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Municipal Wastewater Sludges: Solids Generation and Pathogen Reduction

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MUNICIPAL WASTEWATER SLUDGES:

SOLIDS GENERATION
and
PATHOGEN REDUCTION

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PREFACE

The residuals which remain after the treatment of municipal wastewater may be only a small fraction of the wastewater volume, but they can be a significant fraction of the treatment difficulty and cost. These residual mixtures of solids and liquids are often referred to as sewage sludge. Their management has always been a challenge for operators and engineers, but recent regulations in both sludge and solid waste management have increased the need to examine technologies available for controlling biological pathogens in sludge. This document was prepared as part of an investigation into sludge quantities and pathogen reduction. It has been written as an introduction and reference for operators, municipal officials, engineers and regulators as they assess their sludge management options.

The authors are indebted to many throughout the State of Kentucky for their input and suggestions during the preparation of this report. In particular, they would like to thank those operators at the 268 Kentucky wastewater treatment plants and facilities throughout the United States who contributed their time and expertise to our survey of their sludge generation and management.

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1. INTRODUCTION

When municipal wastewater is treated, constituents of the wastewater are modified and concentrated. The residual mixture of solids and liquid, or sludge, is a complex and challenging waste stream. It will contain substances which have an offensive character, it can decompose, it may contain pathogenic organisms and pollutants, and it is present in significant volumes (Metcalf and Eddy, 1992). Wastewater sludges do, however, possess many characteristics which may be useful for amending soil or providing energy. Proper management of sewage sludge requires minimizing negative impacts of sludge on the environment and risks to the health or well-being of populations in a cost-effective manner. In the United States, new regulations for sewage sludge management have increased attention on the technologies which are available for reducing the pathogen content of sludges. Efficient selection and application of these technologies requires both an appreciation for the properties of sludge, and an understanding of the principles behind the processes. This report will try to summarize the quantity of sewage sludge which is generated and analyze some of the options which are available for achieving pathogen reduction. It is based on a review of pertinent literature and discussions with municipal wastewater treatment plant personnel throughout the United States. The authors hope that it will provide a useful introduction to evaluating sludge generation and pathogen reduction.

2. SEWAGE SLUDGE CHARACTERISTICS

2.1. Sludge Composition

Sewage sludge quantity and quality will reflect the wastewater which was treated and the treatment process employed. Wastewater composition can be somewhat variable, but it represents the nature of the waste sources and collection system. Although most of wastewater is just water, it is usually the other constituents which are of interest with respect to both treatment and residuals management.

Wastewater composition can be generalized by classifying many of the constituents into groups based on their biodegradability and size. For example, biochemical oxygen demand (BOD) reflects, to a large part, the quantity of organic matter in the wastewater which is biodegradable under specific conditions. Total suspended solids (TSS) are those solids large enough to be retained on a filter of a specific size. Both of these are heterogenous groups of different wastewater constituents which share these properties. Domestic wastewaters often demonstrate a similarity in the concentrations of these group parameters. Wastewater is also analyzed for the specific constituents, particularly those for which health risks or treatment problems have been identified. The concentrations of these can be much more variable, reflecting sporadic residential use (e.g., lawn care chemicals), commercial, and industrial wastes in the wastewater.

Treatment of municipal wastewater uses a combination of physical, biological and chemical processes. Primary treatment removes wastewater suspended solids through sedimentation. These solids are both organic and inorganic. Secondary treatment processes usually convert soluble and colloidal organic matter to suspended solids through biological activity. These solids can then also be removed through sedimentation. This biological conversion occurs through both microorganism formation and growth and adsorption onto the biological solids. As a result, solids resulting from secondary treatment usually contain a higher organic content.

A portion of the organic matter in sewage sludge is composed of microorganisms such as bacteria, viruses, protozoans, and helminths. Although many of these organisms do not pose a health hazard and are very short-lived, some can be human pathogens. Most of the inorganic constituents of sludges are naturally occurring minerals and precipitates, but they may also be pollutants which pose a risk to human health if improperly managed. Although they may only be a small portion of the total sludge quantity, pathogens and pollutants must be understood and controlled during sludge management.

2.2. Sludge Quantity

Any attempt to evaluate the management of wastewater residuals requires an understanding of the sludge quantity. For currently operating facilities, this may only necessitate an analysis of existing sludge generation. For facility planning or facilities anticipating changes, sludge quantity prediction may be required. Predicting quantities requires relationships between dry solids quantity and sludge quantity. A dry solid is the residue which remains after all of the moisture is removed from a sludge. The dry solid is an artificial quantity with respect to sludge handling because sludge is never completely dry during normal processing, but it is a useful basis for comparing sludge production. The water content of sludges is important to determining the volume or weight of sludge, but it is highly dependent on the sludge handling and processing. In contrast, the quantity of dry solids from wastewater treatment should be relatively conservative during any thickening or dewatering processes. In Figure 1, the relationship between dry solid weight and the weight of sludge at different solids contents is shown. Sludge volume

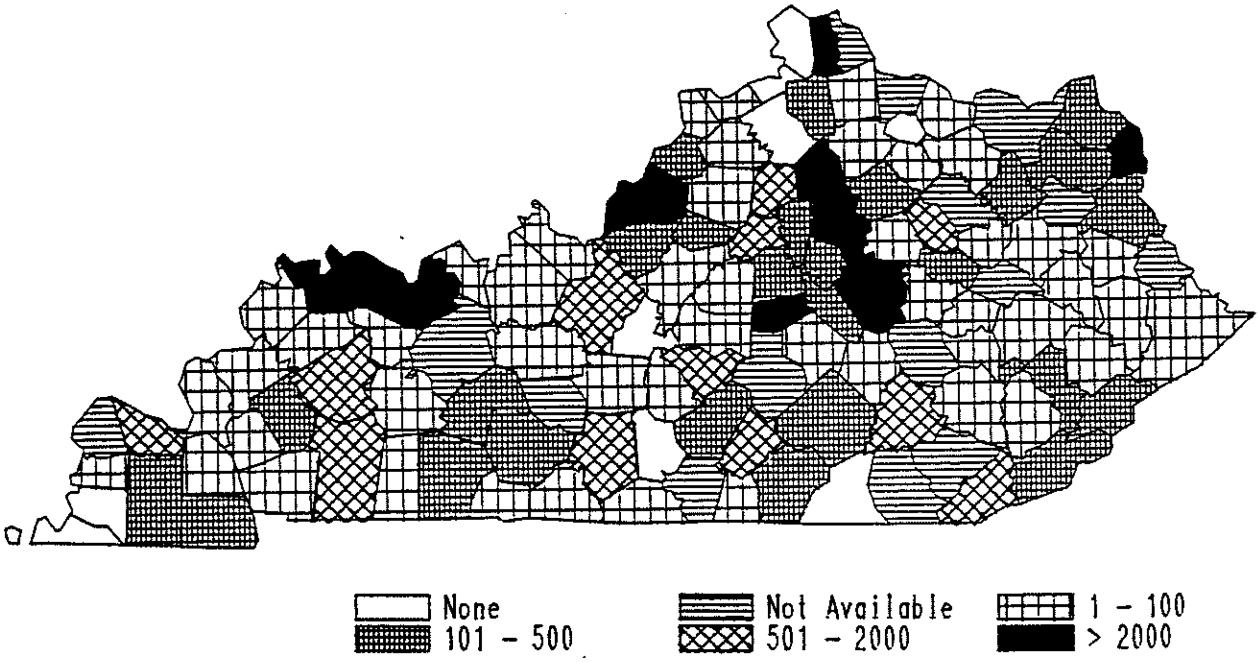


Figure 2. Sludge removed from Kentucky wastewater treatment plants by county. All quantities are in dry tons of sludge solids per year.

relationships will be similar to the weight relationships shown in Figure 1. This relationship can become more complex at high solids contents if the sludge solids are much denser than water or if air filled voids constitute a significant portion of the volume.

