SW-614d

COMPOSTING SEWAGE SLUDGE by high-rate suction aeration techniques

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THE PROCESS AS CONDUCTED AT BANGOR, MAINE, AND SOME GUIDES OF GENERAL APPLICABILITY

This interim report (SW-614d) describes work performed under demonstration grant No. 803828 to the City of Bangor, and was written by DALE MOSHER *and* R. KENT ANDERSON

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contents

PART I: THE OPERATION AT BANGOR

PART II: POINTERS FOR OTHER MUNICIPALITIES

FIGURES

TABLES

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THE ULTIMATE DISPOSITION OF SEWAGE SLUDGE is a major problem facing many municipalities today. There are many ways in which sludge can be processed prior to ultimate land disposal. These most commonly include incineration and anaerobic digestion.

This report describes another method, a composting process developed specifically for sewage sludge, and its full-scale implementation at Bangor, Maine.

Composting is not a disposal method, just as incineration and anaerobic digestion are not disposal methods. All are simply processing techniques. After any of them, one must still dispose of a final product. However, the predisposal processing technique used will not only dictate the nature of the ultimate disposal method but may well determine its success.

The U.S. Environmental Protection Agency (EPA) has been investigating economic and environmentally sound methods of sewage sludge disposal with that point in mind. One project being conducted by the U.S. Department of Agriculture (USDA) with EPA funding led to the adaptation of solid waste composting procedures to sewage sludge only. While this process has been successful with even raw sludges, the USDA work has not resolved many questions on system operation and maintenance, cost, and climatic impacts.

Consequently EPA initiated a demonstration project at Bangor, Maine, to obtain answers to these questions.

The method developed by USDA is similar to the Baden process developed in West Germany for municipal solid waste and sewage sludge. It consists simply of (1) mixing sewage sludge with a suitable bulking agent, (2) placing the mixture over two parallel aeration pipes and (3) drawing air through the pile with a blower regulated to provide optimum aerobic composting conditions. The exhaust air is discharged into a pile of bulking material for odor control.

This process produces a product which is (1) easily stored until needed and (2) odor-free. Properly conducted composting has been found to reduce fecal coliform organisms to insignificant levels.

The City of Bangor had been dumping its raw primary sludge over the embankment of an older portion of the city dump. City officials recognized that this method of sludge disposal was unacceptable and that pending State regulations would prohibit this practice. The city therefore requested EPA's assistance in finding a suitable solution to its sludge disposal problem.

After a review of various options, a preliminary assessment of the composting process indicated that composting might be the cheapest alternative, was not capital intensive, and could be placed in operation in a short period of time. As a result, the city applied to EPA for a grant to demonstrate the forced aeration composting process.

The principal objectives of the demonstration grant were to (1) demonstrate the technical feasibility of forced aeration composting under cold climatic conditions, (2) evaluate the costs of such a system, (3) evaluate operational, maintenance and personnel requirements, and (4) evaluate potential local uses of the compost product. These objectives were to be met by the following qualitative and quantitative evaluations:

(1) evaluate different ratios of bulking agent to sewage sludge to determine the optimum ratio; (2) determine the degree of pathogen reduction; (3) make a subjective evaluation of odors; (4) evaluate public reaction to the composting operation; (5) determine the optimum application rates for use of compost in city projects such as recreation area development; and (6) determine the value of compost as a replacement for loam, peat and fertilizer to the city.

Composting got under way at Bangor on an operational scale in August 1975 and has since continued full scale as the standard procedure there.

Studies are continuing and much more complete data are being obtained on the on-going operation as further improvements are made in it. In particular, much fuller cost data will become available as variables including drying, screening, the optimum level for bark recovery, and the relative usefulness and marketability of different finenesses of the compost product are further examined.

However, the technical feasibility of the process has been established and the operating procedures have been developed to the point where they are ready for testing and practical application by other municipalities if desired. Prior to beginning such an operation, economics should be carefully evaluated. This interim report is therefore being issued because of the wide public interest in the project.

Part I covers specifically the experience at Bangor. Part II is extrapolated from the Bangor experience, and provides more general guidance to other communities in establishing their own composting projects.

Where space for land disposal of sludge is a limiting factor, composting obviously does not of itself solve the problem, since the final volume is somewhat greater than the original. However, composting may indirectly offer major relief on the matter of disposal space—through providing a product of far wider usefulness than sludge.

It will be noted that composting at Bangor also sharply reduced the heavy metals content in the finished compost over that which had been in the unprocessed sludge. Where the metals are a critical factor, composting will offer no final solution to the problem of ultimate accumulation of heavy metals residues in the soil when the disposal method requires repeated applications of material to the same land. However, substitution of compost for sludge could here again significantly alleviate the problem, since a greater number of applications of material could be made before the critical residue level in the soil is reached. Composting could make a contribution of considerably larger scope towards the resolution of the metals problem in another way, however—again indirectly—because composting greatly increases the number of potential uses for the product to be disposed: from a material limited strictly to use on farming land, as sludge now is, composting expands the potential avenues for use to such areas as plant nurseries, home lawns and flower gardens.

With these pluses, aerobic composting offers a promising option as a predisposal treatment method which eliminates the problems of pathogenic organisms and odor when reasonably careful operating practices are observed.

The product is much more manageable than sludge. And from the standpoint of aesthetics—which becomes crucial when sites for ultimate disposal must be found—by comparison with sludge disposal, the disposal of compost should be far more acceptable to the public.

The EPA studies at Bangor are expected to be essentially complete by May 1978. Once all the data are compiled and analyzed, a final report will be issued on the project.

part I
the operation at bangor

THE DIMENSIONS

The City of Bangor, Maine, has a permanent year-round population of 38,900 residents, of whom 32,000 are served by the sewage treatment plant. The 32,000 provide a flow of about 3 million gallons per day (mgd)—or 11.4 million liters per day (mld)—to the plant. Commercial and industrial establishments produce an additional 1 mgd and 0.7 mgd respectively, for a base flow of about 4.7 mgd. Infiltration and storm-water runoff contribute an additional 2.3 mgd, making the average total flow about 7 mgd (26 mld).

This flow receives primary treatment consisting of passage through bar screens, settling in primary sedimentation tanks, and prechlorination. Sludge is pumped from the primary sedimentation tanks through a hydrocyclone for grit removal. The sludge then flows by gravity to two sludge thickeners. When the thickeners are full as indicated by the torque on the rotating bar, the sludge is pumped to a conditioning tank where lime and a polymer are added and the mixture is dewatered by vacuum filtration (Figure 1).

SLUDGE: QUANTITY AND CHARACTERISTICS

The treatment plant currently produces about 3,000 cubic yards or 2,500 tons per year (2,300 cubic meters or 2,260 metric tons per year) of vacuum-filtered sludge with an average solids content of 20 percent. The

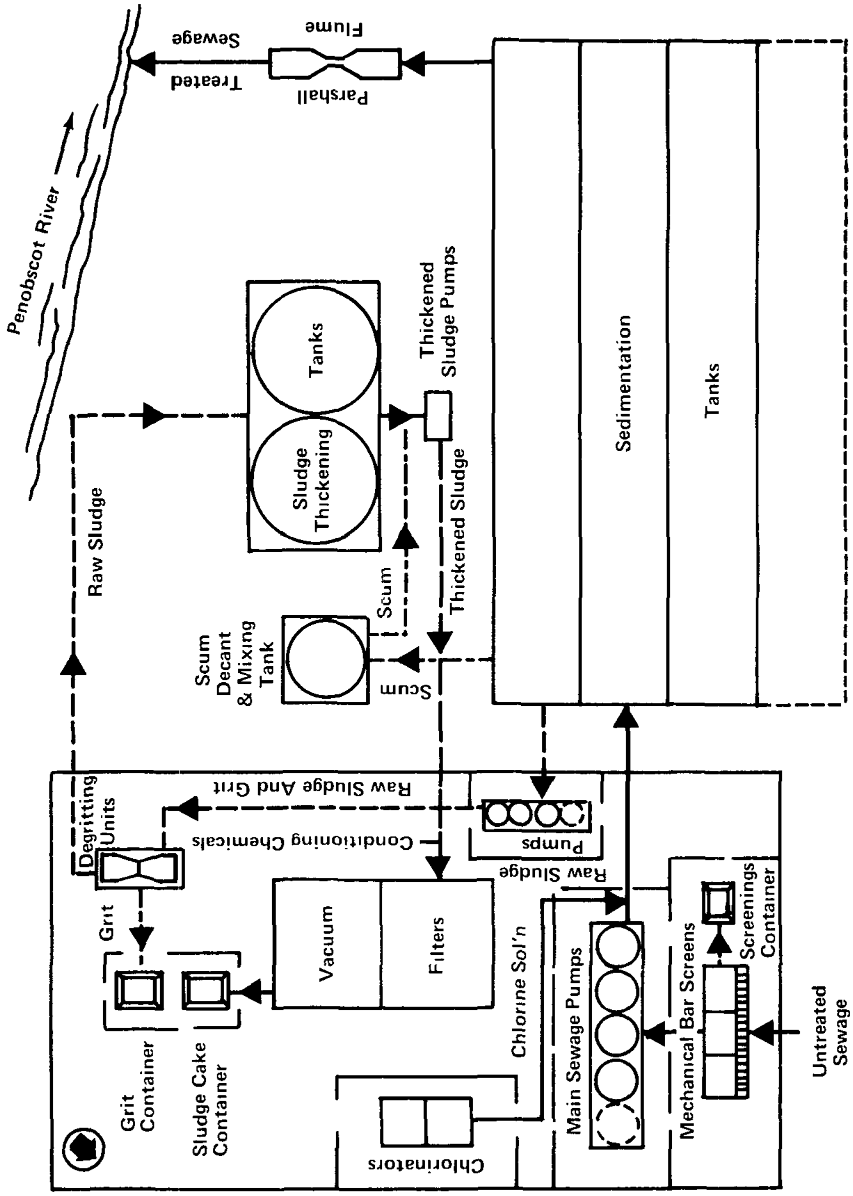

FIGURE 1. SEWAGE TREATMENT PLANT AT BANGOR, MAINE

The plant provides primary treatment followed by vacuum filtration, producing a sludge with average solids content of 20%. The vacuum filters are operated about 70 times per year, producing 40 to 60 cubic yards of sludge each time. Annual output totals about 3,000 cubic yards or 2,500 tons of dewatered sludge.

vacuum filters are operated about 70 times per year, producing 40 to 60 cubic yards (30 to 45 cubic meters) of sludge each time.

The chemical characteristics of Bangor's sludge and of the compost produced from it are analyzed for selected constituents (Table 1). Bangor sludge would be generally classified as a very good sludge in that it is very low in heavy metals, and the compost would be considered acceptable for land disposal.

No effect of metals on composting action itself is known to occur. However, the metals content of the compost product must be known in order to adequately determine acceptable uses for the compost product. It will be noted that some dilution of trace metals occurs as the result of composting. This can be of benefit in the event that the metals content of the raw sludge itself does not meet standards established by regulatory agencies for utilization of sewage sludge.

TABLE 1. SLUDGE AND COMPOST ANALYSIS FOR SELECTED CONSTITUENTS
(Dry Weight Basis - Milligrams/Kilogram)

	Pile A*		Pile B*	
Constituent	Sludge mg/kg	Screened compost mg/kg	Sludge mg/kg	Screened compost mg/kg
Total sulfide	121.8	0.5	192.7	0.5
Total phosphorus	3002.2	1010.7	2052.6	787.3
Total chloride	661.8	694.4	718.2	762.3
Total nitrogen	19350.0	8620.0	10710.0	6850.0
Cadmium	4.78	0.67	0.92	0.58
Copper	277.7	83.9	167.3	32.2
Chromium	28.6	17.0	33.4	10.0
Mercury	93.12	1.46	19.02	0.97
Nickel	22.6	25.2	34.8	19.2
Lead	408.0	118.1	274.2	64.2
Zinc	453.0	153.7	282.0	98.3
Iron	7550.0	4173.0	13708.0	3041.0
Arsenic	0.394	0.260	1.738	0.208
Manganese†	110.7	779.7	295.0	616.0
Potassium†	1015.0	1946.0	1725.0	1683.0
Calcium†	14429.0	23689.0	12986.0	18163.0
Magnesium†	2198.0	3602.0	4525.0	3066.0
Sodium†	234.9	698.0	373.9	274.9

*The sludge used in Pile A and that used in Pile B came from separate batches processed through the sewage treatment plant more than 6 months apart.
†Increases noted in some cases are due to the bark in the compost.

