A SURVEY OF MASSACHUSETTS BIOSOLIDS COMPOST OPERATIONS; CONCERNING PATHOGEN INDICATOR LEVELS AND REGROWTH POTENTIAL

An Engineering Report Presented

By
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Abstract:

This study is a survey of sixteen biosolids composting facilities in Massachusetts. Site tours and interviews were conducted providing information about operations and samples of finished compost were taken. Collected samples were tested in the laboratory for pathogen indicator levels and regrowth potential. A questionnaire was sent to operators of each facility and returned or completed over the phone. Of the active facilities in Massachusetts, eleven facilities were using aerated static pile or aerated windrow systems, while four facilities were using in-vessel systems. Finished composts were used mainly for landfill application with five facilities distributing biosolids compost for agricultural applications. Operational parameters and materials used in biosolids composting varied among sites. Four of the composts tested contained pathogen indicator levels above 1000 MPN/g and one sample was above 2 x 10^6 MPN/g. Laboratory results suggested that composts with water contents below 30% or above 70% may be more susceptible to pathogen regrowth.

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Introduction:

The composting of biosolids is a relatively new technology that has developed along with the increased application of municipal wastewater treatment. In the interest of protecting the aquatic environment, federal regulations have been developed which govern the disposal of wastewater. The increasing amounts of biosolids (sludge) generated from wastewater treatment, present a number of human health and economic challenges. The economics of sludge handling and disposal are driven primarily by the increasing costs of various disposal options. Ocean dumping has been banned, while incineration has become difficult and expensive, due to strict air pollution regulations. Safe landfill disposal is becoming expensive, as effective liner designs and leachate collection systems are implemented. An attractive alternative for disposal is biosolids composting. Composting allows the sludge to be used as a soil conditioner, and as such, represents a beneficial use of biosolids. This option however, must include assurances that human health risks are minimized. Biosolids composting operations must be designed and operated under conditions that will effectively remove pathogens and the potential for regrowth if pathogens are reintroduced into the finished compost.

Pathogen reduction in biosolids composting is achieved primarily by disinfection via elevated temperatures for an extended period of time. If the process is not controlled (i. e. the temperature gets too high or the moisture level gets too low) desirable organisms can also be removed [1]. These organisms degrade organic material into more stable forms that are less available as a substrate for pathogen regrowth. Carefully controlled composting processes have proven effective at accomplishing this goal.

Sludge management options which include composting, are governed by regulations established nationally, by the Environmental Protection Agency (EPA) [2] and in Massachusetts, by the Department of Environmental Protection (DEP) [3]. Both of these organizations have defined standards and guidelines that concern the use and disposal of wastewater biosolids. These regulations establish minimal levels of both metals and pathogens that are allowed in the finished compost for various applications. Both pathogen and metal concentrations are used to establish classifications, which are in turn used to specify the handling requirements, and the allowable applications. In addition, the regulations specify methods that may be employed to meet pathogen reduction requirements. These regulations govern the design of biosolids management options and help to insure the quality and safety of the applied material.

Massachusetts is one of the leading states at present, practicing biosolids composting. This study evaluates the present status of the composting facilities in terms of operational conditions and compost quality, as indicated by pathogen indicator levels and regrowth potential. This evaluation was performed by conducting a survey and evaluating samples. The survey was designed to explore the operational conditions of biosolids composting facilities in Massachusetts. Tours of sixteen different facilities included interviews with compost operators and collection of finished material samples. These samples were then tested in the lab for pathogen indicator levels and regrowth potential. In addition, a questionnaire about composting operations was sent out to the managers of biosolids composting facilities. Most of the surveys were completed and returned by mail, while the others were completed by phone interview.