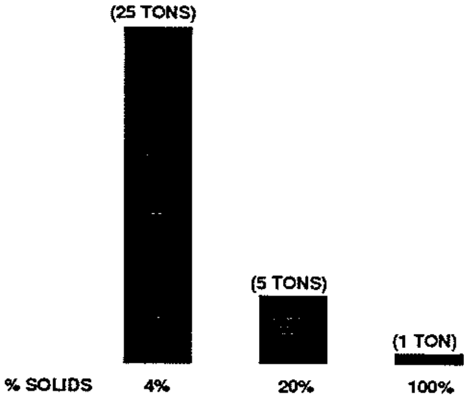


Figure 1. The weight of one ton of dry sludge solids is compared to the weight of a corresponding sludge quantity at 4% and 20% solids.

To determine the quantity of solids generated in Kentucky wastewater treatment plants and their distribution throughout the state, a database was developed through a mail survey and follow-up communication with all municipal wastewater treatment plants in Kentucky (KPDES permit holders). Parts of the survey will be summarized in this document, and the complete database is available from the authors.

In 1993, more than 60,000 tons of dry sludge solids were removed from municipal wastewater treatment plants in Kentucky. Figure 2 illustrates the distribution of solids on a county basis, results which are presented in Appendix A. Not surprisingly, the largest quantities of sludge are in those areas of the state with the highest population.

The quantity of sewage sludge which has been removed from different wastewater treatment plants in the state can be shown, as expected, to increase with increasing size of the treatment plant. For example, in Figure 3 the relationship between solids quantities and wastewater flow is shown. The considerable range in solids quantity at a flow rate is thought to reflect variations in treatment methods, operation, wastewater characteristics, and difficulties in assigning an accurate annual sludge removal at some of the facilities.

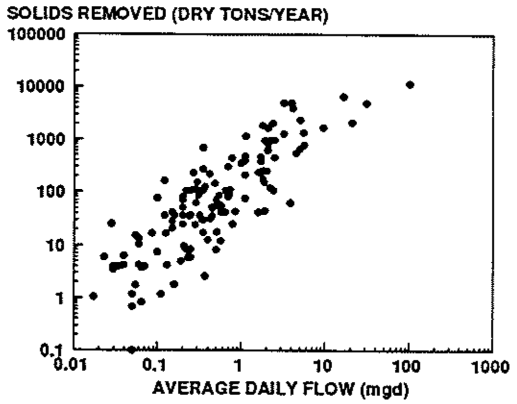


Figure 3. Wastewater sludge solids removed from Kentucky treatment plants.

Data from the sludge survey was used to compare the quantity of solids removed at the different treatment plants per million gallons of wastewater treated. The results, shown in Figure 4, demonstrate that most of the facilities in the state report a dry solids generation rate which is in the range of 0-0.8 tons dry solids per million gallons of wastewater treated. These results are similar to the average 0.6 tons of dry solids per million gallons reported by the USEPA Sludge Task Force (1983), and 0.2 tons per million gallons found in a recent survey of large treatment plants in the northeast U.S. (Hermann and Jeris, 1992). The differences between these numbers, and the range in values for Kentucky wastewater treatment plants does point out the care with which these numbers must be applied. Variation in sludge generation at different facilities should not be surprising as variations in treatment

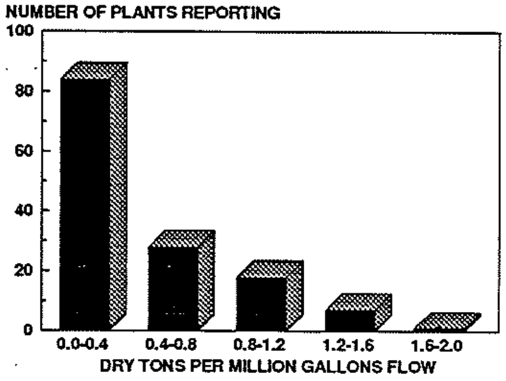


Figure 4. Tons of dry sludge solids removed per million gallons of wastewater treated in Kentucky.

methods, operation and wastewater are always encountered. This has led to the development of more refined techniques to determine solids generation.

A mass balance approach to solids generation quantifies inputs and outputs to the treatment process and solids generation and destruction inside the process. Figure 5 shows a generalized schematic of a very simple mass balance approach, where the entire treatment process is considered as a single box. More refined methods have been described in the literature (Metcalf and Eddy, 1992). The organic matter (e.g., BOD) and suspended solids (e.g., TSS) entering the treatment process are related to sludge solids or effluent composition. The conversion of these quantities to sludge solids is complicated by the biological conversion of both of these groups of compounds, overlapping of some of these characteristics of the groups, and differences between different treatment techniques, but expressions which relate BOD and TSS to solids generation have been developed. These expressions are simplifications of complex processes and it may also be necessary to include variables such as residence time of solids in the system and type of treatment process.

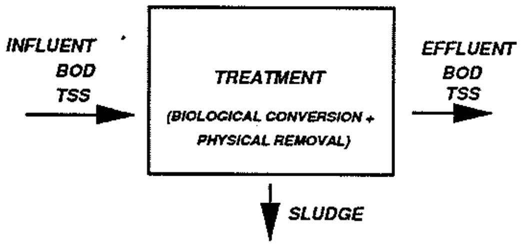


Figure 5. A simplified mass balance approach to sludge generation uses the biochemical oxygen demand (BOD) and total suspended solids (TSS) quantities and relationships for their conversion and removal.

3. CURRENT SLUDGE MANAGEMENT AND USE IN KENTUCKY

In Kentucky, the sludge generated during the treatment of municipal wastewater is managed and used in several different ways (Figure 6). Many plants report they currently report more than one end-use for their sludge. As a result, the totals in Figure 6 may exceed the total number of plants which reported that information. As illustrated in Figure 6, a variety of different end-uses are currently employed. It is likely that all of these methods will be affected in some way by the new regulations for landfilling and sludge management.

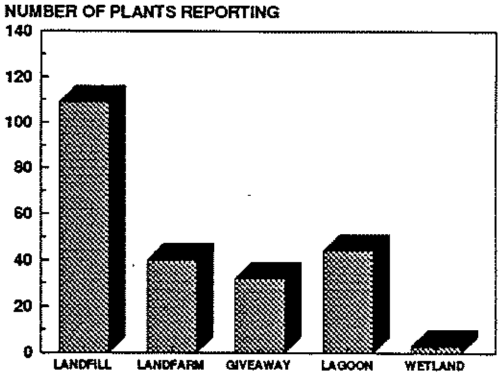


Figure 6. Comparision of sludge end-uses reported at Kentucky wastewater treatment plants.

