. Information Transfer, Silver Spring, MD, pp. 88-108.

(15) LeBrum, T.J., M.D. Iacoboni and J.R. Livingston. 1980. Overview of Compost Research. In Proc. National Conference on Municipal and Industrial Sludge Composting, Philadelphia, PA. Information Transfer, Silver Spring, MD, pp. 109-116.

(16) Marsh, P.B., P.D. Millner, and J.M. Kla. 1979. A Guide to the Recent Literature on Aspergillosis as Caused by Aspergillus fumigatus. USDA, SEA, Agric. Reviews and Manuals, ARM-NE-5. 28 pages.

(17) Memoli, M.A. 1979. Impact of Filter Press Dewatering on Nassau County Composting. In Proc. National Conference on Municipal and Industrial Sludge Composting, New Carrollton, MD. Information Transfer, Silver Spring, MD, pp. 24-29.

(18) Millner, P.D., D.A. Bassett, and P.B. Marsh. 1980. Dispersal of Aspergillus fumigatus from Sewage Sludge Compost Piles Subjected to Mechanical Agitation in Open Air. Appl. Environ. Microbiol. 39:1000.

(19) Millner, P.D., P.B. Marsh, R.B. Snowden and J.F. Parr. 1977. Occurrence of Aspergillus fumigatus during Composting of Sewage Sludge. Appl. Environ. Microbiol. 34:765-772.

(20) Murray, J.J. 1978. Use of Composted Sewage Sludge in Turf Grass Production. In Proc. of Waste Water Conference. Chicago, IL. Sponsor - American Society Golf Course Architects.

(21) Olver, W.M. Jr. 1974. Static Pile Composting of Municipal Sewage Sludge: The Process as Conducted at Bangor, Maine. US EPA Draft Report, Office of Solid Waste, Washington, D.C.

(22) Olver, W.M. Jr. 1979. The life and Times of A. fumigatus. Compost Science. 20#2:36-40.

(23) Sopper, W.E. and S.M. Kerr. 1979. Utilization of Municipal Sewage Effluent and Sludge on Forest and Disturbed Land. The Pennsylvania State University Press, University Park, PA, 537 pages.

(24) Gruber, E.K. and Brown, C.D. 1979. Bulking Agent Recovery from Philadelphia Compost. In Proc. National Conference on Industrial and Municipal Sludge Composting, New Carrollton, MD. Information Transfer, Silver Spring, MD, pp. 136-143.

(25) U.S.E.P.A. 1977. Municipal Sludge Management: Environmental Factors. Office of Water Program Operations, Washington, D.C. EPA 430/9-77-004, MCD-28.

(26) U.S.E.P.A., 1978. Sewage Sludge Composting. In Sludge Treatment and Disposal. Environmental Research Information Center, Cincinnati, OH. EPA 625/4-78-012, 2:35-55.

(27) U.S.E.P.A. 1979. Composting. In Process Design Manual for Sludge Treatment and Disposal. Environmental Research Information Center, Cincinnati, OH. EPA 625/1-79-011, Chapter 12.

(28) U.S.E.P.A. 1979. Criteria for Classification of Solid Waste Disposal Facilities and Practices, 40 CFR Part 257. In Federal Register, September 13, 53438-53468.

(29) U.S.E.P.A. 1980. A Guide to Regulations and Guidance for the Utilization and Disposal of Municipal Sludge. Office of Water Program Operations, Washington, D.C. EPA 430/9-80-015, MCD-72, 48 pages.

(30) U.S.E.P.A. 1980. Distribution and Marketing of Sewage Sludge Products, Preproposal Draft Regulation. Office of Water and Waste Management, Washington, D.C., May 6.

(31) U.S.E.P.A., F.D.A. and U.S.D.A. 1981. Land Application of Municipal Sewage Sludge for the Production of Fruits and Vegetables: A Statement of Federal Policy and Guidance. EPA Office of Solid Waste, Washington, D.C. SW-905, 21 pages.

(32) Using Municipal and Agricultural Waste for the Production of Horticultural Crops. 1980. Proceedings of a Symposium. Hort. Science. 15(a):161-178.

(33) Walker, J.M., M.S. Winsten, J.E. Hall. 1979. A Critical Review of the Performance of Sewage Sludge Composting Operations, In Proc. of National Conference on Municipal and Industrial Sludge Composting, Philadelphia, PA. Information Transfer, Silver Spring, MD, pp. 5-14.