PREPARATIONS FOR COMPOSTING

Assembling the Tools

This chapter describes in detail the composting site and all other elements which it was necessary to bring together and put in readiness in order to undertake composting operations as currently conducted by the City of Bangor.

There have been significant improvements in the materials and equipment used and operational procedures during the first 12 months of composting. Other changes are currently being evaluated which it is hoped will further reduce the cost of composting.

This discussion, however, is limited generally to a description of the facility, equipment, materials and practices currently employed at Bangor. The chapter on Composting describes their actual use in the composting operation.

Site Selection and Preparation

The composting site selected by the City of Bangor is located about 3 miles from the sewage treatment plant. This temporary location was necessary because space available at the sewage treatment plant was not adequate.

In selecting the site for the composting operation, the city evaluated several possibilities on the basis of the following criteria: (1) accessibility; (2) proximity to residential, commercial and industrial areas; (3) distance from the treatment plant; (4) required area (1.7 acres); (5) availability of electrical power; and (6) ability to control surface water runoff.

The site ultimately chosen is located on an abandoned taxiway at Bangor International Airport (Figure 2).

Accessibility is provided by a paved road leading to the mixing area at the western end of the site. Sludge is normally delivered to the site via Union Street and Griffin Road. Because these roads serve residential, commercial and industrial areas, they are kept clear of snow during winter months. Thus the city does not have

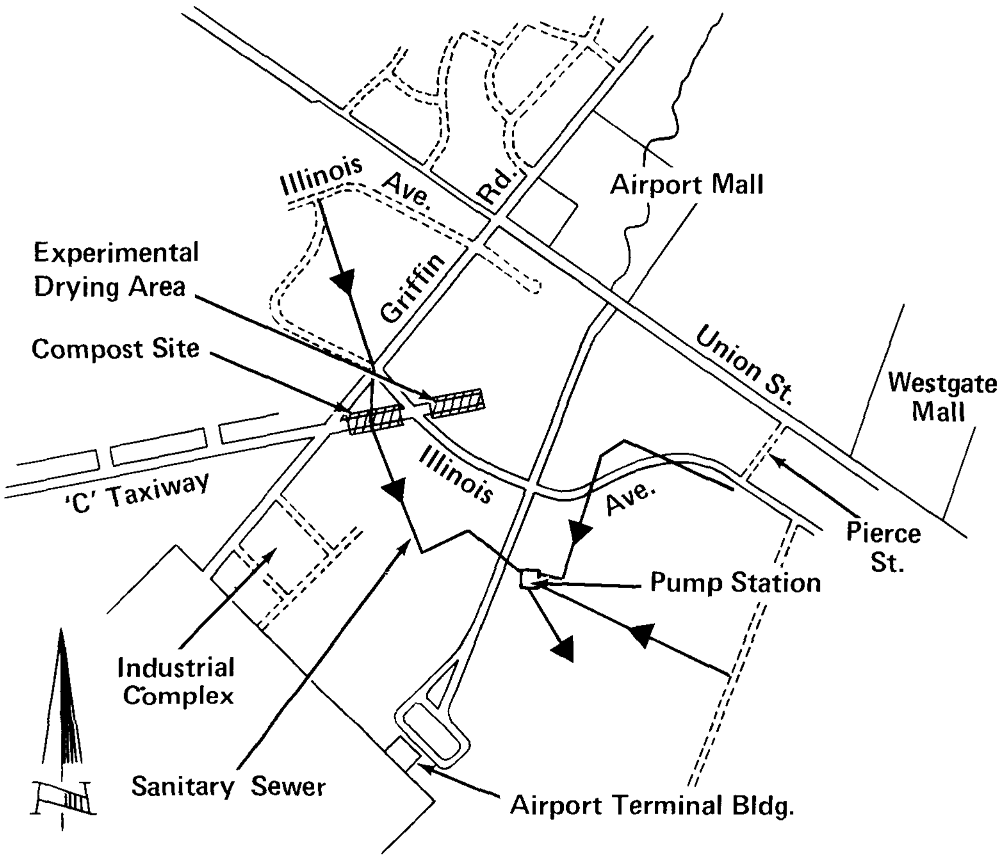

FIGURE 2. COMPOSTING SITE LOCATION

Shy of space at its sewage treatment plant site, Bangor had to find a separate site for composting. It needed about 1.7 acres to handle the volume of sludge produced. Other criteria were accessibility; location relative to residential, commercial and industrial areas; distance; availability of electrical power; and ability to control surface water runoff. The site chosen was an abandoned taxiway at Bangor International Airport, about 3 miles from the sewage treatment plant.

to make extra effort to provide access to the composting site during winter months.

The site is about 2,000 feet from residential, commercial and industrial areas. The compost operation, while in plain view of the public, is not located in anyone's "back yard."

The total area required for composting 3,000 cubic yards per year of dewatered sludge at 20 percent solids is about 1.7 acres. This area is divided into three sections: storage of bulking agents, 0.2 acres (3 sq. ft./annual cu. yd. of sludge); mixing and composting, 0.5 acres (7.7 sq. ft./annual cu. yd. of sludge); screening operations and screened and unscreened compost storage, 1.0 acre (1.5 sq. ft./annual cu. yd. of sludge). An additional 1.2 acres (19 sq. ft./annual cu. yd. of sludge) is used for experimentation with drying unscreened compost and reusing it directly as a bulking agent.

Electrical power was available within 500 feet of the composting site. This circumstance minimized efforts and expenditures required in obtaining electrical power to operate the aeration fans.

The ability to control surface water from the mixing and active composting site was perhaps the single most important factor in site selection for Bangor. There are two sources of water which must be controlled: runoff from precipitation, and condensation which forms in the aeration pipes leading from the piles to the blowers. Control of these sources is necessary because of the probability of their being contaminated by organic and inorganic chemicals and pathogenic organisms. Control of these waters is provided by a drainage ditch leading to the sanitary sewer line which transverses this site downslope from the mixing and active composting area.

Satisfaction of the factors listed provided the City of Bangor with a composting site requiring minimal preparation costs. Those costs were limited to providing electrical power, establishing the drainage collection ditch, and fencing the area. A detailed site plan was prepared that depicts the location of all facilities pertinent to the composting operation (Figure 3).

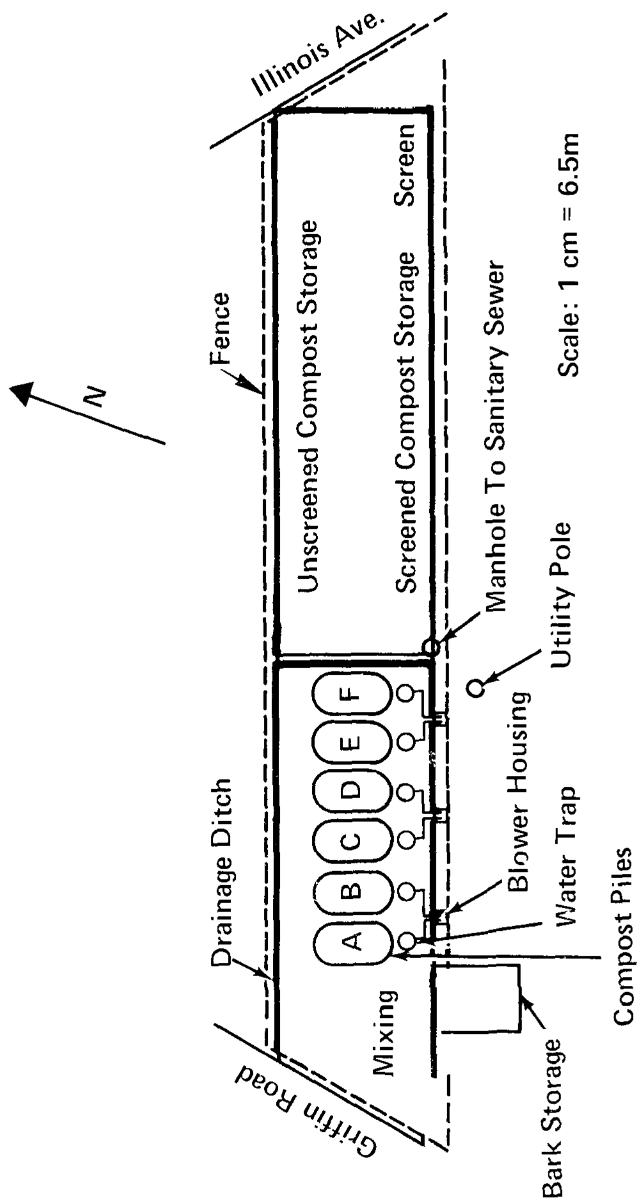

FIGURE 3. COMPOSTING SITE LAYOUT

The flow of materials as composting operations proceed is from left to right above. For obvious reasons, Bangor spotted its mixing area for sludge and bark closest to the delivery road (Griffin Road, at left) for materials, and set up its bark storage adjacent to both the mixing area and compost pile locations (A-F). Composted product is moved from piles to upper right area to await screening and storage at lower right, from where it is readily hauled away via Illinois Road at right. Drainage ditch (top and bottom left) was dug to collect surface water runoff; delivers it direct into previously existing sanitary sewer line (center).

Equipment and Materials

The equipment and materials used for composting are generally readily obtainable. Of the equipment and materials needed (Table 2), only major items will be elaborated upon here.

The city currently uses a front-end loader equipped with a 3-cubic yard bucket for mixing of bark and sludge and transporting bark and compost within the site as necessary. During the first 6 months of operation, loaders used were those already in the city's motor pool inventory. These loaders, with smaller buckets than the one now used, were found to be less efficient than a larger unit would be. As a result the city purchased the larger loader. This loader is used for other purposes also, and an hourly rental charge is assessed when it is used at the compost site.

The shredder/screener used for composting was purchased by the city's motor pool. Unlike the front end loader, this piece of equipment is used exclusively for the composting operation. The shredder portion of the screening device has been removed, however, and no shredding is done, as it is more economical to separate and recover as much of the bark as possible for reuse as bulking agent. The screen is a self-cleaning rotary screen, 3 feet in diameter and 6 feet long. The screen opening currently used is 1 inch. However ¼-inch and ½-inch opening replacement screens are available for recovering greater quantities of bulking materials.

The blowers used to provide aeration are rated at 335 cubic feet per minute when operating under 4 inches of water pressure. The on-off time of blowers is controlled by a timer with 2-minute intervals.

The bulking agent used by the City of Bangor is bark waste obtained from a pulp and paper facility of the Diamond International Corporation. The bark is provided to the city free of charge but is hauled 8 miles at city expense. The purpose of the bark is to provide voids for air movement and reduce moisture content so as to provide a favorable environment for biological activity.

TABLE 2. EQUIPMENT AND MATERIALS USED FOR COMPOST PILE OF 50 CUBIC YARDS SLUDGE AND 150 CUBIC YARDS BULKING AGENT*

Item	General specification	Purpose
Pipe	100 ft. of 4-in. diameter carbon steel pipe—80 ft. perforated	Aeration pipe
	2 30° 4-in. elbows per pile	Blower connections
	4-in. flexible plastic pipe	Connecting aeration pipe to blower and blower to deodorizing pile
Blower	115 AC, 335 CFM 4-in. pipe (Dayton Model 7C504 or similar)	Aeration fan
Oxygen analyzer	Portable 0 to 25% dry gas oxygen analyzer	Oxygen measurement
Temperature indicator and probe	Thermistor type with at least a 3-ft probe and scale from 0 to 100° C	Temperature measurement
Timer with tripper	2-min. intervals on or off	Control blower operation
Front-end loader	2.5 to 3.0 cu yd bucket†	All materials handling relative to composting including mixing of bulking agent and sludges
Screen	Self-cleaning rotary drum 3 ft diam x 6 ft long with ¼, ½, or 1 in. openings	Separating reusable bark from compost products
Bulking agent	Ability to reduce moisture content of mixed sludge and bulking agent to below 60 percent and provide adequate voids for air flow	Create optimal condition for aerobic composting

*38 cubic meters sludge and 115 cubic meters bulking agent.