In 1993, most Kentucky wastewater treatment plants landfilled at least a portion of their sludge and in most cases, the sludges were handled as waste material. Several facilities processed sludges to be used in combination with soil as a daily cover for the waste. Several respondents to the survey expressed concern that new design requirements for landfills has led to an increase in tipping fees and increased hauling distances as landfills have closed. In 1993, tipping fees for Kentucky sludge disposed of at landfills ranged from 10 to almost 60 dollars per ton of sludge, as shown in Figure 7. Using the approximate median cost of $25/ton of wet sludge, on a dry ton basis that represents a cost between $50 to $125 per dry ton of sludge solids for sludges at 50% and 20% solid contents, respectively. It is likely that with continued landfill regulation, tipping fees for sludge disposal will continue to increase over the next several years.

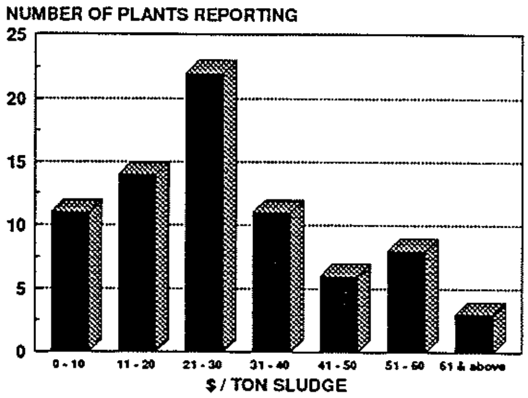


Figure 7. 1993 landfill tipping fees for Kentucky wastewater treatment plants.

Sludge landfarm and giveaway programs were also used by many plants in 1993. Many of these facilities have begun to investigate meeting pathogen reduction requirements of the new regulations. Lagoons were also a common sludge management option and almost 50 facilities in Kentucky reported some use of lagoons for sludge management. In many cases, this is temporary storage which will eventually require additional handling, although there is evidence that in some facilities, the quantity of sludge will be reduced. The survey information cannot be used to demonstrate such a reduction because of sludge storage in many of these facilities, but it is an area of on-going research (Keeling, 1994).

4. WASTEWATER RESIDUALS REGULATION

An important aspect of sludge management are the new regulations for the use and disposal of sewage sludge, 40 CFR 503. These regulations may increase interest in taking advantage of the benefits of wastewater residuals because they detail conditions under which the sludge will be applied to land. The regulations focus on three aspects to minimize potential negative impacts during management: pathogen content, attractiveness to vectors, and pollutants. The rule was based on an analysis of the different pathways that components of residuals could take after final use. The following is only a brief introduction to the rule, and interested readers should examine other references that are available (USEPA, 1992).

4.1. Pathogen Reduction

Biological pathogens can be components of wastewater residuals and they can be reduced through a variety of different processing methods. The 503 regulations identify two degrees of pathogen reduction: Class A and Class B. Class A sludges have very low levels of pathogens and can be applied to land with fewer restrictions than a Class B. Class A sludges are those which have met the appropriate pathogen criteria or have been processed using methods which have been designated as a PFRP (Processes to Further Reduce Pathogens) or equivalent. All residuals which are applied to land must at least meet Class B, and if they are applied to lawns and home gardens or are sold or given away in bags, must meet the Class A pathogen reduction.

4.2. Vector Attraction

If the residuals are attractive to vectors (including birds, rodents, insects), these vectors could transport potentially harmful components to nearby populations. To prevent this from happening, the sludge rule requires that the residuals either be made less attractive to vectors or managed in a way which will not permit vectors to come in contact with it. Vector attractiveness can be reduced through a variety of processing techniques or the residual can be managed in a way which does not permit vector contact (e.g., subsurface injection, incorporation into soil shortly after application, or landfilling).

4.3. Pollutant Content

Pollutants in the residuals from wastewater treatment can limit potential uses. Unlike many other residual components, many pollutants are not reduced through natural activity in the soil and can accumulate to levels which might be undesirable if not controlled. The 503 rule establishes two levels of pollutant concentration in sludges: ceiling and high quality. If pollutant concentrations are below the high quality limits, the sludge can be used in a variety of ways. Provided appropriate vector and pathogen requirements are also met, they can be applied to lawns or gardens or sold in bags. If the concentrations of pollutants are below the ceiling values, but above the high quality limits, the sludges can be applied to land only after using a cumulative loading criteria. If the pollutant concentrations exceed the ceiling levels, the sludges should probably be managed through methods other than land application.

Table 1. Sludge Pollutant Limits

Pollutant	Ceiling (mg/kg)	High Quality (mg/kg)
Arsenic	75	41
Cadmium	85	39
Chromium	3000	1200
Copper	4300	1500
Lead	840	300
Mercury	57	17
Molybdenum	75	18
Nickel	420	420
Selenium	100	36
Zinc	7500	2800

Recordkeeping requirements are more stringent for solids which do not meet the high quality limits. Even if the pollutant concentrations are below the ceiling levels, once they are in excess of the high quality level, annual whole sludge application rates must be monitored to ensure that the annual pollutant loads are not greater than those permitted.

5. SLUDGE PROCESSING FOR PATHOGEN REDUCTION

Pathogen reduction is a key feature of the current sludge regulations and sludge management may require processing to reduce viable pathogens. The method and amount of pathogen reduction will depend to a large extent on the anticipated final use of the solid residuals. This section will summarize some of the available technologies for pathogen reduction and discuss characteristics of several processes which may determine their suitability for meeting the needs of individual treatment plants. The findings are based on an examination of current literature and discussions with plant operators. These sources were also used to identify those technologies which have been sufficiently developed to warrant review.

Many processing options can reduce pathogen content of sewage sludge. For example, biological activity, drying, heat, pH changes, and high temperatures all act to alter the viability of pathogens. The following discussion will focus on several pathogen reduction methods for sludges. The criteria for selecting these methods was that they be able to meet the most stringent pathogen reduction level (Class A), that they be appropriate for smaller wastewater treatment plants, and that they have data available from currently operating facilities. Based on discussions with operators and regulators, the following pathogen reduction methods were selected for examination:

- composting
- alkaline stabilization
- heat drying/pelletization
- thermophilic aerobic digestion.

Although these do not represent all the possible pathogen reduction methods which meet the above criteria, it is hoped that they provide a framework within which other methods can also be compared.

5.1. COMPOSTING

5.1.1. Introduction

Composting is the biological decomposition of organic material under controlled temperature, oxygen, and moisture conditions. Both digested and undigested primary and secondary sludges have been successfully composted. To assist in the biological processing, bulking agents such as wood chips, sawdust, or finished compost are blended with the sludge to increase porosity and absorb moisture. Various methods are then employed to assist converting the blended sludge into a biologically stable, humus-like material. Such composted sludge can be used to improve the physical properties of soil, including its water retention, aggregation and aeration. As a soil amendment, composted sludge is often used in gardens, nurseries, parks and for re-vegetation of disturbed lands.

Composting can lead to a substantial volume reduction because organic sludge solids are biologically degraded. Depending on the degradability of additives (e.g., bulking agents), volume reductions can range from 35% (using slowly degraded wood) to 73% (using shredded mixed paper waste) of the original volume (Smith and Anderson, 1994)

Some of the principle concerns with composting sludge have been the issues of public health and odor generation. The heat generated during composting is capable of killing all four groups of pathogens present in sewage sludge, although the efficiency of pathogen destruction depends on "the ability of the process to subject the sludge to uniformly high temperatures." (Corbitt, pg. 8.137) Sewage sludge contains compounds which during decomposition can produce unpleasant odors. Proper process design and management can minimize, although not completely eliminate odor production (Benedict, 1986).