(34) Willson, G.B. 1977. Equipment for Composting Sewage Sludge in Windrows and in Piles. In Proc. National Conference on Composting Municipal Residues and Sludges, Silver Spring, MD. Information Transfer, Silver Spring, MD, pp. 56-60.

(35) Willson, G.B., J.F. Parr, and D.C. Casey. 1979. Basic Design Information on Aeration Requirements for Pile Composting. In Proc. of National Conference on Municipal and Industrial Sludge Composting, New Carrollton, MD. Information Transfer, Silver Spring, MD, pp. 88-99.

(36) Willson, G.B., J.F. Parr, E. Epstein, P.B. Marsh, R.L. Chaney, D. Colacicco, W.D. Burge, L.J. Sikora, C.F. Tester, and S. Hornick. 1980. Manual for Composting Sewage Sludge by the Beltsville Aerated Pile Method. EPA 600/8-80-002, 65 pages.

VIII APPENDICES

Appendix A

Concepts and Background of Sludge Composting

Sewage sludge composting is an aerobic, microbiological decay process. Under favorable environmental conditions (i.e., correct values for moisture, pH, oxygen levels, etc.), microorganisms contained in the sludge will begin to break down (decompose) the large organic molecules also present in sewage sludge. Using the organic matter as a substrate, the microorganisms raise their metabolic rates and hence, the surrounding temperatures. Elevated temperatures in the compost mixture, as well as microbial antagonism are primarily responsible for the elimination of pathogenic organisms. The resulting material, after completion of the process, is an earthy, humus-like material which can be used as a soil conditioner.

Composting can effectively transform an undesirable municipal organic waste into an agriculturally and horticulturally useful product that is easy to handle and readily accepted by the public. Several composting methods have been extensively researched and tested, and have been found to be reliable for stabilizing and minimizing the pathogen content in sewage sludge and septage. The two most widely used and accepted methods of sewage sludge composting in the United States are the static aerated pile method developed by the U.S. Department of Agriculture at Beltsville, Maryland, and the windrow method.

The two methods basically utilize the same biological processes but the operational procedures for each method differ slightly. The two methods differ mainly by the way oxygen (air) is supplied throughout all parts of the pile. The windrow method relies on natural convective forces to pull air into the pile along with periodic mechanical mixing. The mixing is necessary for reaeration of the pile, to bring wetter material from the inside to the surface for drying, and to ensure that all material will be in the interior of the pile long enough for the high temperatures to destroy pathogens. The static aerated pile, however, is mixed only once. A perforated pipe aeration system with vacuum pumping (negative aeration) is used to ensure adequate oxygen supply, and a "blanket" of finished compost aids in achieving maximum temperatures for pathogen elimination. In some installations, a combination of forced aeration and periodic mechanical mixing has been used successfully with windrow systems.

Some windrow and static pile composting systems have replaced manual labor with automated machines (i.e., mixers, conveyors, feeder hoppers). This replacement has the advantage of lower operating cost (due to the high cost of labor) and the possible added control of odors (many automated systems are enclosed). However, automation often has the disadvantage of greater complexity and the inability to adjust readily to constantly changing variations in operational procedures and quality or quantity of materials (e.g., variation in bulking material, sludge type, or moisture content).

There were several attempts at the development and introduction of refuse composting, before sludge composting, in the United States. These ventures failed, in part, due to the necessity of selling the composted product at a profit to make the system pay for itself. The sale of composted sewage sludge and/or solid waste has not made a profit for municipalities, and should not be made part of any sludge composting plan, other than to reduce expenses. While the compost product has value as a soil conditioner and fertilizer, its commodity value has not been sufficient to cover the processing and handling costs. It is important to note, however, that the potential value of composted sludge or refuse may be reduced, or its use may be limited, by excessive levels of heavy metals or other contaminants.

In some European composting operations, confined (invessel) systems have been developed and operated for sewage sludge or sludge and solid waste composting. A few such confined systems have been developed in the United States for the composting of animal wastes, solid wastes and/or a combination of sewage sludge and solid wastes.

Future improvements in materials handling technology will increase the feasibility and desirability of invessel and/or mechanized composting of sludge. A recent conference in Cincinnati revealed major advances in invessel design. Many of the systems featured simplicity of design and flexability of operations which are necessary for cost-effective and reliable composting operations (4). Sewage sludge composting systems with greater mechanization and complexity will probably be developed in the future. The flexibility, reliability and costs of these more complex systems should be adequately demonstrated in the United States before adoption for full scale use.