†A larger bucket would be more cost effective if used only at the compost site or for composting and other low-density materials only. Bangor uses the loader for other types of operations and materials also.

Pile Aeration Equipment Setup

In the major remaining step prior to the mixing of bark and sludge, the compost pad was prepared. Pad preparation consists of connecting aeration pipe, water traps, blowers and deodorizing piles (Figure 4). The aeration pipe was a 4-inch diameter steel pipe with 1-inch holes at 1-foot intervals on opposite sides.

Two parallel 40-foot aeration lines made up from 7-foot lengths of pipe were placed on the compost pad (Figure 5). Short lengths of pipe facilitate pile take-down. The lengths of aeration pipe were connected with plastic connectors. The connectors were 10-inch lengths of plastic flexible tube. These were cut down one side to facilitate placement over the ends of the pipes being coupled together. Coffee cans were placed over the open ends of the aeration lines to keep out the sludge-bark mixture.

Flexible plastic pipe was used to connect the aeration pipe to the water trap and blower. In the early stages of the project a layer of unscreened compost was used on the pad both under and on the aeration lines. This measure was discontinued later. The aeration system was covered with a layer of unscreened compost to prevent the wetter, freshly mixed bark and sludge from plugging the aeration holes. The unscreened compost, while partially beneficial, did not completely prevent the material from entering the pipe and its use was discontinued because of the large quantities of fresh bark which it required.

A water trap was provided at each pile. The water trap is a 55-gallon steel drum equipped with an automatic draining device. All materials used in construction of the water traps were essentially scrap or used parts (Figure 6 and 7). The length of the drain tube must be slightly longer than the maximum head of water pulled by the blower, to prevent air from entering through the drain. For the blower used at Bangor, this length is 10 inches.

The quantity of water discharged from the water trap

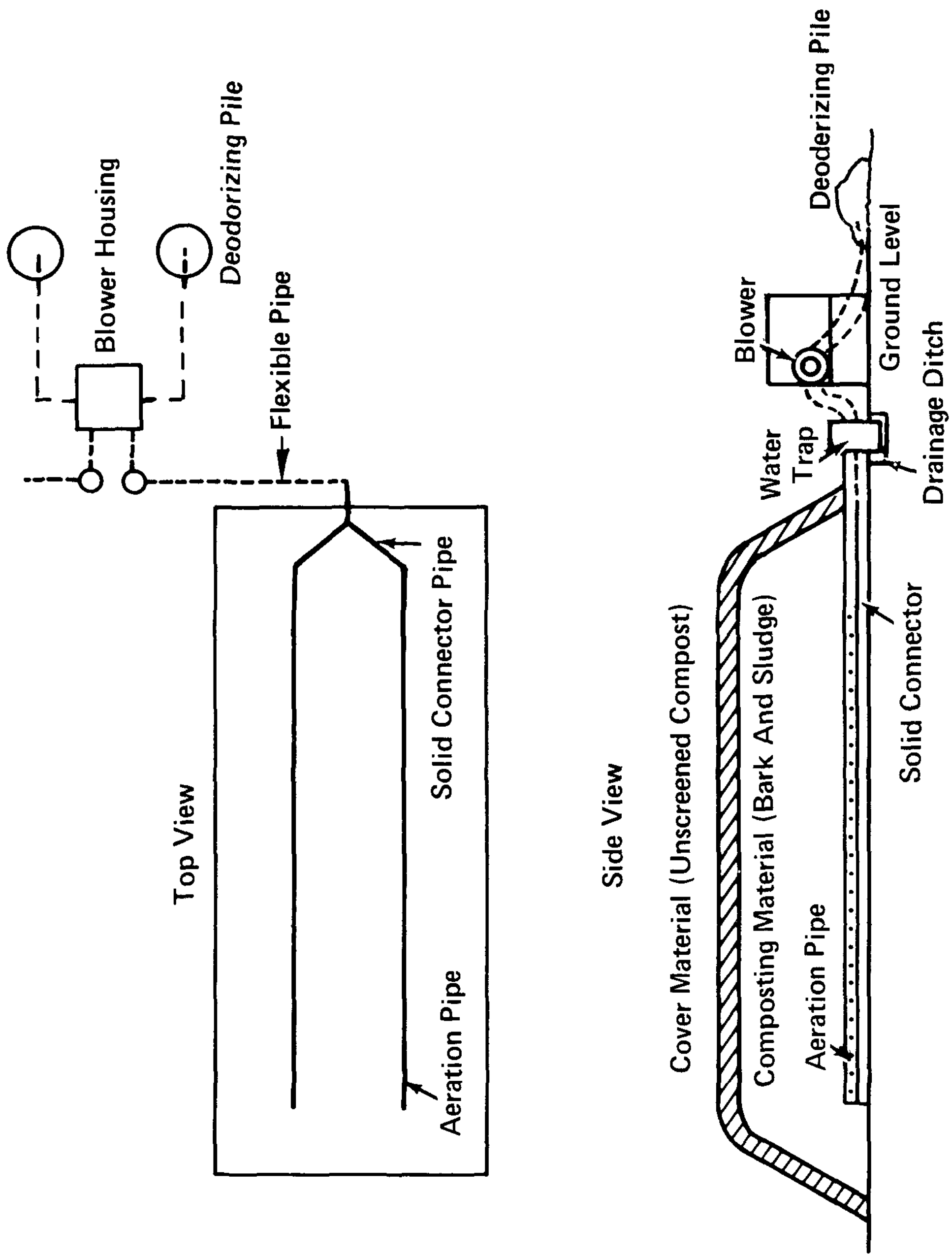

FIGURE 4. PLAN VIEWS OF COMPOSTING SYSTEM LAYOUT

Two aeration lines are laid parallel on the composting pad and linked by solid connector pipes to the water trap and blower before a pile is built. Once the pile of mixed bark and sludge is built, it is covered with a layer of unscreened compost for insulation so that outer edges of the composting mixture will reach the desired temperatures. Exhaust air from the pile is pulled through a separate pile of bark to scrub odors. The deodorizing pile was found to be unnecessary at Bangor in cool weather.

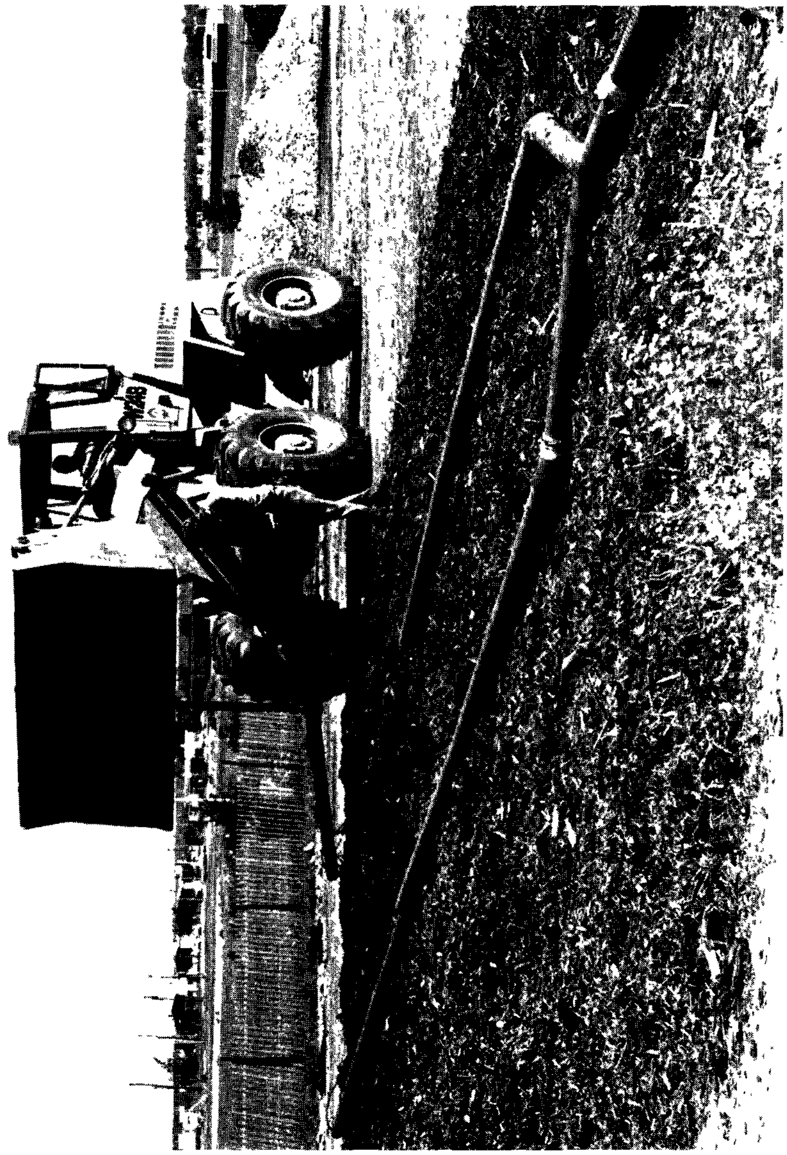

Figure 5. Assembling the Aeration Lines on the Compost Pad

Two parallel 40-foot aeration lines are made up on the pad from 7 ft lengths of 4 in. diam. perforated carbon steel pipe connected by 10-in. plastic connectors. (Short lengths of pipe facilitate pile takedown.) Flexible solid plastic pipe is used (right) to connect aeration lines to water trap and blower. In early stages of the project, when this photo was made, a layer of unscreened compost was used on the pad beneath aeration lines, in addition to a layer placed over them, to prevent plugging of lines by the sludge-bark mixture.

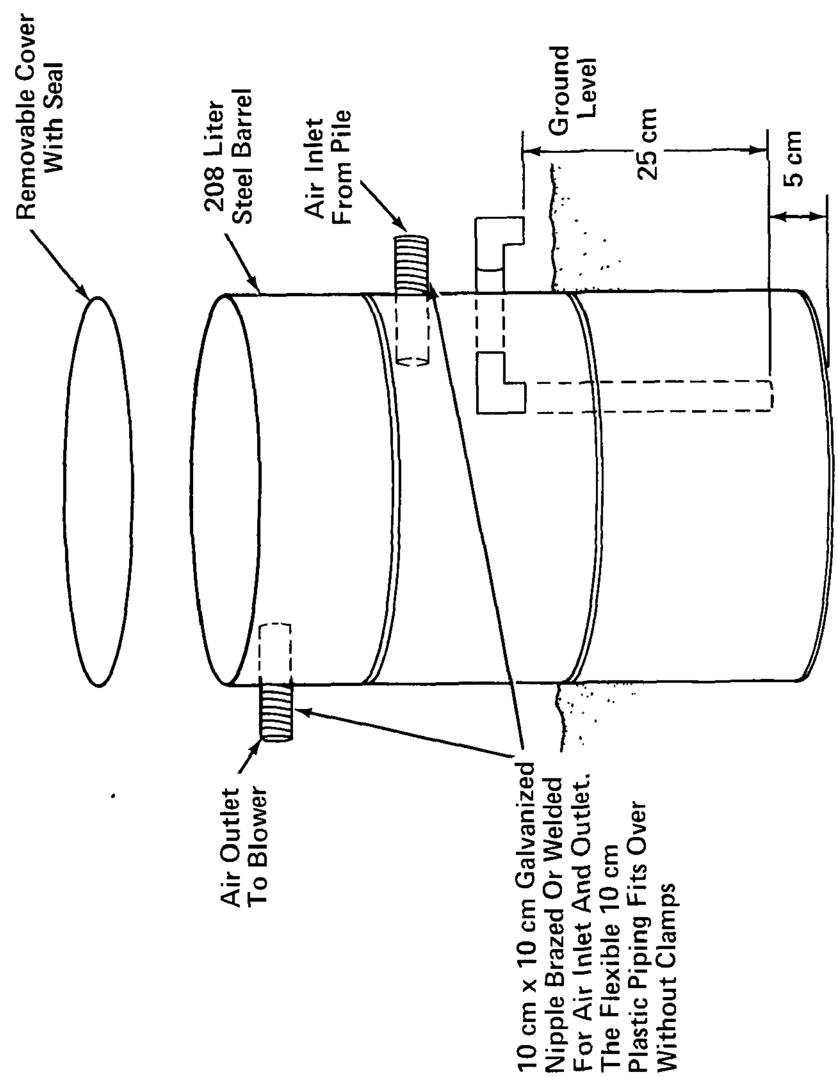

FIGURE 6. SELF-DRAINING WATER TRAP

The water trap is a 55-gallon steel drum equipped with an automatic draining device. The length of the drain tube must be slightly longer than the maximum head of water pulled by the blower, to prevent air from entering the drain. For the blower used at Bangor, this length is 10 inches. All materials used in construction of the traps were essentially scrap or used parts.