Previous surveys of biosolids composting operations nationally [(4)] and in New England [(5)] have provided encouraging evidence of the viability of this method of sludge management. Increasing numbers of communities have developed and built facilities over the past few years with considerable success. Markets for the application of biosolids compost have gradually been developed, as confidence in the quality of this product has grown. However most other surveys do not go into detail about the specific operations involved and the control parameters of different facilities. Operational conditions and variations of the materials used in biosolids composting may greatly effect the quality of the finished material. More specifically, pathogen survivability and regrowth may be largely effected by variations in biosolids composting operations. The objective of this study is to evaluate the status of the biosolids compost facilities in Massachusetts. Operational systems, production, final use and quality of the finished material is evaluated, in terms of pathogen indicator levels and regrowth potential.

Background:

WASTEWATER TREATMENT PROCESSES

Municipal wastewater is commonly treated to remove various constituents before discharge into natural waters. The major focus of wastewater treatment is the removal of suspended solids and BOD_5. Most suspended solids are removed by primary sedimentation, but secondary treatment, which involves a biological oxidation process removes an additional fraction. Dissolved and colloidal organic matter, are removed from the wastewater stream by biological treatment processes [(6)]. In Massachusetts, wastewater treatment commonly involves an activated sludge secondary treatment process to remove organics. The combination of primary sedimentation and activated sludge is usually sufficient to meet secondary treatment standards, in terms of suspended solids and BOD_5. However large amounts of residuals are generated.

BIOSOLIDS (SLUDGE) CONTENT

The settled material generated from wastewater treatment processes is referred to as biosolids or sludge. The main residuals are primary and secondary sludge. Primary sludge is typically about 4% solids, where secondary sludge is approximately 1% solids. The two sludges are often mixed together and have a moisture content of approximately 2-3% [(6)]. To reduce the volume of this mixture it is typically dewatered by belt filter presses or other such devices.

In general, sludge consists of material that may be characterized as organic matter, nutrients, microorganisms, pathogens, and various metals. The solid portion of sludge typically contains 60-90% volatile solids or organic content [(6)]. Much of the organic content contains various microorganisms (aerobic, anaerobic and pathogenic), which are capable of degradation. Sludge contains many nutrients including nitrogen, phosphorus and potassium (potash), that are used by the microorganisms for growth in the degradation processes. On the other hand, heavy metals such as Cadmium, Zinc, Mercury, Copper, etc. may be present in poor quality sludge. These metals may be harmful for plants and animals and therefore limit the use and allowable rate of land application.

REGULATIONS

The handling, land applications, and/or disposal of municipal sludges is governed in Massachusetts by two separate sets of regulations. Land application restrictions include the use of biosolids compost. Nationally, the EPA has established a regulation referred to as 40 CFR Part 503 [(2)]. This regulation is superseded by state primacy, as established by the DEP [(3)]. The EPA regulation concerns "general requirements, pollutant limits, operational standards, and management practices, as well as monitoring, record keeping and reporting requirements." [(2)]. It defines requirements for two classes (A & B) of sewage sludge quality as shown in Table 1. Sludges which meet the stricter standards for Class A designation are required to have consistent minimal levels of inorganic pollutants (i.e., metals), pathogenic and non-pathogenic indicator organisms, and vector attraction characteristics. Similar requirements for Class B sludge status are generally less stringent, but more restrictive in terms of land application practices. Corresponding limitations as to land application and disposal options are restricted by these classification standards. Various alternatives for monitoring, measuring and defining these standards are also described.

The Massachusetts Department of Environmental Protection (DEP) has established regulations [(3)] which generally impose stricter standards. Classifications are designated by type (I, II & III) with corresponding restrictions as to land application and disposal options. The concentrations of various metals allowed to meet these classifications are at least the same or usually lower than the corresponding EPA requirements. In addition minimal required levels of boron and PCB's are also included.

Materials derived from sludge (including compost) which do not meet Type I standards are not allowed for use in land applications where resulting crops will be consumed by humans or animals. Various methods are suggested to achieve pathogen reductions. These regulations are, by definition, more stringent than the EPA regulations and are imposed in addition to it.