5.1.2. Composting Methods and Conditions

Most sludge composting operations use one of three principal methods:

- static pile
- windrow
- in-vessel.

The results of a recent survey provided a breakdown of active sludge composting processes by the number of plants which employ each method. The results are shown in Figure 8.

The static pile method, currently the most widely used in the United States, was developed by the U.S. Department of Agriculture at Beltsville, Maryland. The aerated static pile method uses forced air to supply oxygen and remove excess moisture. Perforated plastic pipe covered with a porous bulking agent is commonly used to distribute air. Blended sludge is placed over that system in piles seven to eight feet high and of varying widths. Once placed, the piles are covered with either bulking material or finished compost to provide insulation and odor control (Figure 9).

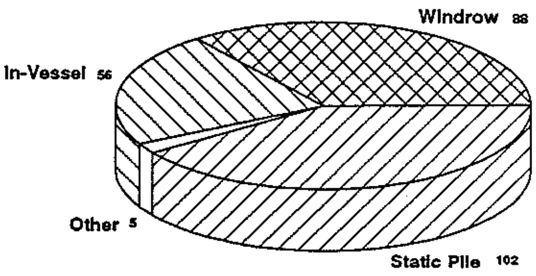
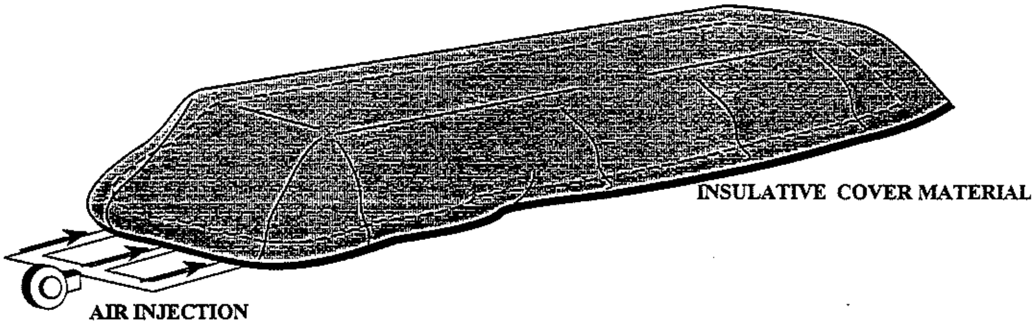
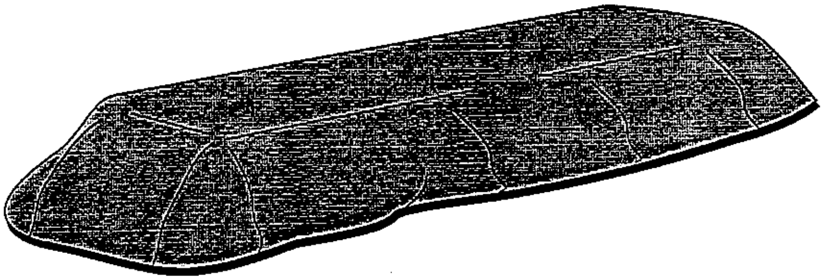


Figure 8. Results of a recent survey of sludge composting facilities showing the number of plants employing each method (Biocycle, 1992).

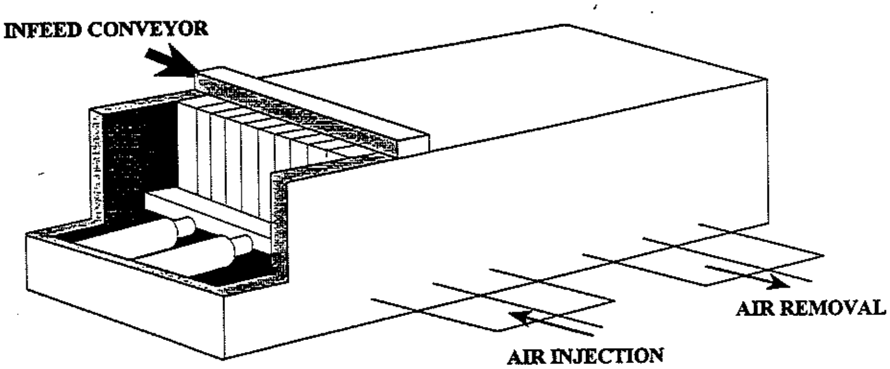
In windrow composting, windrows of blended sludge are mechanically



AERATED STATIC PILE METHOD



WINDROW COMPOSTING



IN-VESSEL COMPOSTING

Figure 9. Schematic of three sludge composting variations.

turned to provide oxygen and control temperature. The windrows range from three to seven feet high depending on the type of equipment used to turn the compost (Figure 9). The length of the windrow will vary according to the size constraints of the composting site. Facilities in warm climates with average rainfalls have been successful with placing windrows in the open air. Those facilities located in cold climates or with excessive rainfall often place the windrows in a covered or sheltered area to allow better control of moisture and temperature. The windrows must be turned periodically to replenish oxygen depleted during decomposition of the organic fraction and to control temperature. The frequency of turning will determine the amount of time required for complete decomposition of organics in the sludge. In general, the more frequently the compost is turned, the faster the rate of decomposition.

The in-vessel composting method uses enclosed containers or vessels to create a controlled decomposition environment. Most common of these are agitated or mechanically mixed reactors. The sludge and bulking agent is placed in the reactor and periodically mixed to provide oxygen and distribute moisture (Figure 8). The controlled conditions of an in-vessel system generally provide an accelerated rate of decomposition as compared to windrow or static pile methods. Because the composting occurs within a closed reactor, in-vessel systems may also allow for more efficient control of odors.

5.1.3. Composting Parameters

In order to assure efficient composting, several important parameters must be understood and controlled:

- Oxygen Content
- Temperature
- Moisture Content
- Carbon/Nitrogen Ratio

- Particle Size

An adequate supply of oxygen must be available in the compost for sufficient aerobic decomposition to take place. Microorganisms responsible for the decomposition of the organic fraction of compost require oxygen for survival and growth.

To achieve pathogen reduction through composting, elevated temperatures between 55°C and 60°C are required. (Burnham et al.. 1992; USEPA, 1986, 1987; Benedict, et al., 1986; Finstein, et al., 1986; Andrews, et al., 1991; Corbitt, 1990; and McGhee, 1991) Temperatures in excess of 60°C can reduce biological activity, while temperatures below 55°C may not sufficiently destroy pathogens (Burnham et al., 1992). Compost samples which have been taken from low-temperature (25°C to 45°C) areas of a pile reportedly had a much greater microbial activity than did samples from high temperature (60°C to 75°C) areas (USEPA, 1986).

Aerobic decomposition also requires adequate moisture. Sources state that the optimum moisture content for composting sludge is "less than 60 percent but more than 40 percent." (McGhee, 1991) Because most sludges have a moisture content of between 75 to 95 percent after thickening and dewatering, moisture content is usually further reduced through the addition of a bulking agent. Several facilities which were contacted as part of this study reported that moisture control was a critical operating parameter in sludge composting.

The balance between the amount of available carbon and nitrogen is important in ensuring successful biological decomposition. This balance can be described with the C/N ratio. Sewage sludges typically have low C/N values, indicating an excess of nitrogen. In contrast, wood waste and paper have generally higher ratios. Other organic wastes, such as food and grass clippings can also have a low C/N ratio. Composting with a low C/N ratio may lead to odor production, while a ratio which is too high may result in slow decomposition.