FIGURE 7. A WATER TRAP IN PLACE

The quantity of water discharged from the trap is affected by the length of flexible pipe from pile to trap, the temperature difference between ambient air and exhaust gas, and the moisture content of the exhaust gas. Placing water trap and blower as close as possible to the composting pile will minimize amount of condensate to be dealt with. Discharge air from the blower is still normally saturated; however, this causes no problem.

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Deodorizing Piles

Deodorizing piles were made with about 5 cubic yards of bark to scrub odors from the exhaust air. It was found that over time, the warm moist air caused settlement of the deodorizing pile, and this settling eventually restricted air flow. After this development was noted, the deodorizing piles were disconnected in September 1976. Because previous checking of exhaust air suggested that deodorizing piles were unnecessary, at least during cool weather, they were not replaced. The operation since that time has still not experienced any significant odor problems.

COMPOSTING

This chapter describes the composting process itself as carried out at Bangor, beginning with the mixing of the sewage sludge and bark and proceeding through construction and active biological "working" of the pile, on through pile take-down to storage with further "curing" of the product on the premises of the composting facility prior to ultimate disposition elsewhere.

The expected effect of cold temperatures in slowing down the biological activity, and measures developed to counter this effect, are discussed.

The step-by-step description of the composting process which follows, deals with the subject essentially from the standpoint of the managing of a single pile. However, at any given time at Bangor, at least three piles were composting.

This fact has practical, economic importance for an on-going operation: the sequential handling of multiple piles at different stages of maturity makes for economies of time and motion in terms of optimum use of labor and equipment.

Mixing

On normal mixing days approximately 150 cubic yards of bark and 50 cubic yards of sludge are combined. This ratio of 3 parts bulking agent to 1 part sludge by volume has been found by experience to result in adequate air movement within the pile. This ratio also normally results in an initial moisture content of not more than 60 percent, which is the maximum for a good composting operation.

The sludge was delivered to the site in either 5- or 10-cubic yard containers. Prior to receiving sludge at the site, the loader operator laid down a bed containing about 10 cubic yards of bark on the mixing area (separate from the compost pad). The sludge was dumped onto this bark bed (Figure 8).

The loader was then used to lift and dump the sludge and bark in a rolling motion (Figure 9). As the material was mixed, bark was added as necessary to achieve the desired bark-to-sludge ratio of 3:1 by volume. This general ratio was arrived at by the operator's knowing the number of cubic yards of sludge delivered (each truckload was either 5 or 10 cubic yards) and the number of loader buckets (each 3 cubic yards) of bark.

Building the Pile and Composting

As each batch was mixed, it was placed on the previously prepared composting pad (Figure 10). After all sludge had been delivered, mixed and placed on the compost pad, the pile was covered with a blanket of unscreened compost 1 foot thick. This blanket provided insulation so that the outer edges of the pile would reach the desired temperatures.

The blowers were then turned on and composting normally was conducted for 3 weeks. Measurements of temperature and oxygen were made 3 days per week.

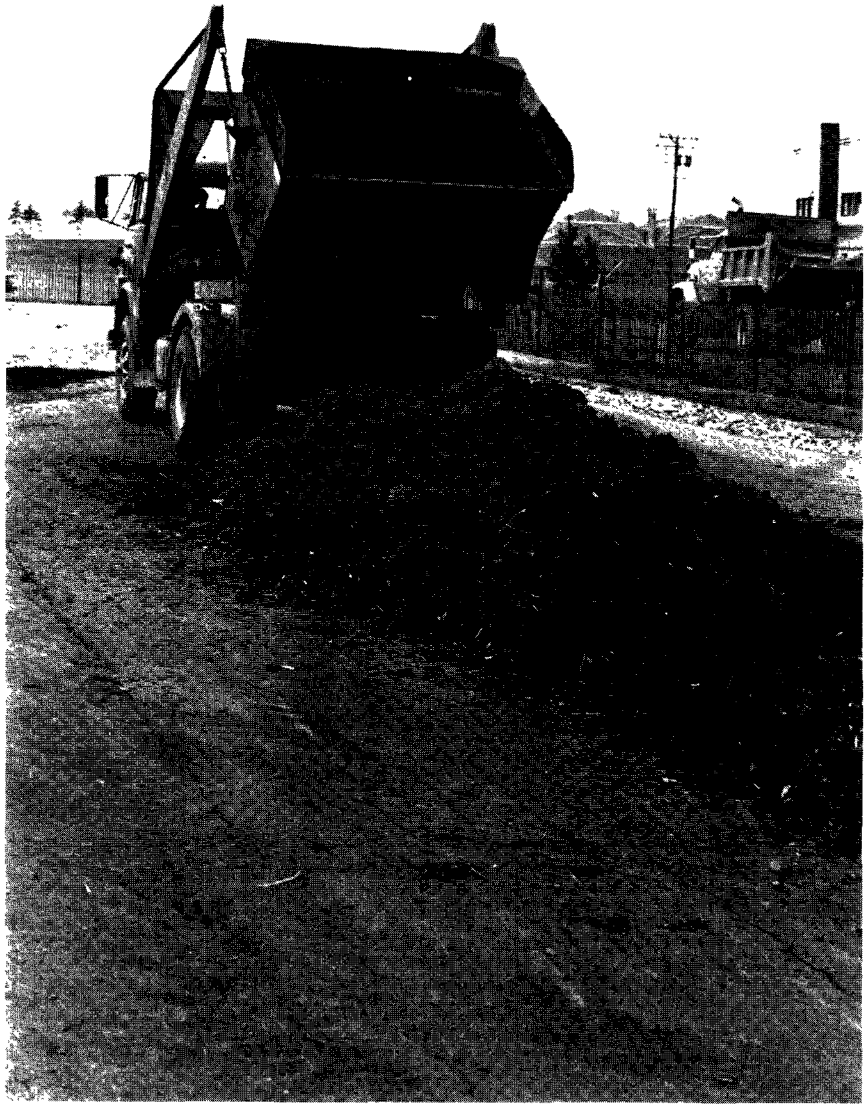

FIGURE 8. BED OF BARK IS LAID AND SLUDGE IS DUMPED ONTO IT

On normal mixing days at Bangor about 150 cu. yd. of bark and 50 cu. yd. of sludge are combined. These volumes make one pile. Sludge is delivered to the site in 5 cu. yd. or 10 cu. yd. containers. In the final step preliminary to mixing, shortly before the sludge arrives, the loader operator lays down a bed of about 10 cu. yd. of bark on the mixing area near the compost pad. The sludge is dumped onto this bark bed for mixing.

FIGURE 9. LOADER MIXES SLUDGE AND BARK AT MIXING AREA

The loader lifts and dumps sludge and bulking agent in a rolling motion to mix them. As more sludge arrives at the site and mixing proceeds, bark is added as necessary to achieve the desired bark-to-sludge ratio of 3:1 by volume. Operator achieves and maintains this general ratio by knowing the number of cubic yards of sludge delivered (each truckload is either 5 or 10 cu. yd.) and the number of loader buckets (each 3 cu. yd.) of bark. The 3:1 ratio has been found to result in adequate air movement within the composting pile; it also normally results in initial moisture content of not more than 60%—the maximum for a good composting operation.

FIGURE 10. SLUDGE-BARK MIXTURE IS PLACED ON PREVIOUSLY PREPARED COMPOSTING PAD

As each batch is mixed, the loader places it on the pad. After all sludge is delivered, mixed with bark and placed on the pad, the pile is covered with a blanket of unscreened compost 1 ft thick. This blanket provides insulation so that outer edges of the composting pile itself will reach desired temperatures. During winter months when ambient temperatures are very low, the cover thickness may need to be increased.

These data were used to determine the blower on-off time. (The chapter on monitoring and analysis presents data.)

A time-temperature combination in which temperatures in the pile stayed at 55 degrees Centigrade or higher for at least 2 days should be sufficient to kill most bacterial and viral pathogens.

Countering Cold Weather Effects

It was noted, predictably, that the time required for average pile temperatures to reach 55° C. was greater when ambient temperature were very low. It became obvious from the data that during winter months cold temperatures retard biological activity. The reason is that after mixing, the temperatures of the bark and sludge are very close to ambient. The initial low temperature of the compost material, as well as the colder air being used to aerate the piles, increases the time needed for the piles to achieve a given temperature. During winter months it has been found that operating the blower enough to maintain oxygen at a minimum of 5 percent resulted in cooling of the outer edges of the pile. During the winter of 1975-76 this problem was alleviated by increasing the thickness of the cover material from 1 foot to 2 feet.

Several alternatives to this procedure are being investigated. One is reversing air flow after internal pile temperatures (3 feet from the surface) have achieved 55° C. A variation on this would be to reverse the air flow and use the hot exhaust from an adjacent pile as input to the new pile so as to avoid cooling the center of the pile. Another alternative is to turn the blower completely off after internal pile temperatures have reached about 65° C.

A different approach embodies efforts to speed up the initial achievement of 55° C. throughout the pile. One such method being tried involves taking some of the hot compost from a pile being taken down and placing the hot material within the pile being constructed, to generate initial heat. Use of the combination of reverse flow and hot exhaust air from an adjoining pile to furnish initial heat would provide heat more uniformly throughout a new pile.

With the latter method there is some possibility that obnoxious odors could be produced, but based on current experience, this is not expected to occur. In the use of this method, however, care must be taken that the exhaust air from the adjoining pile carries adequate oxygen to the next pile to keep it aerobic.

It should be noted that the composting operation has significantly improved since the project was initiated. The improvements were made for both technical and economic benefit.

Pile Takedown

The composting pile was taken down at the end of 3 weeks under normal operating conditions if temperatures in the pile had been at 55° C. or higher for at least 2 days. The unscreened compost was placed in stockpiles to await screening. Stockpiling of the compost also allows additional time for further composting action to continue.

Pile takedown was normally accomplished while another pile was being built. This was possible at Bangor because mixing time per load of sludge was about 15 minutes less than the time required to deliver a load to the site. While waiting for sludge delivery, the loader was used to take down a pile. Chains attached to the aeration pipe were connected to the loader, which pulled the pipe from the composted material (Figure 11). After switching to 7-foot links of aeration pipe rather than the original 21-foot links, this was no longer needed. After the first section of aeration pipe was removed, the loader transferred the unscreened compost to the storage area.