Governing Agency	Compost Classification	Defining Standards
EPA	Class A	Processes to Further Reduce Pathogens (PFRP) *And* Less than 1000 MPN/g dry solids Pathogen Indicator *or* Less than 3 MPN/4g dry solids *Salmonella sp.*
EPA	Class B	Processes to Significantly Reduce Pathogens (PSRP) *And* Less than $2x10^6$ MPN/g dry solids Pathogen Indicator
DEP	Type 1	Processes to Further Reduce Pathogens (PFRP)
DEP	Type 2	Processes to Significantly Reduce Pathogens (PSRP)
DEP	Type 3	Processes to Significantly Reduce Pathogens (PSRP)

TABLE 1: PATHOGEN LEVELS FOR SLUDGE CLASSIFICATION

Table 1, summarizes both EPA and DEP classification standards in terms of pathogen reduction requirements. The terms: "Processes to Significantly Reduce Pathogens (PSRP)" and "Processes to Further Reduce Pathogens (PFRP)", refer to biosolids processes which are defined in the regulations. These processes may be used to classify the finished material, but the EPA also stipulates that the pathogen indicator levels must also be below the established minimum for each classification level. In terms of pathogen reduction levels, the Massachusetts DEP classifications are defined only by the terms: PSRP and PFRP. However the EPA regulations restrict the options available for final disposal or land applications for the corresponding classifications (A or B).

COMPOSTING METHODS

Biosolids composting has become an affordable, environmentally sensitive alternative to other methods of sludge disposal. Properly composted biosolids, provide a sanitary humus-like material that meets regulations for land application. Various composting methods are capable of accomplishing a number of objectives; pathogen concentrations are significantly reduced, organic material is degraded, moisture is removed, the overall mass is reduced, and organic material is stabilized to prevent vector attraction or reinoculation by pathogens.

Wastewater sludge already contains microorganisms (bacteria, fungi and actinomycetes) which are capable of degrading organic material, stabilizing it and producing humic substances. The composting process may be characterized by four stages as depicted in Figure 1: mesophilic, thermophilic, cooling and maturation [7]. The initial mesophilic stage includes a rise in temperature to about 40° C which corresponds to the appearance of mesophilic bacteria and fungi. These microorganisms are largely replaced by thermophilic bacteria, actimonycetes and thermophilic fungi, in the thermophilic stage, where the temperature rises to 60° C. As this temperature is sustained, heat is released and maximum degradation is achieved. Pathogen concentrations are also significantly reduced at this higher temperature. A cooling down stage coincides with a drop in temperature and the replacement of thermophilic bacteria with mesophilic bacteria and fungi. Microbial activity is slowed as degradable organics are reduced. Some of the water is evaporated, pH is stabilized and humic substances form. Mesophilic bacteria continue to gradually degrade diminishing organic material in the maturation stage, which can last indefinitely. The relative stability of the biosoilids compost also increases throughout the maturation phase.