The particle size of the bulking agent is important for both mixing and decomposition. Reducing bulking agent particle size creates greater available surface area, a more homogeneous sludge/bulking agent mixture, and may increase the rate of decomposition. The desired particle size of the bulking agent may also govern the type of equipment which is necessary for processing.

Based on a review of the literature, examples of typical values for these and various other composting parameters are listed in Table 2.

Table 2. Typical Sludge Composting Conditions*

Optimum Temperature	55°C to 60°C
Optimum Moisture	40% to 60%
pH	6 to 7.5
Carbon to Nitrogen Ratio	25 to 30
Particle Size	1" to 3"

*adapted from USEPA, 1987; McGhee, 1991; Andrews et al., 1991; Corbitt, 1990.

5.1.4. Bulking Agents

An important issue to address when considering sludge composting is the availability of bulking agents to blend with the sludge. Bulking agents ensure adequate porosity and moisture content which is important to maintaining active decomposition. To help minimize the cost of composting, attention should be given to the use of locally available materials. It became apparent in discussions with sludge composters, that many readily available, local materials, including some that would normally be landfilled, have properties that make them excellent bulking agents.

Yard Waste: Yard waste may include grass clippings, brush, leaves and tree trimmings. As more states are banning or actively discouraging the disposal of yard waste in landfills, the option of composting sludge together with yard waste is becoming increasingly popular. One survey found more than 70 projects were using or planned to use yard waste as part of their composting mix in 1990 compared to only a few such projects 3 years earlier.

Some sludge/yard waste composting facilities are operated in conjunction with municipal landfills. Although landfills may accept a variety of mixed yard wastes, including leaves, grass, brush and tree trimmings, the type of yard waste used in composting will depend on the composting equipment, sludge type and the individual process. Flexibility in preparation of the composting mixture may be important in using yard wastes. For example, several operators reported difficulties controlling the moisture content of the compost when using mixed yard waste. Most minimized this problem by keeping tree trimming waste separate from mixed yard waste and varying the components in the overall mix depending on the amount of moisture present.

Paper Waste: A facility in North Carolina successfully used mixed paper waste, diverted from the municipal solid waste-stream, as a bulking agent

(Smith and Anderson, 1994). Mixed paper, consisting of hard to market paper grades, constitutes 15% - 20% of most municipal solid waste streams. Results of the North Carolina project showed a 70% reduction in volume, Class A pathogen reduction, and a dark colored product resembling topsoil. Problems they reported with this bulking agent included finding equipment to shred the paper and controlling wind-blown paper.

Wood-Chips and Sawdust: Some operators of small plants have found it to be more economical to purchase bulking agents such as wood chips or sawdust rather then processing their own. These operators report that although yard waste was available, the high initial cost of processing equipment made it more economical to purchase processed wood. Operators have also reduced the high capital costs of processing equipment by forming cooperatives with other communities and sharing processing equipment.

5.1.5. COMPOSTING VARIATIONS

An attempt was made to identify sludge composting facilities throughout the U.S. which were currently operational, of medium size and employing the range of composting techniques. Discussions with operators indicated an overall satisfaction with the process. Eighty percent of the plant operators contacted were able to achieve a high degree of pathogen reduction (e.g., Class A) with the other twenty percent meeting a lower reduction (e.g., Class B). Some characteristics of the facilities which were contacted are summarized in Table 3.

Outside of individual process variations (windrow, static pile, in-vessel), the greatest variations between facilities were the bulking agents used. Regional characteristics seem to have an influence on the availability of some materials such as sawdust or wood-ash. Several operators have found it advantageous to have the flexibility to use materials such as yard wastes when they are available. Other variations which were described include:

- Separate stockpiles of yard and wood waste.
- Possible further de-watering of the sludge prior to composting.
- Re-use of bulking agents by screening the finished compost
- Use of enclosed buildings for composting operations.

One example is Yorktown Heights, NY which is in an area that generates a large volume of leaves in the fall of the year. Initial attempts at using leaves as a bulking agent for sludge composting resulted in excessive moisture in the windrows. They found that further dewatering of their raw sludge was necessary before they could obtain optimum moisture in the compost.

Available equipment and facilities are also important variables when considering composting for sludge processing. Facilities that were not initially successful composting outdoors have converted unused equipment buildings and garages into compost facilities. Most of the plant operators interviewed do not have, or intend to purchase specialized compost turning equipment. Plant operators have found that front-end loaders and backhoes, although slower, are reasonably efficient.

Most plant operators agree that optimizing a composting system is a trial and error process and successful composting may require a willingness to experiment with different conditions. Even the slightest change in one component (e.g., moisture content or bulking agent) can have a significant effect on the final product. Careful research should be conducted prior to the implementation of a composting operation to evaluate markets for the final product, availability of bulking agents, and the need for additional equipment.

5.1.6. Composting Costs

One area of discussion with existing sludge composting operations was the cost of the process. The costs associated with composting operations will be dependent on factors such as:

- use of existing facilities and equipment
- size of the treatment plant
- availability and cost of bulking materials.

Those composting facilities which could report a unit cost for composting sludge indicated the range of costs which are summarized in Figure 10. Some of the variation in composting costs can be found by looking closely at the individual processes and plant location. Plants A and B are located in the southeast United States. Both facilities use processed yard waste as a bulking agent with the windrow composting method. Plants C and D, which are located in the northeast and mid-west respectively, both use aerated static pile composting. Plant E, located in the northeast, uses an in-vessel system and purchases wood ash and sawdust as bulking agents. Process type can also influence overall operating costs. Plants that use the in-vessel and aerated static pile method may incur additional operating costs because of equipment maintenance on blowers and agitators. Land requirements for windrow composting should also be a concern. Facilities that use windrow composting must also consider the cost of windrow turners and loading equipment. The use of existing facilities and equipment also impacted

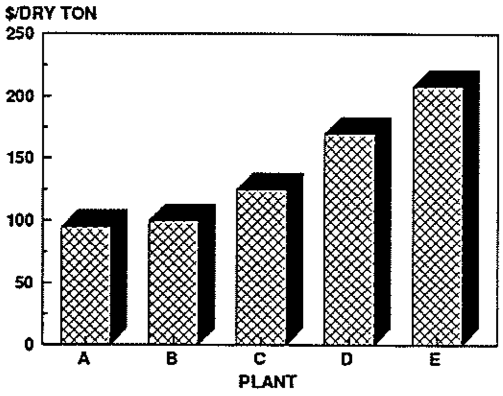


Figure 10. Comparsion of sludge composting costs reported per dry ton of sludge solids processed.

the range of unit costs reported. For instance, some small composting operations use road maintenance equipment such as front-end loaders and backhoes to turn and move windrow compost, thus eliminating the need for specialized equipment.

Most of the composting operations contacted have successful give-away programs with little or no long term stockpiling. Two of the plants contacted were able to charge a nominal fee for the finished compost (\$10 - \$15 /yd^3), but most of the facilities interviewed did not expect revenues from the sale of compost to cover their operating costs. The compost is often given to the public or used by municipal governments in the parks and landscaping departments. These and other results from the interviews are summarized in Table 3.

Table 3. Survey of composting operations.