Appendix B

Health Aspects of Sludge Composting (1,16,19)

Workers at sludge composting facilities encounter disease risks: 1) from the pathogens normally present in sewage sludges, and 2) from fungi and actinomycetes that grow during composting. The former are often referred to as primary pathogens because they can initiate an infection in an apparently healthly individual. The latter are referred to as secondary pathogens because they usually infect only people with debilitated immune systems, such as those weakened by a primary infection, surgery or immuno-suppressive therapy. Densities of secondary pathogens generally are increased during composting. The growth of secondary pathogens is not peculiar to composting sewage sludge but occurs also in many farm and garden operations, such as during the composting of leaves or other materials. Examples of primary and secondary pathogens are listed in Table B-1.

Studies to define the risk of infection by primary pathogens to people working with sewage wastes are not as extensive as might be desired, but available data indicate that the risk is low. The predominant routes of infection from the waste material are through the mouth and inhalation. Prevention of infection involves such precautions as thorough washing of the hands before eating to prevent ingestion of the pathogens. The exposure of workers to primary pathogens in a composting operation is limited to the pile building operation because the temperatures reached in the next processing step (composting) reduce primary pathogen densities to insignificant levels. The initial mixing operation presents little hazard, because the high moisture levels limit particle migration.

Medical difficulty from secondary pathogens may result from inhalation of air containing a high density of spores. The probability that individuals in good health will be infected by secondary pathogens encountered in composting is very small. However, people who are predisposed because of such conditions as diabetes, asthma, emphysema, or tuberculosis, or who may be taking such medication as corticosteroids, broad-spectrum antibiotics, or immunosuppressive drugs may be more susceptible to infection.

The help of local medical authorities should be obtained in compiling a medical history questionnaire for work applicants so that predisposed people are screened out. Individuals who are "atopic", i.e., prone to severe allergies, should also be excluded from employment at composting facilities. Moreover, a complete physical examination is recommended, plus inoculations for typhoid, tetanus, and polio.

Table B-1. EXAMPLES OF PATHOGENS FOUND IN OR GENERATED DURING COMPOSTING OF SEWAGE SLUDGE, TOGETHER WITH HUMAN DISEASES ASSOCIATED WITH THESE PATHOGENS.

GROUP	EXAMPLE	DISEASE
PRIMARY PATHOGENS		
Bacteria	Salmonella enteritidis	Salmonellosis (food poisoning)
Protozoa	Entamoeba histolytica	Amoebic dysentery (bloody diarrhea)
Helminths	Ascaris lumbricoides	Ascariasis (worms infecting the intestines)
Viruses	Hepatitis virus	Infectious hepatitis (jaundice)
SECONDARY PATHOGENS		
Fungi	Aspergillus fumigatus	Aspergillosis (growth in lungs and other organs)
Actinomycetes	Micromonospora spp	Farmer's lung (allergic response in lung tissue)

Appendix C

Related Publications

Colacicco, D.E. Epstein, G.B. Willson, J.F. Parr and L.A. Christianson. 1977. Costs of Sludge Composting. USDA, Agricultural Research Service, ARS-NE-79. 18 pages.

Haug, T.R. 1980. Compost Engineering Principles and Practice. Ann Arbor Science Publishers, Inc., Ann Arbor, MI, 655 pages.

Leighton, G.M., R.D. Harter and G.R. Cranbie. Sewage Sludge Composting in Small Towns. Agricultural Experiment Station, University of New Hampshire, No. Pub. Date.

Mosher, D., R.K. Anderson. 1977. Composting Sewage Sludge by High-Rate Suction Aeration Techniques. U.S.E.P.A. Office of Solid Waste, Washington, DC, SW-614d. 50 pages.

Parr, J.F., Ph.D., G.B. Willson, R.L. Chaney, Ph.D., L.J. Sikora, C.F. Tester. 1978. Effect of Certain Chemical and Physical Factors on the Composting Process and Product Quality. In Proc. National Conference on Design of Municipal Sludge Facilities, Chicago, IL. Information Transfer, Silver Spring, MD, pp. 130-137.

U.S.E.P.A. 1977. User Acceptance of Wastewater Sludge Compost. Office of Research and Development, Cincinnati, OH. EPA 600/2-77-096, 47 pages.

U.S.E.P.A. 1978. Study of Forced Aeration Composting of Wastewater Sludge. Office of Research and Development, Cincinnati, OH. EPA-600/2-78-057.

Workshop on the Health and Legal Implications of Sewage Sludge Composting, Vol. 1 and Vol. 2. 1979. Energy Resources Co., Inc., Cambridge, MA. 402 pages.

[illegible]
[illegible]
[illegible] Street
[illegible] 60604 [illegible]