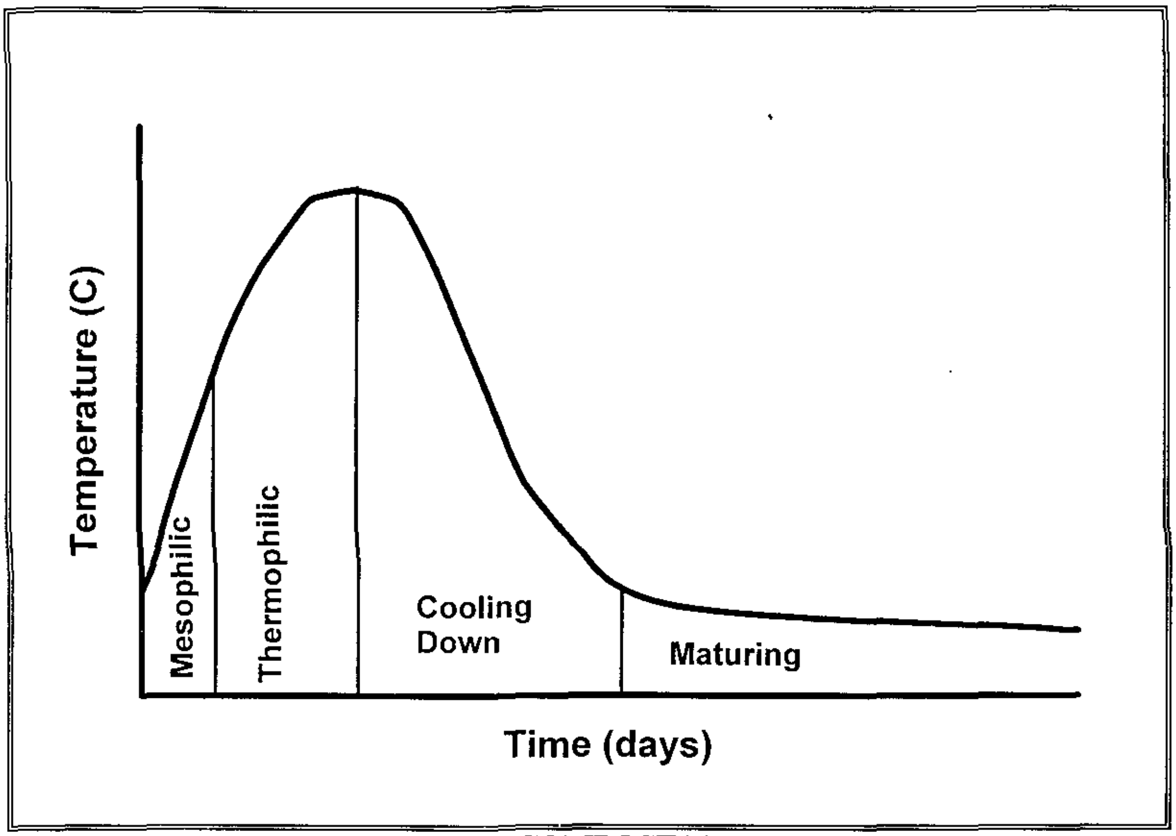

FIGURE 1: COMPOST PHASES

Production methods for biosolids composting must provide environmental conditions that promote this process. Sufficient moisture and air must be provided throughout the process to allow growth and transport of the microbes as well as access to available nutrients. Aeration and mixing can provide homogeneity of the process improving efficiency and assuring finished compost stability. The addition of a bulking agent to the sludge increases the portion of voids and reduces the moisture content making it easier to aerate and mix, while the addition of an amendment also increases the quantity of degradable organics. Wood chips from lumber production, and municipal landscaping operations are commonly used as a bulking agent, and may be recycled by screening the finished compost. Amendment materials include wood ash, sawdust, yard wastes and recycled compost. Various methods and manufactured systems are available for biosolids composting.