MUNICIPAL WW TREATMENT PLANT COMPOSTING SURVEY

FACILITY	PLANT SIZE/ PRODUCTION MGD (dry tons/month)		PROCESS	BULKING AGENT(S)	END USE OF PRODUCT
Manchester, NY	0.45	(2-4)	Aerated Static Pile	Wood Chips	Given to Local Residents for use as a Soil Amendment
Plymouth,NH	0.7	(20)	In-Vessel	Sawdust and Wood Ash	Given to Residents and Highway Department
Macinac Island, MI	1.0	(400 wet tons/ year)	Windrow	They tried to compost the sludge with horse manure but it killed the microorganisms. Currently looking for new bulking agent.	
Yorktown Heights, NY	1.5	(75 yd^3/ month)	Windrow	Leaves and Yard Waste	Given to Local Residents as a soil Amendment
Nantuckett Island, Mass	1.6	(7.5 - 30)	Aerated Static Pile	Wood Chips	Sold to Local Residentsas a soli amendment for $15.00 / Cubic Yard
Scottsboro AL	4.5	N/A	Windrow	Mixed Yard Waste	Compost operation is constracted out. The final product is used as Landfill daily cover,
Fairfield, CN	9.0	N/A	In-Vessel	Ground Landscape Waste	Used as a Soil Amendment at Landfill
Longmont, CO WWTP	11.55	(134)	Aerated Static Pile	Wood Chips	Given to County Public Works Department for use as a Soil Amendment
Myrtle Beach, SC	12.0	(70)	Windrow	Mixed Yard Waste	Sold to Local Public for $10.00 /Cubic Yard

5.2. ALKALINE STABILIZATION

5.2.1. Introduction

Lime has long been used to deodorize, disinfect, and enhance the dewatering characteristics of wastewater solids. Alkaline stabilization is the process of adding an alkaline agent (e.g., quick lime, hydrated lime, flyash, cement kiln dust) to wastewater sludge in quantities sufficient to raise and hold the pH for a specified time period. Sludge so stabilized may have a reduced number and a reduced regrowth of pathogenic and odor-producing organisms. Heat is also usually important to reducing pathogen viability in the sludge. Heat is either generated by combination of sludge with the alkaline amendment, and it may be added externally.

Alkaline stabilization may require less overall space compared to static pile or windrow composting and less capital investment compared to heat-drying/pelletization processes. Disadvantages associated with alkaline stabilization are the generation of odors and an increase in sludge solid weight.

5.2.2. Alkaline Amendments

A variety of compounds have been used as alkaline agents for sludge stabilization. One of the most common is quicklime or calcium oxide (CaO). The addition of quicklime has a two-fold effect on pathogen reduction. Quicklime has the capability to raise the pH to 12 and also generates heat which reduces pathogen viability (Burnham et al., 1992).

In recent years Cement Kiln Dust (CKD) and Lime Kiln Dust (LKD) have gained acceptance as alternatives to lime in alkaline stabilization processes. CKD and LKD are by-products of the cement and lime manufacturing industries. They posses some alkaline properties similar to lime. In addition, their large surface areas may give them better absorption and drying capabilities. In processes that use CKD or LKD, quicklime may also be added to ensure that the desired pH and temperature is attained.

5.2.3. Stabilization Criteria

Contact time, pH and temperature are the three primary factors to consider in using alkaline stabilization processes for pathogen reduction. They can determine whether the product will be Class A or Class B with respect to pathogens. The actual alkaline dosage required for each process will depend on factors such as the type and chemical composition of the sludge, the sludge solids content and the alkaline agent used.

When lime addition raises and maintains the pH of the sludge at 12 for a contact period of 2 hours, pathogens and microorganisms are sufficiently inactivated or destroyed to qualify the process as a PSRP. Sludge stabilized through a PSRP is a Class B product. Several variations of the alkaline stabilization process have been able to produce a Class A product, for example, one manufacturer describes a process which uses "a minimum dose of 6% lime, plus the addition of 20 to 40% cement or lime kiln dust and maintenance of a 50% total solids sludge at pH above 12 for three days or dried to 65% total solid" (Burnham et al., 1992). There are several process-patented or proprietary alkaline stabilization processes currently in use and meeting Class A pathogen reduction. Other facilities have or are conducting research and testing to develop processes for their facilities which will achieve Class A pathogen reduction.

Charlotte-Mecklenburg Utility Department in North Carolina examined the quantity of alkaline amendment which might be necessary to achieve Class A pathogen reduction and form a useful product. They tested quicklime, blends of agricultural lime and quicklime, and blends of LKD and quicklime. Quicklime (87% CaO) at dosages of 1.9/1 lb lime/lb dry solids) produced a pH greater than 12 and a temperature greater than 70 C. A LKD and quicklime blend (42% CaO) was dosed at 2.9/1 (lb/lb) and quicklime/aglime at a dose of 3.1/1 (lb/lb) (Black and Veatch, 1993). Sieger et al. (1993) report that somewhat lower quantities of lime may be required to achieve Class A pathogen reduction, and other processes use supplemental heat to reduce the necessary quantity of alkaline amendment required. In all cases, however, the quantities of alkaline amendment have a significant impact on the physical and chemical characteristics of the product and ultimately its utility for the different end uses.

It is not the intent of this report to describe in detail all of the different process variations of achieving a higher degree of pathogen reduction using alkaline amendments, but based on a review of several process variations and discussions with existing facilities, it appears that most of the alkaline stabilization processes which achieve class A pathogen reduction employ at least one of the following:

- Alkaline dosages (by weight) of at least 2-3/1 (alkaline/dry sludge solid)
- Temperatures greater than 70 C.
- Accelerated drying using alkaline addition or supplemental heat.

Based on a review of the literature and discussions with personnel at facilities which use this technology, it is also apparent that the nature of the final product is very dependent on the stabilization process. Care must be exercised in selecting a process not only for pathogen reduction, but for suitability of the product for the desired end-use.

5.2.4. Use of Alkaline Stabilized Sludge

The process used to stabilize the sludge and consequently the classification of the end product determines what if any restrictions are placed on the use of the final product. Class A material has few restrictions on food crop usage or public contact whereas a Class B product has more restrictions on food crop usage and public access. Alkaline stabilization can meet Class A pathogen reduction and combine the benefits of organic matter and alkaline content for soil improvement. Many treatment plant operators currently give the stabilized product away and in some cases deliver and land apply it free of charge. These facilities hope to establish the benefits of the product, build a customer base and eventually create a demand for the product. Many of the treatment plants that use alkaline stabilization are in located in agricultural regions where lime products have the potential to be commercially valuable. Stabilized sludge may also offer benefits in reclaiming disturbed lands. At solids contents greater than 50%, processed sludge can be spread and manipulated much like topsoil. Most operators agree however that the potential revenue generated from the sale of the finished product does not currently cover the cost of processing.

Landfills are also using alkaline stabilized sludge, either a soil amendment or as a daily cover for the waste. Cover material requirements can be quite substantial and alkaline stabilized sludge mixed with native soils at ratios of 2:1 to 5:1 have been used (Mendenhall et al. 1992). Alkaline stabilized sludge products can also be mixed with topsoil and used to enhance vegetative growth on completed areas of final cover.

5.2.5. Alkaline Stabilization Costs

A phone survey of facilities currently using alkaline stabilization to achieve Class A pathogen reduction indicated an overall satisfaction with the process and the results. More that half of those contacted currently use a proprietary process. Costs for alkaline stabilization processes will vary depending on the type and quantity of alkaline agent used, current facilities and equipment which might be available, and costs associated with proprietary processes.