Screening

A rotary drum screen is used by the city to recover bark from the compost (Figure 12). The city obtained its

FIGURE 11. REMOVAL OF AERATION PIPE PRECEDES PILE TAKEDOWN

The composting pile was taken down at the end of 3 weeks under normal operating conditions if temperatures in the pile had been at 55° C or above for at least 2 days. Chain attached to a hole cut in end of aeration pipe was connected to front end loader, which pulled the pipe from the pile. After the first section of aeration pipe was removed, the loader transferred the compost to storage area. Pile takedown was normally accomplished at Bangor while a new pile was being built. By using shorter lengths of pipe under the current operation, a chain is no longer needed to remove the pipe.

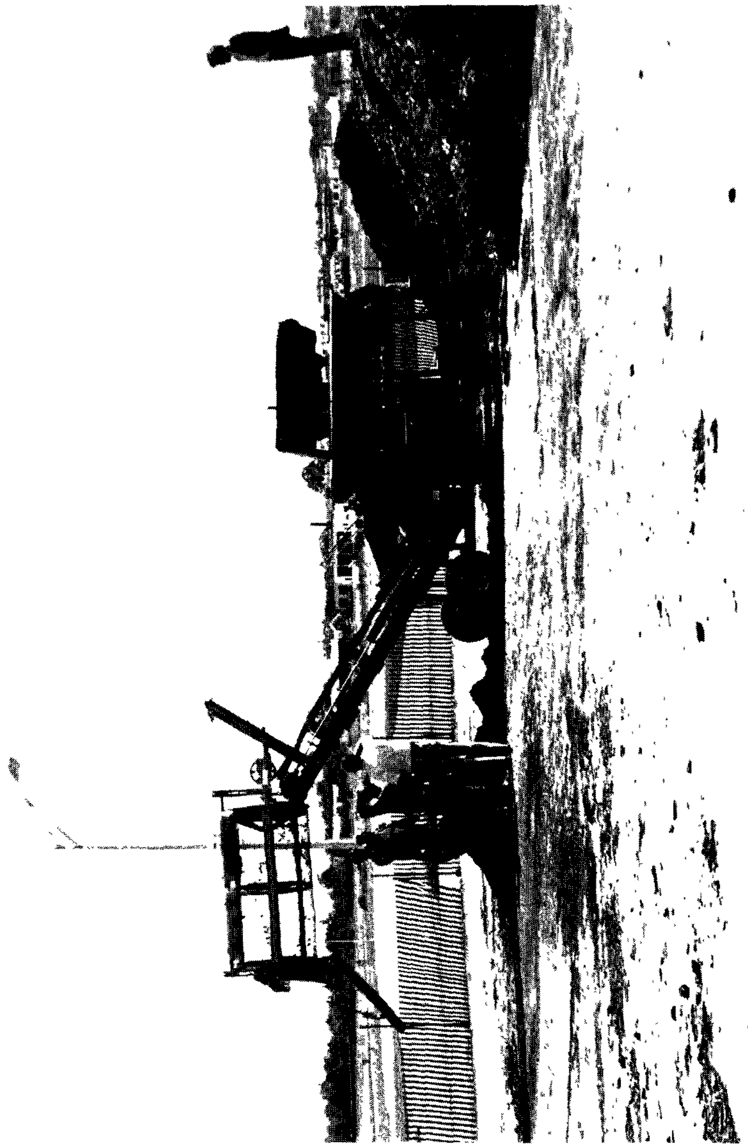

FIGURE 12. ROTARY SCREEN IS USED TO SEPARATE BARK FROM COMPOST

A self-cleaning rotary drum screen 3 ft in diam. x 6 ft long is used at Bangor to recover bark and at the same time produce a more manageable compost product with wider potential usefulness because of the improved carbon-to-nitrogen ratio and greater fineness of the material ultimately to be disposed. The size of screen openings used depends on the moisture content of the composted material. With 50% or greater moisture, a 1-in. screen opening was necessary at Bangor. This yielded a compost suitable for most uses where the material would be incorporated into existing soil. The hopper on the right is filled with unscreened compost by a front-end loader. A belt conveyer moves the material up to the rotating drum. The finer compost falls through the screen while the bark comes out the end of the drum.

rotary screen in August 1976. Thus, little material had been screened by the time information was assembled for this report.

The size of screen opening used depended on the moisture content of the composted material. For Bangor it has been found that with a moisture content of 50 percent or greater, a 1-inch screen opening is necessary. If drying of the composted material were done, then a ½-inch screen would function adequately, and this would make possible the recovery of a greater quantity of bark. The economics of greater bark recovery versus drying has not been fully evaluated. The compost product produced by the 1-inch screen was, however, suitable for most uses where the material would be incorporated into existing soil. Regardless of the screen size used, the screened compost has a high carbon-to-nitrogen ratio and for many potential uses, additional nitrogen would need to be applied to the soil.

Additional marketability and/or market value of finer material could offset the added cost of drying. Based on current available data, the cost of screening with 1-inch openings without drying was $2.10 per cubic yard of sludge processed.

MONITORING AND ANALYSIS

Monitoring is basic to the success of the entire composting process.

Once a pile is built for processing, conversion of the sludge to compost depends totally on biological activity within the pile. This activity must proceed under aerobic conditions (with adequate air supply) to ensure destruction of pathogenic organisms and to eliminate odors. Thus it is crucial to know at any given time how the process is proceeding.

Two tests—both fortunately relatively simple to perform—give the basic clues necessary. These are tests to determine temperatures and oxygen content within the pile. Data must be obtained to demonstrate pathogen destruction. Monitoring of other factors is also essential. But pile temperatures and oxygen must be read most often.

Because of the nature of the raw materials involved in the process, variations in conditions will always occur from pile to pile, and within piles. Temperature of the ambient air is a dominant factor. Pile density varied as a result of variable moisture content of the bark and sludge used at Bangor. Thus the air flow varied from pile to pile.

The potential for such changes on the scene of operations gives added emphasis to the need for good monitoring. Adjustments in operating conditions are often necessary after a pile is built and the composting process is under way. Keeping tab on temperatures and oxygen in the pile enables the operator to make adjustments which can markedly improve the efficiency of the operation en route.

Permanent improvements in the process have been made at Bangor based on analysis of the data, and other potential improvements are being evaluated there.

Since monitoring is the key, the efficiency of the monitoring procedure itself and its cost become important.

This chapter describes the monitoring conducted at Bangor; changes made with experience to cut monitoring time and cost; the data collected; and how these data were analyzed and the results put to use to improve the overall composting process.

For the Record: The Obvious

Knowledge of the nature and composition of the sludge to be handled was a prerequisite for the entire project (Table 1).

For completeness of records for future reference as well as for current use, the following information was recorded at the outset for each pile: (1) type of bulking material used (bark and/or unscreened compost), (2) mixing ratio, and (3) ambient air temperature.

Pile Temperature and Oxygen

Pile temperature and oxygen data provided the handle for "management" of the composting operation. They were used directly to control the blower operation— to regulate blower on-off time to achieve thermophillic aerobic composting.

At the onset of the project, temperature and oxygen measurements were made at 16 locations throughout each pile 5 days per week (Figure 13). This proved to be very time-consuming because it required about 1 hour per day per pile, and since there were three piles composting at one time, monitoring took about 3 hours per day or 15 hours per week.

At an average labor rate of $4.00 per hour, monitoring thus was costing about $80 per pile for a pile containing 50 cubic yards of sludge. This translated to about $1.60 for each cubic yard of sludge composted. After the first 3 or 4 months it was decided that, for temperature measurements, reading 3 days per week at the 16 locations would be sufficient. Monitoring costs, however, were still excessive, and the data were again examined to see if further reduction could be made.

It was determined that the lowest temperatures were occurring at the ends of the piles. It was also noted that temperature variation within any plane surface was minimal. Selected data from three locations each in the east and west end planes of two compost piles over a 10-day period provided an example of uniformity of temperature within a plane (Table 3). Therefore it was decided that a total of four readings, one location representing each end and side of the pile would be sufficient for temperature measurements (Figure 14). The depth at which temperatures are read is equal to the cover thickness. For a 1-foot cover, readings are taken at 1-foot depth.

Oxygen data, however, do not always display the same degree of consistency. Oxygen readings of 3 and 15 percent have been obtained within 6 inches laterally at the same depth. This is believed to be due to nonhomogeneity of air flow within the compost pile, the result of different densities of material from one location to another. Furthermore, the sampling tip of the oxygen

FIGURE 13. PILE MONITORING LOCATIONS USED IN EARLY PHASE OF PROJECT

Initially temperature and oxygen readings were made at Bangor 5 days per week at 16 locations throughout each compost pile as shown here. This procedure required about 1 hour per day per pile. Since there were 3 piles composting at one time, monitoring thus took some 3 hours per day or 15 hours per week. Later, the frequency was reduced to 3 days per week at the same number of locations, but monitoring costs were still excessive and a further examination of the data showed that the number of monitoring locations could be reduced.

Table 3. Temperature Data from Two Planes of the Compost Piles over a Nine-Day Period

Pile 5

Plane	Location	Day 2	Day 3	Day 4	Day 5	Day 9
Temperature °C						
1	11	48	56	71	70	74
	12	56	67	72	74	76
	13	78	50	77	78	72
2	14	59	61	60	60	67
	15	62	62	65	67	75
	16	66	68	67	67	77

Pile 13

Plane	Location	Day 2	Day 3	Day 7	Day 9
					Temperature °C
1	11	11	11	54	62
	12	11	12	58	60
	13	22	22	54	58
2	14	11	11	50	54
	15	12	12	51	55
	16	12	12	51	54

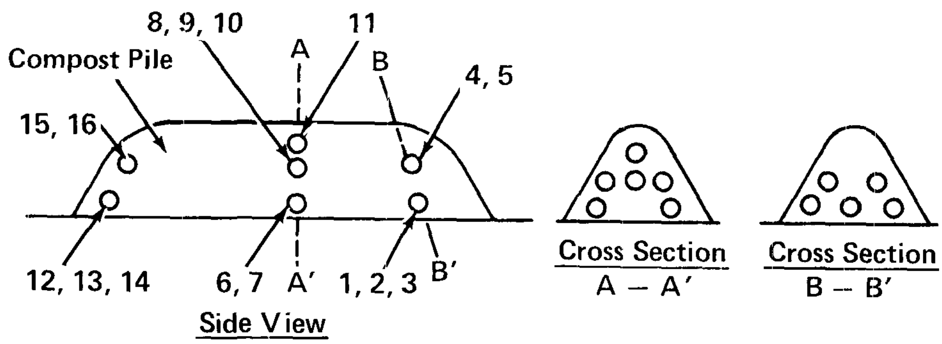

Figure 14. Current Pile Monitoring Locations

Once it was determined that the lowest temperatures within compost piles occurred at the ends and that temperature variations within any plane were minimal, it was decided that monitoring locations at each end and side of a pile would provide an adequate temperature check. Only the four locations shown are now used routinely for both temperature and oxygen monitoring. However, when low oxygen readings are obtained, the operator must test additional locations to establish the real pattern. New operators should check more than the minimum numbers of locations for both temperature and oxygen for some months until they get a feel for the process.

probe is only 2 inches long; thus it is entirely possible that low oxygen readings obtained adjacent to high oxygen readings could be due to placing the probe into a "glob" of sludge. It was, however, decided that the four locations for temperature measurement would be used for oxygen measurement as well. Then when low oxygen readings (less than 5 percent O_2) are obtained, the operator must take additional oxygen readings in different locations to determine if the low reading is true of the pile in general or only the specific location.

The reduction in number of sampling points to four has reduced monitoring cost from $1.60 to $0.24 per cubic yard ($2.10 to $0.32 per cubic meter) of sludge and has proved to be satisfactory for both temperature and oxygen.

More recently it has been discovered that temperature increased with increasing depth in the pile. This point is still under investigation. Aspects of the response to such conditions are discussed in the Composting chapter and briefly summarized along with the presentation of the actual data in the section which follows this one.

Temperature Relationships Observed

The time required for average pile temperatures to reach 55° C. increased during colder weather (Table 4). As noted earlier, the effect of cold in winter was dual: the colder air used to aerate the piles retarded biological activity. The initial low temperature of the compost mixture itself was also an inhibiting factor. For example, ambient temperature was minus 4° C. when pile 15 was being mixed. Pile temperatures recorded immediately afterwards were between 1° and 2° C.