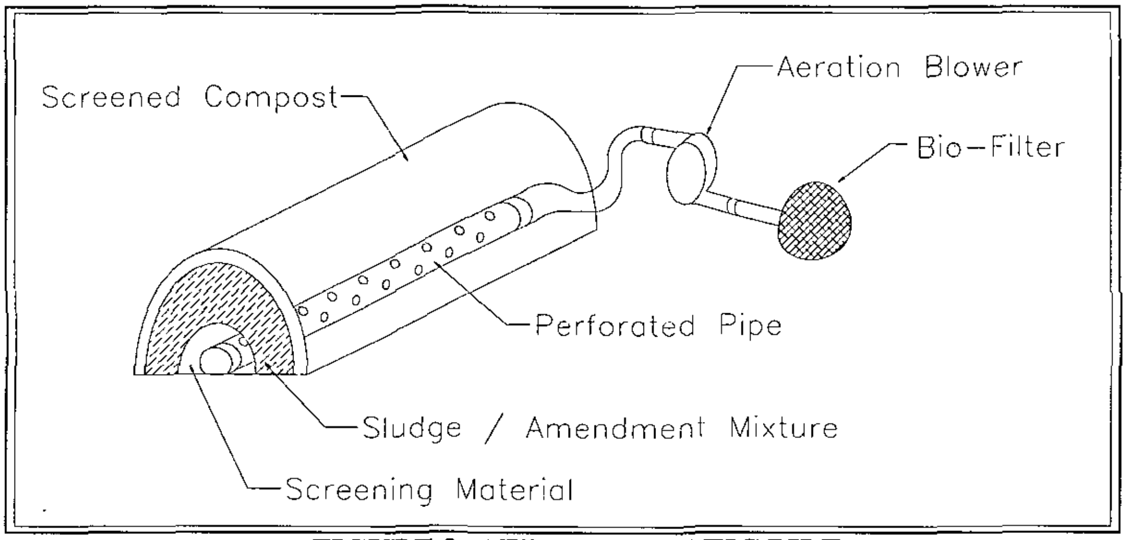

FIGURE 2: AERATED STATIC PILE

Figure 2 illustrates an aerated static pile composting system. This system may be operated outdoors, but is often placed under cover or in sheds. Wastewater sludge is mixed with amendment material in a pug mill or on a concrete pad with a front end loader. To avoid clogging, the perforated pipe aeration system is prepared by covering it with a screening material (typically wood chips). The mixed biosolids are placed in a row over the screening material and (often) covered with additional screening material or finished compost for insulation. An aeration period lasting up to 30 days is initiated which includes temperature and moisture monitoring. These measurements are in turn used to establish aeration schedules which control the process. Air blowers are connected to the perforated pipe and operated periodically in either a negative (sucking) or a positive (blowing) direction, drawing air through the pile, providing oxygen and cooling the pile. Often the exhaust from negatively oriented blowers is vented through a bio-filter to reduce odor problems by removing gases from the exhaust air. Bio-filters consist of layers of wood chips, gravel, finished compost and often plants on the surface. The aeration stage is generally followed by a curing stage where the material is moved to an area without an aeration system and allowed to stabilize for an additional 30 days or more.