Based on the results of the phone interviews, the cost of sludge processing by alkaline addition varied depending on the individual process used and, to some extent, location. Not all of the facilities interviewed were able to break down their sludge processing costs completely. A summary of reported cost data from plants that tracked sludge processing costs is shown in Figure 11. The range in sludge processing costs associated with alkaline stabilization reflect some variations in how the costs were determined. For example, Plant G uses a private contractor for its sludge processing. The contractor charges $265 per dry ton which includes thickening, dewatering and alkaline stabilization. The final sludge product is sold to local farmers as a liming agent for $3 /ton, and is used as landfill daily cover. Plant F uses excess amounts of blended quicklime and lime kiln dust to produce a class A product and to further dry the sludge. This results in a product that can be easily spread on agricultural land by conventional equipment. Plant E has a very seasonal waste water flow. They purchase a pre-blended alkaline agent and use excess amounts to produce a class A product. They also use excess lime to dry the sludge to a spreadable consistency. Plant D is currently in a pilot study using a proprietary system. Plants A, B and C all use another proprietary process and all produce a class A product. Additional information from the facilities contacted is summarized in Table 4.

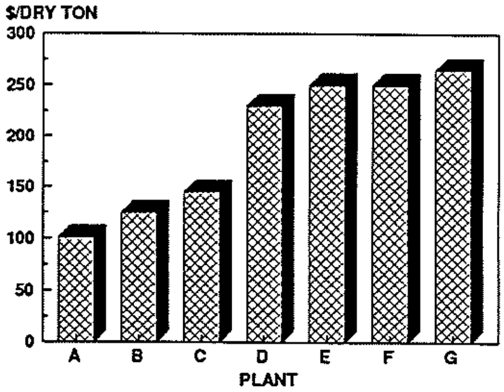


Figure 11. Comparison of costs for sludge processing using alkaline addition.

Currently few of the facilities contacted have been able to generate any revenue from selling the final product. Many are able to eliminate tipping fees normally assessed for landfilling sludge by using their product as landfill daily cover. Most of the facilities indicated that having a marketable end-product weighed heavily on their decision to use the alkaline stabilization process.

Table 4. Survey of alkaline stabilization operations.

ALKALINE STABILIZATION SURVEY SUMMARY

FACILITY NAME	PLANT SIZE/ PRODUCTION MGD (dry tons/month)		ALKALINE AGENT(S)	END USE OF PRODUCT
Troy, IL WWTP	0.7	(3.5)	Cement Kiln Dust	Used as Landfill Daily cover
Easley, SC WWTP	1.5	(16.7)	Purchase Blended Alkaline Agent	Used as Landfill Daily cover
Circleville, OH WWTP	2.0	(18.0)	Cement Kiln Dust	Class A product, current used on agricultural land as lime amendment
Boone , IO WWTP	2.0	(25)	Cement Kiln Dust	Used on agricultural land as a lime amendment
Penn Township, PENN	2.2	(29)	Lime Kiln Dust	Class A product given away as an agricultural soil amendment
Galion, OH WWTP	2.5	(39.8)	Cement Kiln Dust	Class A product given away as an agricultural soil amendment
Maggie Valley, NC	3.5	N/A	Cement Kiln Dust	Given away as a soil amendmet to local Christmas tree farmers
Tarpon Springs, FL	4.0	N/A	Cement Kiln Dust	Land applied by private contractor
Norfolk, NB, WWTP	5.0	(160)	Cement Kiln Dust	Used on agricultural land as a lime amendment
Barberton, OH WWTP	5.25	(200)	Quicklime	Used on agricultural land as a lime amendment

Table 4 continued

ALKALINE STABILIZATION SURVEY SUMMARY

FACILITY NAME	PLANT SIZE/ PRODUCTION MGD (dry tons/month)	ALKALINE AGENT(S)	END USE OF PRODUCT
Fort Smith, AK	10.0 (300)	Cement Kiln Dust	Class A product, currently used on agricultural land as lime amendment
Kent County, DL	15.0 (420.0)	N/A	Stabilization is performed by a private contractor who sells the final product as fertilizer.
Lexington, KY	22.3 (200.0)	Cement Kiln Dust	Currently used as a landfill daily cover.
Charlotte-Mecklenburg	80.0 N/A	Blended Kiln Dust and Quicklime	Class A product given away as an agricultural soil amendment

5.3. HEAT DRYING AND PELLETIZATION

5.3.1. Introduction

Heat drying of sludge, often to form pellets, is a sludge processing alternative which achieves a high pathogen reduction through a combination of drying and high temperatures. In terms of pathogen reduction, these methods are distinct from air drying processes both in terms of water removal and pathogen reduction.

5.3.2. Heat Drying Methods

Dryers that have been employed in sludge processing include: spray, rotary, flash and the patented Carver-Greenfield process (Metcalf and Eddy, 1991). Spray dryers atomize liquid sludge into a spray which is dried. Rotary dryers use a heated drum containing the sludge which revolves as it is heated. Flash dryers expose fine sludge particles to hot gases to evaporate moisture and heat the particles. The Carver-Greenfield process mixes sludge with hot oil and the water is boiled from the oil. The resulting mixture is centrifuged to separate the oil from the sludge solids.

5.3.3. Uses of Pelletized Sludge

Producing heat dried pellets may be an advantage in marketing the product. Milwaukee has used heat drying methods for years, and successfully markets both directly to users and to fertilizer blenders. One facility which uses heat drying to process sludge is the Clayton County Water Authority of Clayton County, Georgia. The pelletized sludge is marketed as Agri-Plus 650 which is a registered fertilizer with an analysis of 6-5-0 (N-P-K). The pellets are then marketed to the Florida citrus growers and used as a base material for more complete fertilizers. An recent evaluation of potential markets for pelletized sludge performed by a Florida municipality indicated a growing market for the

the "low value" pelletized products for use by agricultural end users, but a relative saturation of the "high value" market which is retailed to homeowners and turf applications (Wohlgemuth, 1993).

5.3.4. Heat Drying Costs

Heat drying and pelletization process do require substantial capital investments. Only a few of these plants are in operation in the United States and three facilities were contacted regarding their use of the method. Personnel at those facilities indicated that they were producing a Class A product and were satisfied with the processing technique. The costs shown in Figure 12 demonstrate a signficant range in unit costs for heat drying. It appeared that plant C included costs for other aspects of sludge handling and processing in addition to the pelletization.

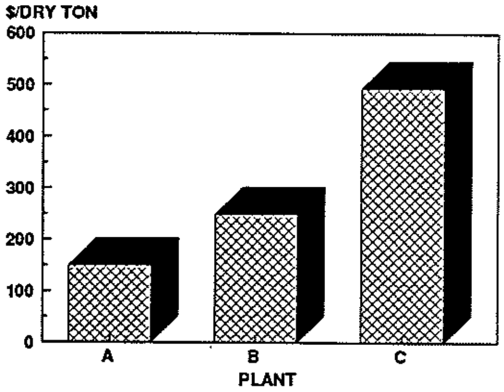


Figure 12. Comparison of sludge processing costs for heat drying/pelletization.

Based on discussions with users of heat drying technology and a review of the literature, it does appear that product marketing should be an important consideration when evaluating the use of heat drying. One plant operator interviewed indicated that they were having some problems finding local markets for the final product and that costs to transport it to other areas could be substantial.