There was considerable variability in the maximum temperature of the coolest location from pile to pile. It is presumed that this was the result of poor mixing, improper blower operation, and related factors. Variability was greater during subzero temperatures, suggesting that cold weather accentuates this problem. (As already observed, running the blower enough to maintain at least 5 percent oxygen in the pile during

Table 4. Number of Days Required for Average Pile Temperature to Reach 55°C for Ambient Temperatures Above and Below Freezing

Pile	Average ambient temperature °C	Days to 55° C
1	17	2
2	17	2
3	9	2
4	17	4
5	12	6
6	10	3
13	-10	8
14	-17	11
15	-4	18
16	-5	14
17	-5	9
18	0	7

Table 5. Coliform and Salmonella in Samples of Sludge and Compost

Pile		Total coliform	Fecal coliform	Salmonella
		MPN*	MPN*	MPN*
31	Sludge	430	430	.3
	Compost	15	3 6	.3
33	Sludge	240 x 10^6	2400	.3
	Compost	.36	.3	.3
34	Sludge	2400	.3	.3
	Compost	240	.3	.3
35	Sludge	240	.91	.3
	Compost	.3	.3	.3
38	Sludge	93	.3	.3
	Compost	430	.3	.3

*MPN = Most Probable Number of organisms/gram winter months resulted in cooling of the outer edges of the pile.) Temperature variability decreases as temperatures in the pile approach 70° C (Table 3).

Various measures used or being studied to reduce the time required to achieve 55° C. throughout the pile during winter operations include increasing the thickness of the unscreened compost cover; reversing the air flow after temperatures 3 feet inside the pile have reached 55° C.; reversing the flow but using hot exhaust from another pile as input to the new pile; cutting off the blower entirely after internal temperatures reach about 65° C.; placing inside the pile being constructed some hot compost from a pile being taken down. These alternatives are covered more fully in the chapter on Composting.

Bacterial Destruction

Many piles have been sampled for bacteria at the end of their composting to verify that adequate pathogen reduction has been achieved.

Bacterial analysis of sludge and compost was limited to total coliform, fecal coliform and salmonella. Data were obtained on selected samples. During the first 6 months, the data collected were largely from compost samples only. Later, data were obtained from both sludge and composted sludge to show the degree of pathogen reduction achieved (Table 5). As is apparent from these data, Bangor's sewage sludge does not have high bacterial counts.

This is because the sludge is limed to a pH of 11 or 12 prior to vacuum filtration. Fecal coliform does, however, show a further sharp decrease upon composting. Liming to pH 11 or 12 was standard operating procedure at the sewage treatment plant to prevent odors during vacuum filtration. As previously discussed, sludge flowed from the primary settling tanks to the sludge thickeners where it had a residence time of up to 7 days. This resulted in anaerobic conditions and the production of odors which were quite noticeable during vacuum filtration.

Fecal coliform counts are made on most completed piles. For piles analyzed from pile 25 through pile 38, it appears that fecal coliform counts are lower and more consistent from pile 33 on (Table 6). Other data which could possibly explain this change were examined in an effort to account for it. The only factor which showed a relationship was the number of days required for average pile temperatures to reach 55° C. This time was 4 days for piles 25, 31 and 32. Beginning with pile 33 the time needed to reach 55° C. was about 3 days.

Basically the improvement can only be attributed to general changes which had been made in the blower operation, aeration system and deodorizing piles. In the most recent compost piles, internal temperatures of 78° to 80° C. have been attained routinely. This condition has apparently resulted in establishing a natural air flow induced by hot air escaping through the top of the pile and drawing fresh air into the pile from the sides. As a result, oxygen has been maintained at 10 percent or higher even with the blowers off in some piles.

Oxygen Content in Relation to Odor Control

As previously mentioned, oxygen content is related to odor production. Because odor cannot be quantified, however, it is not possible to determine a precise

TABLE 6. FECAL COLIFORM FOR SELECTED COMPOST SAMPLES

Pile	Fecal coliform
	MPN*
25	160
31	3.6
32	39
33	.3
34	.3
35	.3
36	.3
38	.3

*MPN = Most Probable Number of organisms/gram relationship between oxygen content and level or strength of obnoxious odors.

Strong obnoxious odors have never been experienced during the composting operation itself at Bangor regardless of the compost pile oxygen content. Piles which have had less than 5 percent oxygen during the composting period have produced strong obnoxious odors only while the pile was being taken down. When oxygen content had been between 5 and 10 percent during the composting period, some odor occurred during pile takedown. In both sets of circumstances, however, the odor dissipated within the boundaries of the compost site. The strong objectionable odors have occurred only three times. These occurrences all resulted from either mixing with bulking materials which were too wet or mixing during heavy rains. These conditions resulted in compaction of the compost piles, restricting air flow to the point where continuous blower operation was required to maintain 2 to 3 percent oxygen. Temperatures in such piles were generally in the range of 50° to 70° C.

In the case of the separate bark piles used for deodorizing, the unnoticed compaction occurring over time resulted in restriction of air flow such that maintaining oxygen above 10 percent in the compost piles became increasingly difficult. This development was discovered in early September 1976, and corrected by replacing all deodorizing piles. As mentioned previously, 55° C. can now be achieved in the composting piles in 1 to 3 days, and these piles will apparently become self-aerating after 10 to 15 days.

Where oxygen was maintained at or above 10 percent for at least the last few days, the odor during pile takedown has generally been that of wet bark.

Overview

The scope of the project involved data collection for compost management and pathogen destruction. The readings taken have been useful for these purposes. They do not provide sufficient data yet for statistical analysis. Nevertheless, several relationships of practical significance to the composting operation have been established.

ECONOMIC ANALYSIS

The economic analysis presented here is based on carefully documented expenditures for the period of August 1975 through November 1976. Expenditures during this period have been placed in two categories: normal operating costs and development costs. The latter include costs incurred for special testing for pathogens and trying different materials or techniques. This analysis is of the normal operating costs incurred with currently used equipment, materials and techniques. Alternative equipment, materials and techniques, which may further lower composting costs, are still being examined. The current cost for Bangor is $11.41 per cubic yard ($14.91 per cubic meter) of sludge based on costs for September through November 1976.

This cost is pertinent to conditions at Bangor, Maine, for composting 3,000 cubic yards (2,300 cubic meters) of raw vacuum-filtered sewage sludge of 20 percent average solids content per year. Labor and equipment hours are discussed as an aid to other municipalities in estimating their costs. In development of a cost figure for composting, a number of assumptions had to be made for one factor—screening—because screening had taken place for only 6 weeks prior to the assembling of data for this report. Costs of screening are based on one 4-hour test. More complete data are being obtained.

Another area where it was necessary to make assumptions was in taking credit for reclaimed bulking agent (bark) and compost product after screening. These assumptions are discussed in greater detail later.

Costs for normal composting operations are broken down into three areas: capital costs, startup costs and operating costs. Each is discussed separately.

CAPITAL COSTS

Capital cost items have been broken down into two areas: major items and minor items. The major items—land, front-end loader, and screen— are discussed here. The minor items—aeration pipe, blowers, and monitoring equipment—have been classified as startup costs and are discussed in the next section. This separation has been made here for clarity because of the budgeting method used at the Bangor composting operation. That method does not separate capital and operating costs, but carries everything as operating costs. It does, however, use one device (rental) for charging off major capital items and a different device for charging off the minor capital items—writing off the entire cost of the latter in their first year.

Using its airport property for the composting site, the city of course did not incur major capital expenses for land acquisition and preparation. If land and preparation costs had, for example, been $40,000 for a 2-acre site, these costs would have been $1.31 per cubic yard or $6.88 per dry ton of sludge, and the cost of the process would have been increased by identical amounts. Actual capital costs were incurred for the loader and screen. The cost of each, however, is passed on to the user (the composting operation) as a rental fee (Table 7).

Startup Costs

Startup cost items are items which have a projected life of at least 5 years but cost less than $2,000 (Table 8). These costs were borne by the city in their entirety in the first year of composting. Replacement and upkeep cost is estimated to be approximately $400 per year.

If startup costs had been capitalized over 5 years (the anticipated replacement time) at 7.5 percent, the annual cost would be $1,300 capital costs plus about $400 maintenance costs. As a result of their not being capitalized, the first-year cost of sludge processing runs about $1.30 per cubic yard higher than the annual cost for the following years.

Operating Costs

As mentioned, all capital costs associated with

TABLE 7. CAPITAL COSTS FOR COMPOSTING CITY OF BANGOR

Item	Description	Cost	
		Purchase Price	Annual Cost*
Land acquisition and preparation	Area required is approximately 21 sq. ft. per annual cubic yard of sludge at 20% solids. Bangor used a section of abandoned taxiway at Bangor International Airport	No costs were incurred	
Front-end loader	Case W-24 front end loader purchased by city's motor pool. First priority is composting. This equipment rented to using department at $10/hour to cover capital and operating costs	$40,000	$5,702
Screen	A rotary screen purchased by motor pool—rental charge to composting (sole user) is currently estimated at $8.00/hour to cover capital and operating expenses.	$15,000	$2,136

*Annual cost computed on basis of 7.5% interest over 10 years

composting appear as operating costs. The cost information presented here consists of actual costs, initial and present and estimated costs based on optimum operating efficiency.

The costs of composting decreased steadily over time (Table 9). These costs include all process steps. Costs went down from approximately $27 per cubic yard of sludge to $10 per cubic yard as the project progressed.

Increased quantities of sludge composted and improved operating efficiencies brought about this improvement. During the initial 12-month period, only 46 percent of sludge produced was composted, and many piles were built containing less than 25 cubic yards of sludge. All bulking agent used during this period was fresh bark except for a few "experimental" piles for which unscreened compost was used as the bulking agent.

Table 8. Startup Costs for Composting City of Bangor

Item	Description	Cost*
Drainage	750 linear feet of open drain were constructed to collect all water emanating from mixing and active compost areas	$ 750
Electrical hookup	300 ft of electrical wire and a utility pole	$ 400
Aeration pipe	500 ft of 4 in. standard wall steel pipe for aeration	$1,360
Temperature indicator and probe	0 to 100° C	$ 700
Oxygen analyzer and probe	0 to 25% oxygen	$1,000
Plastic pipe	250 ft of 4 in. flexible pipe	$ 250
Blowers	Three 115 V AC, 335 CFM (Dayton model #7C504 or similar)	$ 230
Building materials	Housing for blowers	$ 750
	TOTAL†	$5,440

*Cost includes installation where appropriate.

†If these costs had been amortized for 5 years at 7.5 percent interest, the cost per year would have been about $1,300. Upkeep and replacement cost of the above items for the ensuing year was estimated at $400.

Table 9. Actual Costs of Composting Sewage Sludge at Different Stages of the Program

Period	Sludge processed cu. yd.	Totals costs* $/ cu. yd. of sludge	Unit costs/cu. yd. of sludge Operating	Bulking agent	Screening
Aug 75 - Aug 76	1,384	$27.06	$13.37	$9.00	$4.69
Sept 76	229	$12.97	$ 7.87	$3.00	$2.10
Oct 76	207	$12.25	$ 7.15	$3.00	$2.10
Nov 76	241	$ 9.21	$ 4.11	$3.00	$2.10
Sept - Nov 76 Avg.		$11.41	$ 6.31	$3.00	$2.10

*Includes actual capital costs as shown in Table 7, startup costs as shown in Table 8, and operating costs.

Based on these experimental piles and improved operator efficiency, the city, in August 1976, modified the composting operation as follows: (1) all bark would be used as bulking agent twice prior to screening, thus reducing the cost of bulking agent by 50 percent; (2) all sludge produced would be composted, thus all piles contain about 50 cubic yards of sludge each; (3) the building of one compost pile and the taking down of another compost pile would be done on the same day as much as possible.

The net effect of these changes has been reduction of bulking agent costs by 66 percent and of operating costs by 40 percent, based on average costs for the initial and current periods of operation.