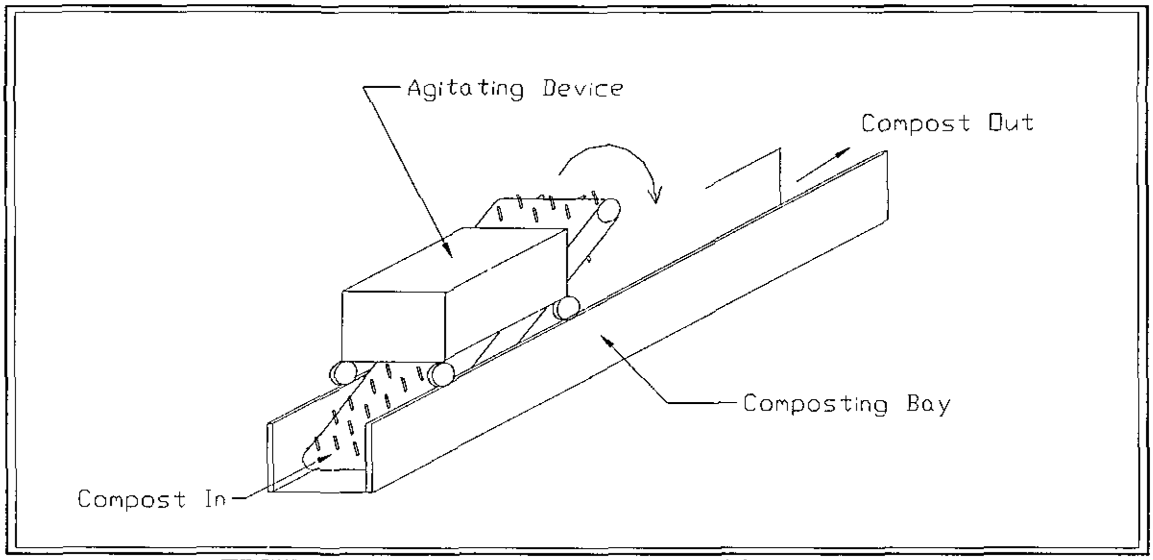

FIGURE 3: AGITATED BIN IN-VESSEL SYSTEM

In-vessel systems provide another method for biosolids composting. These systems are operated entirely indoors where temperature and moisture may be controlled more consistently [8]. Often, air scrubbing equipment is included in these systems to provide odor control. One such system, illustrated in Figure 3, employs an agitated bin method. Here the mixed biosolids are placed in one end of each bay and progress down the system as they are agitated. The agitating device rides on rails along the walls of the bays and has blades which project down into the compost mixture. This device is operated periodically, lifting the compost and replacing it some distance further down the bay. Aeration blowers connected to vents beneath the bays at various stages can be operated on complex schedules to provide oxygen, cooling and moisture control throughout the process. Once the compost mixture reaches the end of the bay it is complete and may be removed for distribution. The advantages of these systems are that they provide more consistent and reliable finished compost and have better opportunities for odor control through process control and containment.

PATHOGEN INDICATORS

Among the major concerns in biosolids composting are the destruction and removal of pathogenic organisms. Methods have been developed to detect and estimate the number of potential pathogens and indicate the effectiveness of treatment processes. While many pathogens are difficult to detect and quantify directly, other organism may provide an indication of their presence and relative numbers. Ideally, such indicator organisms would have identical behavior and growth characteristics, in addition to being safe to handle and easily quantified. Many organisms with such similarities do exist and methods have been devised to provide reasonable estimates of pathogen concentration, under controlled environmental conditions. Such methods are commonly employed to measure finished compost quality and the effectiveness of disinfection processes.

During this study the pathogen indicators total and fecal coliform were used to provide estimates of biosolids compost quality. Both total and fecal coliform are operationally defined parameters. Total coliforms are indicated by the concentration of many organisms with similar responses to environmental factors, where fecal coliforms are indicated by the concentration of the bacteria *Escherichia coli.* (*E. coli*). The Autoanalysis Colilert (AC) method [9], used in this study, gives positive or negative responses to both of these indicators throughout a series of dilutions with a defined media. Samples were prepared, diluted with sterile water, mixed with Colilert solution and incubated for 24 hours. The indicator nutrients ONPG and MUG contained in the Colilert solution were metabolized by constitutive enzymes that are unique to coliforms and *E. coli,* respectively [10]. The indicator portion of these molecules provides a response once cleaved from the nutrient portion. Positive response to total coliform is indicated by a yellow color, while positive response to fecal coliform is indicated by fluorescence. The results of the dilution series provides an estimate of the concentration of these indicators using the MPN technique. Fecal coliform (*E. coli.*) concentration estimates are considered indicative of pathogen concentrations [2].

Another technique for estimating total and fecal coliform is called the "multiple-tube fermentation technique for members of the coliform group". This method is described in Standard Methods Section 9224 [11]. Multiple incubation periods in three different nutrient broths lasting up to four days are required to obtain reliable results. The presence of both total and fecal coliform are indicated by gas formation in nutrient broths. Evaluations comparing the multiple tube fermentation (MTF) method and the Autoanalysis Colilert (AC) method in drinking water, found no significant difference between the results [12]. However, the AC method provides results within one day rather than four required by MTF. In addition the AC indicators, color and fluorescence are easier to identify than gas formation in MTF. Previous experience using the Colilert (AC) method have indicated that it is an effective means of estimating coliform concentrations.

PATHOGEN REGROWTH POTENTIAL

Finished biosolids compost gradually stabilizes as pathogens are unable to compete with indigenous organisms for diminishing organic carbon constituents [13]. In other words, when food is not available or scarce, the concentration of pathogens will dwindle. Organic carbon may be present in stable finished compost as cellulose or lignin, but these constituents are difficult to degrade and will not sustain significant pathogen concentrations. Unstable compost, on the other hand, has organic carbon sources which are easily degraded and may be utilized as a substrate for pathogen growth.