5.4. THERMOPHILIC AEROBIC DIGESTION

5.4.1. Introduction

Thermophilic aerobic digestion is an emerging technology in the United States. The autothermal thermophilic aerobic digestion (ATAD) process obtains pathogen reduction by using heat generated during aerobic digestion. The ATAD technology has been refined in Germany were there are currently 35 full-scale operating facilities. (EPA, 1990)

5.4.2. Thermophilic Aerobic Digestion Methods

Most ATAD systems are two-stage processes that use aerobic digestion in the thermophilic temperature range (40°C to 80°C). Insulated digesters capture and retain heat produced during digestion. Although supplementary heat systems can be installed, most systems are able to maintain thermophilic conditions without it. First stage temperatures range between 40°C to 50°C with the second stage operating between 50°C to 65°C (EPA, 1990).

ATAD systems are commonly operated in a batch mode with average detention times in each reactor of almost 24 hours and are charged daily. The aeration system inside each reactor may use both spiral and circulation aerators. A tangentially mounted spiral aerator provides vertical and horizontal mixing and a centrally mounted circulation aerator prevents settling in the center of the tank. The net effect is that the final flow pattern represents a spiral. Specialized foam controllers break up and densify the foam layer created by the mixing of the substrate. The foam controllers allow for improved oxygen utilization and better insulative characteristics of the densified foam. (Schwhinning et al., 1993). An example ATAD flow scheme is shown in Figure 13.

The ATAD process can achieve Class A pathogen reduction. Other

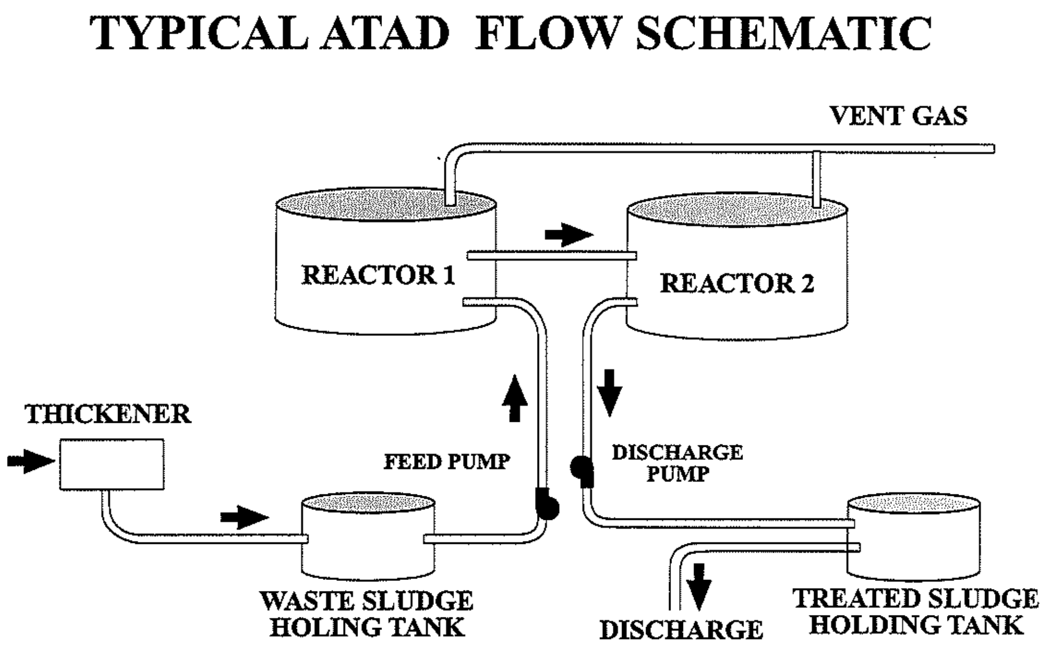

TYPICAL ATAD FLOW SCHEMATIC

Figure 13. Schematic of ATAD sludge process (adapted from Kruger)

reported benefits of the ATAD process include low tank, space, monitoring and staffing requirements (EPA, 1990).

5.4.3. Cost Comparison

No currently operating ATAD facilities were found in the United States. Several municipalities contacted, Grand Chute-Menasha, WI, and Franklin TN, are currently constructing facilities which will be operating before the end of 1994. The USEPA (1990) and Vik and Kirk (1993) summarize estimates of the process costs based on European experience.

6. SUMMARY

The quantites of sludge generated and the variations in potential processing technologies for pathogen reduction pose a challenge to those evaluating sludge management. It should be apparent from the previous sections that some of the key factors which should be considered when evaluating sludge management options include:

- Land Requirements
- Equipment Requirements
- Availability of Required Additives
- Desired Product End Use

These extent to which these factors influence the implementation of a particular processing technology will vary, but in all cases, they will influence the cost and application of any of the technologies.

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APPENDIX A
KENTUCKY MUNICIPAL WASTEWATER SLUDGE SOLIDS BY COUNTY

Kentucky Wastewater Sludge

Annual Dry Tons of Sludge Solids by County

Adair	106
Allen	25
Anderson	949
Ballard	NA
Barren	610
Bath	NA
Bell	1913
Boone	None
Bourbon	350
Boyd	5113
Boyle	4954
Bracken	NA
Breathitt	72
Breckenridge	79
Bullitt	125
Butler	109
Caldwell	110
Calloway	301
Campbell	NA
Carlisle	0.02
Carroll	17
Carter	140
Casey	NA
Christian	614
Clark	63
Clay	54

Kentucky Wastewater Sludge

Annual Dry Tons of Sludge Solids by County

Clinton	24
Crittenden	18
Cumberland	NA
Daviess	2682
Edmonson	NA
Elliott	NA
Estill	32
Fayette	5064
Fleming	62
Floyd	8
Franklin	773
Fulton	None
Gallatin	None
Garrard	106
Grant	148
Graves	109
Grayson	95
Green	6
Greenup	307
Hancock	2
Hardin	1190
Harlan	171
Harrison	57
Hart	0.84
Henderson	2409
Henry	22

Kentucky Wastewater Sludge
Annual Dry Tons of Sludge Solids by County

Hickman	None
Hopkins	607
Jackson	NA
Jefferson	11810
Jessamine	283
Johnson	17
Kenton	5102
Knott	2
Knox	NA
Larue	None
Laurel	669
Lawrence	270
Lee	18
Leslie	4
Letcher	117
Lewis	NA
Lincoln	80
Livingston	19
Logan	400
Lyon	8
McCracken	695
McCreary	None
McLean	31
Madison	2691
Magoffin	6
Marion	75

Kentucky Wastewater Sludge

Annual Dry Tons of Sludge Solids by County

Marshall	22
Martin	NA
Mason	76
Meade	76
Menifee	4
Mercer	300
Metcalfe	None
Monroe	31
Morgan	12
Montgomery	1184
Muhlenberg	81
Nelson	4
Nicholas	80
Ohio	NA
Oldham	246
Owen	None
Owsley	53
Pendleton	38
Perry	396
Pike	55
Powell	154
Pulaski	469
Robertson	None
Rockcastle	33
Rowan	118
Russell	969

Kentucky Wastewater Sludge

Annual Dry Tons of Sludge Solids by County

Scott	2493
Shelby	17
Simpson	44
Spencer	477
Taylor	1292
Todd	94
Trigg	13
Trimble	0.06
Union	42
Warren	462
Washington	84
Wayne	127
Webster	37
Whitley	NA
Wolfe	NA
Woodford	205