Based on the assumption that the procedures as modified will be implemented at 100 percent efficiency, the future annual cost for composting at Bangor is projected to be $28,655, or $9.55 per cubic yard or $50 per dry ton ($12.49 per cubic meter or $65 per dry metric ton) of dewatered sludge (Table 10).

Net Cost

The composting costs just presented do not take into account any credits for reclaimed bulking material after screening or for the value of the compost product. When these credits are taken, final cost figures will be lower. An accurate net cost cannot be developed at this time because the balance of materials after composting and screening is not known. The value of the compost product has been set at $3.00 per cubic yard ($4.00 per cubic meter) as a replacement for loam in city projects. The net costs presented here are based on the following: (1) the volume of material is reduced by 10 percent during the composting process (assumed), and further reduction may occur in the stockpile; (2) the ratio of reclaimed bulking agent to compost product using a 1-inch screen is 1:3.7 (estimated on the basis of 4 hours of testing); (3) all bulking agent is used twice prior to screening.

Under those conditions Bangor should produce 4,050

TABLE 10. ANTICIPATED OPERATING COSTS FOR COMPOSTING DURING 1977 AT BANGOR

Operation	Hours required	Costs in dollars Labor	Equipment	Total
Mixing and	600	2,526	6,000	8,526
stockpiling[1]	280	1,000		1,000
Monitoring[2]	312	1,248		1,248
Screening[3]	300	2,400	3,900	6,300
Bulking agent[4]	870	3,480	5,655	9,135
Miscellaneous[5]				2,446
Cost totals		$10,654	$15,555	$28,655

[1]Labor required in setting up the aeration system for each pile.

[2]Monitoring requires approximately 1 hour per day and is currently done 3 days per week.

[3]These are estimates based on limited practice. The screen has a rated capacity of 35 cu. yd./hour. It was operated at 20 to 30 cu. yd./hour for a 4-hour period. Projections here are based on a rate of 20 cu. yd./hour.

[4]Transportation costs for obtaining 4,500 cubic yards of bark for bulking agent using city-owned and -operated dump truck with a 6-8 cubic yard capacity.

[5]Repair or replacement of blowers, aeration pipe, etc. and overhead of $1,240.

cubic yards (3,100 cubic meters) of unscreened compost per year. After screening, this will be split into 862 cubic yards (660 cubic meters) of reclaimed bulking agent valued at $1.00 per cubic yard ($1.30 per cubic meter) and 3,188 cubic yards (2,440 cubic meters) of compost product valued at $3.00 per cubic yard ($4.00 per cubic meter). Total credits at the end of the year are then $10,426 or $3.47 per cubic yard ($4.54 per cubic meter) of sludge.

If the assumptions listed are accurate, then based on current operating costs, Bangor's net cost for composting was $6.08 per cubic yard or $31.82 per dry ton ($7.95 per cubic meter or $41.62 per dry metric ton) of sludge.

part II pointers for other municipalities

SITE, EQUIPMENT, AND MATERIALS REQUIREMENTS

This chapter and the next constitute an attempt to distill what has been learned of the process of converting sewage sludge to compost, as now routinely conducted full scale at Bangor, Maine, and to condense the essence of the Bangor experience into a sequence of practical pointers that can be generally applied elsewhere. The step-by-step discussion is meant to provide guidance for other municipalities interested in establishing a similar process. For convenience, the subject is sorted by chapters into the preparatory and actual operating stages.

On some points it was not possible to generalize, and therefore specific methods, criteria, or equipment used at Bangor are given. This does not imply that other methods, criteria, or equipment will not work as well. But this approach does serve as a reasonable starting point. As was found at Bangor, periodic modifications should be made to achieve greater efficiency in composting.

It must be kept in mind that composting is an alternative method of stabilization prior to utilization. At present it appears that the method can be competitive on the basis of cost with other options. Composting should not necessarily be viewed, however, as a break-even or profit-making operation.

Site Requirements

LOCATION. The composting operation should be located at the sewage treatment plant if at all possible. This will eliminate sludge transportation costs and reduce costs associated with the collection and treatment of condensate and surface water runoff at the site.

SIZE. The size of the site will depend on the quantity of sludge produced and how fast the compost product is removed for utilization. Each compost pile will occupy an area approximately 20 x 60 ft Bangor has found that an additional minimum of 10 ft between piles or other obstructions is necessary for loader maneuvering during pile construction and takedown. Therefore, approximately 2,000 sq. ft. are required per pile for 21 days. In addition, a storage area is needed for bulking material, unscreened compost, and screend compost. Sufficient area should be available to store 3 months' bulking agent and up to 6 months' accumulation of unscreened and screened compost. Additional area is required for mixing. This can be as little as 2,000 sq. ft. if mixing is done in batches of up to 10 cu. yd. of sludge. The area required for screening is minimal, being only that necessary for the screen and for maneuvering of the loader used to fill the screen hopper. Bangor uses about 1,000 sq. ft. for screening operations for the entire composting of 3,000 cu. yd. of sludge per year. Bangor has a composting site of 65,000 sq. ft.

CONTROL OF DRAINAGE WATER. Surface water runoff from the mixing and active composting pile areas must be collected because of possible contamination with pathogenic organisms and organic and inorganic pollutants. The quantities of surface water requiring collection and treatment will depend on local climatic conditions and size of affected area. In addition to surface water, condensate must be collected and treated. Condensate forms in the aeration system from the compost pile to the deodorizing pile. The condensate may also contain some leachate which can enter the aeration system. Quantities of condensate up to 20 gallons per day per pile have been obtained.

If the site is at the treatment plant or near a sewer line, both sources of water can easily be returned to the treatment plant. At remote compost locations, it may be necessary to collect such water in a holding pond.

SITE SURFACE. The surface of the compost site should be of an all-weather type. Asphalt or concrete surfaces are preferred; however, hard-packed gravel will suffice. Where a gravel pad is used, it may be necessary to provide an underdrain to prevent ground-water contamination. Furthermore, a gravel surface will most likely require periodic maintenance.

OTHER SITE CONSIDERATIONS. Other factors which must be considered at any site, but especially sites located away from the sewage treatment plant, include the following: availability of electrical power, availability of sanitary facilities, and ability to secure emergency services.

Equipment and Materials

Equipment and materials listed here are sufficient for composting up to 75 cu. yd. (60 cu. m.) of 20 percent solids sewage sludge per day on a 5-day/week basis. Where sludge production exceeds this quantity, other system designs currently being developed by USDA at Beltsville, Maryland, should be used for economy.

ESSENTIALS REGARDLESS OF NUMBER OF PILES. The equipment itemized here is required for composting regardless of the number of piles constructed per week.

FRONT-END LOADER. This loader must be of sufficient capacity to construct a pile 8 to 10 ft high and about 20 ft wide at the base without running upon the pile. Running upon the pile would compact the pile to the extent that adequate aeration cannot be obtained. The materials handled, bulking agent and sludges, have densities of 1,000 to 1,700 lbs./cu. yd.

The bucket size should match the loader's capacity. Bangor used a Case W24B articulating loader equipped with a 3-cu. yd. bucket. This machine was capable of handling compost with a 5-cu. yd. bucket. Obviously the larger bucket would reduce the time required to move material from one location to another. Bangor's particular circumstances were such that this reduction in time was without economic benefit. Also, aside from the composting operation, the loader was used to load sand onto trucks periodically. The sand which would fill the larger bucket would be too heavy for the loader equipped with the larger bucket.

OXYGEN ANALYZER AND PROBE. The oxygen analyzer should be a portable dry gas analyzer with a 0 to 25% percent oxygen range. The probe, 5 ft in length, should be made of durable material such as stainless steel. Inlet holes about 1/16 inch in diameter should be located about 2 inches back from a pointed tip. Plastic tubing can be used to connect the probe to the analyzer. A small hand vacuum pump is required to draw air into the analyzer.

TEMPERATURE INDICATOR AND PROBE. There are two types of temperature measuring equipment which can be used. Both should have a range of 0 to 100° C. A portable battery-operated temperature indicator with a thermistor probe provides a single piece of equipment which can be used for all required temperature measurements. The probe length should be at least 3 feet; a 5 foot probe length is preferred.

Dial-type thermometers can also be used. A probe length of 3 feet is recommended to allow for taking readings at varying depths. One dial-type thermometer or one portable thermistor temperature measuring device is sufficient for any number of composting piles.

SCREEN. The screen is used to remove bulking material from the composted material. This recovers bulking agent which can be reused, and produces a finer compost product. Where the bulking agent is very fine, screening may not be necessary.

ESSENTIALS FOR ONE PILE. The equipment and materials described next are necessary for the composting of one pile of sludge and bulking material containing about 50 cu. yd. of sludge and 100 to 150 cu. yd. of bulking agent.

Pipe—4-in. steel pipe in 7 or 10 ft lengths; 80 ft must be perforated (two 35- to 40-ft aeration lines are required). Perforations should be 1 in. in diameter every 1 ft on opposite sides of the pipes. An additional 10 to 20 ft of nonperforated steel pipe, 2 elbows, 1 wye and several 10 in. lengths of plastic 4 in. diameter flexible tube slit down one side are required to complete the aeration system hookup. The elbows and wye should be such that the parallel aeration lines are 7 to 8 ft apart.

Flexible Pipe—4-in. flexible plastic pipe has worked well in making connections between aeration pipe, water traps, blowers and deodorizing piles. The length will depend on distance to the blower, etc., but should be minimized.

Blowers—The blowers used by Bangor are rated at 335 CFM under 4 in. static pressure (Dayton model 7C504 or similar). Each blower is powered by a 115 V AC, 1/3 HP motor.

Timer—A timer with 2-minute intervals provides satisfactory control of blower operations.

Shelter—A small accessory building to house blowers, timers and electrical connections has been found beneficial at Bangor to shelter the equipment.

Water Traps—A water trap for each compost pile is necessary to collect condensate in such a manner that the blower does not have to draw against a head of water.

Miscellaneous Items—Duct tape, caulking compound, and hose clamps as needed to seal blower and aeration pipe connections.

Bulking Agent—Bark waste from a pulp and paper plant is used by Bangor. Many materials which can absorb moisture and provide voids for air movement would make suitable bulking agents. For bark waste a mixing ratio of 3 parts bark to 1 part sludge by volume is required if the bark is at 60 percent moisture. The mixing ratio can be decreased if the bark is drier. For other materials the mixing ratio will have to be determined.

SETTING UP AND OPERATING

In preparation for composting, adequate planning must be given to pad layout and equipment setup to minimize land requirements and travel time. Figures 3 and 4 show the general site layout and compost pile design used at Bangor. The compost pile design will be similar for any community using this system. However, even here some variation is possible as needed to fit local conditions.

A description of the permanent and nonpermanent equipment setup for an individual compost pile follows.

The Aeration System and Accessories

AERATION PIPE. The pipe is laid on the ground surface in two parallel 35- to 40-ft lines. A bark pad under the compost pile as well as the layer of coarse bark on top of the aeration system are no longer considered necessary in Bangor.

Other than steel pipe can be used for aeration, such as plastic drain pipe. Where a community is only evaluating the process, the plastic pipe is recommended because of lower initial cost.

A more permanent aeration system providing greater economy can be obtained by use of a trench into which the aeration pipe is laid (Figure 15). The aeration pipe is connected by solid pipes to the water trap.

WATER TRAP. The water trap should be regarded as a permanent installation. As the hot moist air leaves the pile, water begins to condense in the portion of aeration pipe exposed to ambient temperatures. The quantity of condensate produced will depend chiefly on ambient temperatures and length of aeration piping exposed. Under variable conditions at Bangor the condensate has been found to vary from 6 to 20 gals. per day per pile. The amount can be minimized by keeping the length of pipes from the compost pile to the water trap as short as possible and by wrapping all exposed pipes with insulation.