In the absence of rigorous analysis of the chemical and biological composition of finished compost, relative stability is difficult to determine. However, the change in concentration of indicator organisms may be considered a reasonable surrogate measure of stability. Indicator organisms may be estimated by techniques as previously mentioned but, sufficient concentrations of these microorganisms may not be present in finished compost samples for regrowth to occur. Therefore, compost samples were seeded with prepared cultures of *E. coli* and used to measure the change in concentration over time. Increases in the concentration of this indicator organism may be attributed to the availability of organic carbon sources for use as a substrate. This in turn, indicates the relative stability of the finished compost or the pathogen regrowth potential. Other studies [13,14] have suggested that measurement of the concentration of this indicator organism, initially and within 5 days of incubation, should provide a good indication of the pathogen regrowth potential.

Procedures:

FACILITIES TOUR, INTERVIEW AND SAMPLE COLLECTION

During a four week period, between August 18th 1994 and September 9th 1994, a tour of 16 biosolids composting facilities in Massachusetts was conducted. Initially the operators of each facility were contacted over the phone to arrange a visit of their facility. Each visit consisted of a tour of the entire facility including biosolids composting, and wastewater treatment operations where applicable. The tour was combined with a casual interview with one of the facility operators regarding the conditions of their plant. At the end of each tour a sample of the finished biosolids compost was collected.

Biosolids compost samples were collected using aseptic techniques. A sterilized scoop was used to place the sample into a soil sieve with a 1/4 inch mesh screening. The sieve had previously been wrapped in aluminum foil and sterilized by autoclaving. Samples were taken at a depth of approximately 6 inches at a single location of the most recently finished compost. The sample was sieved manually to remove wood chips and material larger than 1/4 inch. The sieved sample was then placed into sterilized plastic bags, sealed and placed in a cooler with ice packs until they could be returned to the laboratory within 24 hours of collection. Once in the laboratory, the biosolids compost samples were kept under refrigeration at 4° C.

SAMPLE PREPARATION

Biosolids compost samples were tested for pathogen indicator levels and regrowth potential within one to six days after collection. Three types of samples were prepared to indicate:

A) Existing coliform concentrations

B) Initial coliform concentration seeded with *E. coli* culture, and

C) Coliform concentration of seeded samples after five days of incubation

The moisture content of each sample was determined by standard gravimetric analysis. Portions calculated to contain one gram of dry solids of each sample were then weighed aseptically and placed into 99 ml of sterile dilution water (Sample type A). Sterile dilution water was prepared as per EPA 600/8-78-017 Section 7.1 [14]. All samples were weighed mixed and transferred in the laboratory under a laminar flow hood.

Another portion of the sample was weighed to contain 50 grams dry solids and adjusted with added dilution water to a final moisture level of 50% or greater. Samples which contained more that 50% moisture as collected were prepared without additional dilution water. One mL of a pure *E. coli* culture was used to seed these 100 g samples and assure an initial level of coliforms for the assessment of regrowth. The *E. coli* culture was prepared at least 24 hours prior to testing by reconstituting freeze-dried cells. A portion of the seeded mixture (containing 1 gram of dry solids) was placed into 99 ml of dilution water (Sample type B) and used to determine initial coliform levels. To determine the change in pathogen indicators levels (regrowth potential), a portion of the remaining mixture was placed in 50 ml BOD bottles and incubated in a 37° C water bath for five days. After five days, one gram of dry solids from each incubated seeded sample was then placed into 99 ml of dilution water and pathogen indicators were determined in the same manner (Sample type C).

LABORATORY TESTING

Each of the three types of prepared samples for each of the sixteen composts collected, were used to estimate total coliform and *E. coli* concentrations. This was achieved using the Autoanalysis Colilert method [9] and an MPN technique from Standard Methods section 9221 D [11]. Series of 10 fold dilutions of each sample were prepared by successively pipetting 10 ml aliquots into 90 ml of dilution water. Sets of three 20 ml test tubes containing 1 ml of each dilution level and 9 mls of Colilert solution were prepared. The test tubes were covered and sterilized by autoclaving prior to this testing procedure.