BLOWER. The location of the blower is critical in areas where freezing temperatures occur. Bangor has a blower located about 2 ft above and within 5 ft laterally of the water traps (Figure 4). This location is necessary

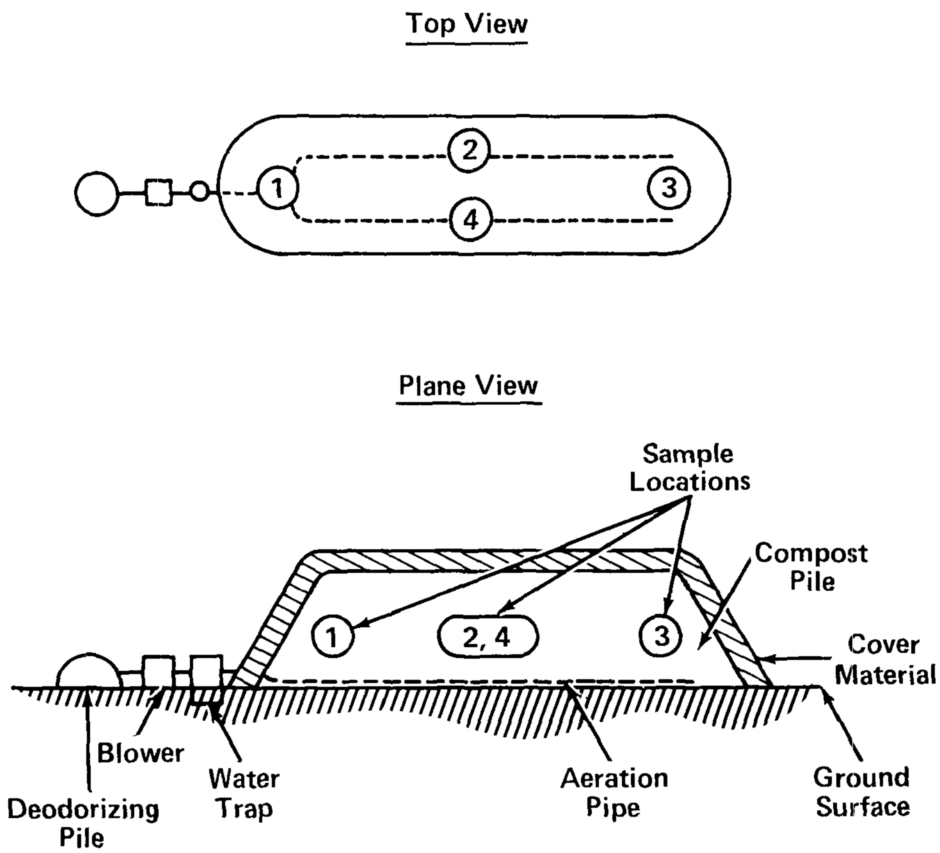

FIGURE 15. CONCRETE TRENCH AERATION SYSTEM

When a municipality is committed to the compost process, a more permanent aeration system providing greater economy than the surface pad arrangement is obtained with use of a trench into which the aeration pipe can be laid below ground level. Concrete is advised for the permanent trench lining.

to prevent entry of condensate into the blower which could then freeze during periods when the blower is off. This problem occurred during the winter of 1975-76, causing several blower motors to burn out. A small building is provided at Bangor to house the blowers as well as all electrical connections.

At present it is not known whether this arrangement will eliminate the problem. Other solutions include placing a small drain hole in the bottom of the blower housing to prevent a buildup of condensate, or wrapping the blower housing with insulating tape.

SCRUBBER PILE. Exhaust air from the blower is passed through a scrubber pile constructed of about 5 cu. yd. of bulking agent to remove odors which may be present. Moisture in the exhaust air will eventually cause the scrubber pile to compact and restrict air flow. Based on experience at Bangor, it is recommended that scrubber piles be replaced every 2 months.

OPERATING: FROM PILE CONSTRUCTION TO STORAGE

Sludge quantities and time in which deliveries are made will vary depending on site location and dewatering equipment capabilities. However, all sludge should be mixed and made into a pile on the day of delivery so as to minimize any fly or odor problems. Beginning shortly before the first load is to arrive, the following sequence (based on delivery of sludge in 10 cu. yd. loads) is performed for each pile in carrying out the actual process of converting sludge to compost.

Step 1—Mixing

The loader operator spreads 10 to 15 cu. yd. of bulking agent in a 6 to 8 in. layer onto which sludge is dumped (Figure 8). The loader then begins rolling the material over with the bucket (Figure 9). Bulking material is periodically added to achieve the desired mixing ratio. Mixing will take about 30 min. for a batch consisting of 10 cu. yd. of sludge and 30 cu. yd. of bulking agent.

Step 2—Building

When the material in Step 1 is thoroughly mixed (determined visually), it is ready to be placed on the aeration pipe. Starting at the blower end of the pipe, the loader operator places the material on the aeration system (Figure 10). Steps 1 and 2 are repeated until all sludge has been mixed and placed on the aeration pipe. The pile should then be about 8 ft high at the center, 20 ft wide at the base and 50 ft long at the base.

Step 3—Cover Material

A cover of unscreened compost should be applied. Bulking agent can be used as the cover material for initial piles; however, unscreened compost is the most economical cover material. The cover provides needed insulation to ensure that temperatures of all new material in the pile reach at least 55° C. Cover material thickness, therefore, depends on ambient temperatures. During periods when ambient is below 0° C., 2 ft of cover is required. For a pile of the dimensions listed, each 1 ft of cover requires about 50 cu. yd. of cover material. In placing both material for composting and cover, care should be taken not to run the loader's tires onto the pile.

Step 4—Blower Operation

This is one of the two most critical factors (proper mixing is the other), as blower operation (time on-off) affects both temperature and oxygen content of a composting pile. In areas where extremely cold winter temperatures are experienced, blower operation is extremely critical.

The blower on-off cycle time depends upon the velocity of air movement, distance from the outer edge of the pile to the aeration pipe, and the oxygen consumption rates. For composting to be aerobic, some oxygen must be present throughout the pile. It is desirable to have at least 5 percent oxygen. When ambient air temperatures are very low, the provision of sufficient air flow to maintain oxygen at 5 percent near the aeration pipes may result in excessive cooling of the outer edges of the pile such that 55° C. is not achieved at this time.

Based on one year's experience at Bangor, it has been found that pile temperature data provide the best information for blower control, and can be augmented by oxygen data where necessary. When the ambient temperature is above 10° C., adequate aeration and temperature buildup have been attained with the blowers timed for 4 min. on and 8 min. off. This time cycle seldom requires changing during warm weather. During cooler times of the year when ambient temperatures are less than 10° C., two problems develop which require careful management to overcome. These are the cited delayed increases in pile temperature and excessive cooling.

Delayed temperature increase results when the sludge mixture cools during mixing to less than 4° C. At such temperatures biological activity is greatly reduced and thus little heat is generated. Once the pile temperature reaches about 10° C., the increase in temperature proceeds normally. At Bangor, piles have taken from 5 to 15 days to reach 10° C. This time lag can be overcome by using hot unscreened compost as bulking agent and/or "seeding" a pile with hot unscreened compost as it is being built. The latter method consists simply of placing a few cubic yards of hot unscreened compost within a pile being built and, once it is built, covering it with hot unscreened compost. The blower should be left off or set for 4 min. on, 26 min. off, until pile temperatures reach 10° C.

The second problem, excessive cooling, can be avoided by increasing the thickness of the cover material. A 2-ft cover works well most of the time. This may need to be increased to 3 ft during extremely cold weather.

At present, no better guidance can be given. However, it is worthy of note that after composting more than 2,000 cu. yd. of sludge in 45 piles, Bangor has had only two piles which were failures. Both of these occurred under "experimental" conditions and were predicted to fail after the first few days. No serious odor problems developed as a result of these failures.

Step 5—Monitoring

Monitoring of the compost process for temperature and oxygen is required to ensure that adequate temperatures are attained in all portions of the pile.

It is suggested that eight locations per pile be monitored for both temperature and oxygen for a least the first 6 months. Based on experience at Bangor, the monitoring locations shown in Figure 14 are recommended with measurements taken just beneath the cover and at depth of 3 ft. While this monitoring program is more rigorous than that currently used at Bangor, it is neccessary initially in order for the compost operation personnel to develop a thorough understanding of how the process changes in relation to pile conditions, weather and other factors.

After the first 6 months, most operators should be able to obtain adequate control using only the shallow locations for routine measurement and using the deeper locations or other locations only for troubleshooting as needed. Moreover, as the operator gains experience he will find that oxygen measurements are valuable only as a diagnostic measurement in troubleshooting problem piles.

In use of the temperature and oxygen measuring equipment, careful attention must be given to carrying out the manufacturers' recommended procedures for calibration prior to each day's use.

Step 6—Stockpiling

The composting process will take 15 to 21 days depending on pile characteristics and climatic conditions. At the end of the composting period the pile is removed from the compost pad and placed in storage to await further processing if necessary. Stockpiles should be made as high as possible to conserve space. The transfer consists simply of using the loader to move the composted material from the compost pad to the stockpile.

The composted material should be cured in the stockpile for at least 30 days. If the nature of the bulking agent is such that screening is required, the compost should stay in storage for about 6 months to allow the material to dry out for more efficient screening. If space is not available, an area will need to be provided for drying the compost sufficiently to be screened. The upper limit of moisture will depend on the bulking agent and the screen being used.

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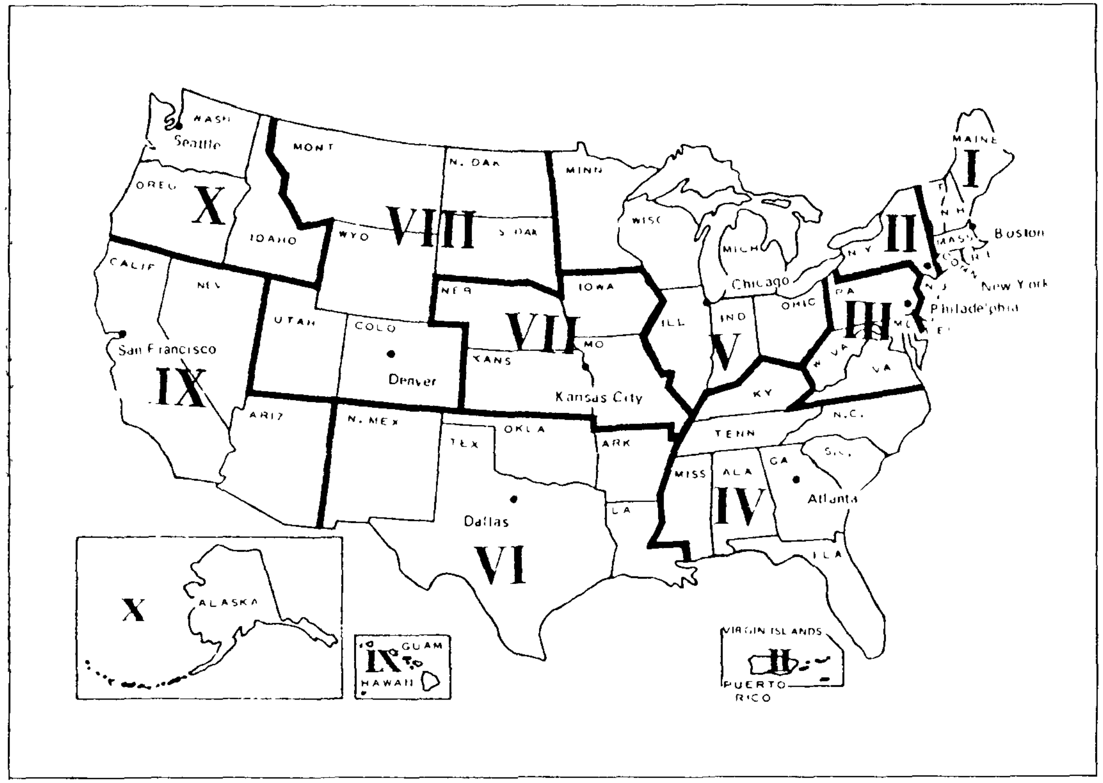

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