The Colilert solution was prepared by adding powdered mix into distilled autoclaved water as per directions [9]. Aseptic procedures using sterilized pipette tips and an open flame were followed. Dilution levels from 10^{-4} to 10^{-10} for sample types A & B and 10^{-4} to 10^{-12} for sample type C were achieved by this procedure. Two of the composts collected required additional dilutions of 10^{-4} to 10^{-12} for sample types A & B to obtain relatively accurate estimates of coliform concentrations.

The mixtures containing Colilert solution and sample dilutions were subsequently incubated at 37° C for a period of approximately 24 hours. Clear test tubes containing the incubated Colilert solution and diluted sample indicated a negative response to the presence of total coliform, while tubes that had turned yellow indicated a positive response. In addition tubes that indicated positive response to total coliform were observed in a darkened room for fluorescence in the glow of an ultraviolet light. Tubes that fluoresced indicated a positive response to the presence of *E. coli*. Positive and negative responses for both coliform indicators at all dilution levels, were recorded in a laboratory notebook. These results were then used to provide estimates of the total coliform and *E. coli* concentrations using the most probable number (MPN) technique.

SURVEY QUESTIONNAIRE

A survey questionnaire was compiled as a follow up to the interviews conducted during the tour of biosolids composting facilities, (see Appendix). This questionnaire was sent by mail to the managers of the sixteen biosolids composting facilities along with preliminary lab results and stamped return envelopes. The preliminary lab results contained estimates of total coliform and *E. coil* concentrations for all sixteen facilities observed. These results were recorded without reference to the location of each facility. Entries were listed by assigned letter identification and each manager was informed only of the identity of his or her facility. Most surveys were returned promptly by mail, while others were completed later over the phone.

Results:

WWTP OPERATIONS

In addition to information concerning composting and compost use, the survey questionnaire provided information about the wastewater treatment operations that generated biosolids material for composting. This portion of the questionnaire provided results which are compiled in Table 2. Of the sixteen facilities surveyed, 12 reported using activated sludge wastewater treatment. Other treatment methods included a rotating biological contacter, a trickling filter biological tower and one facility that used only primary clarification for wastewater treatment. Another facility reported using biosolids from various other wastewater treatment facilities. Wastewater influent flows varied from 0.03 to 43.4 MGD.

Plant I. D.	WWTP Method Used	WWTP Inflow (MGD)	Source of Compost Material	Comments on Compost Material	Dewatering Method Used	Dry Solids of Sludge* (% Solids)
O	Act. Sludge	1.8	Sludge	----	Belt Press	24
M	Primary	1.5	Sludge	----	Belt Press	25 - 35
I	Rot Bio Cont	1	Septage/Sludge	1% Grease	Belt Press	28
L	Act. Sludge	0.03	Sludge	1% Grease	Belt Press	25.5
A	Varies	Varies	Varies	----	Belt Press	30
N	Act. Sludge	3.2	Sludge	----	Belt Press	22-24
C	Act. Sludge	2.5	Sludge	----	Belt Press	20-25
P	Act. Sludge	43.4	Sludge	----	Belt Press	38
H	Act. Sludge	2	Sludge	----	Flit. Press	36
G	Act. Sludge	5.4	Sludge	----	Belt Press	18-22
K	Act. Sludge	0.9	Sludge	----	Vac. Filter	13
E	Act. Sludge	0.13	Sludge	----	Belt Press	18
F	Bio-Tower	2-2.5	Sludge	----	Belt Press	40-45
J	Act. Sludge	0.32	Sludge	39% Septage	Belt Press	40
B	Act. Sludge	4	Sludge	1% Grease	Belt Press	18-23
D	Act. Sludge	0.14	Sludge	----	Belt Press	14-16

TABLE 2: WASTEWATER OPERATION PARAMETERS

* Sludge moisture after dewatering.

Biosolids material used for composting included various combinations of primary and secondary sludge along with septage, grease and grit. One facility reported using biosolids derived from the Zimpro process [15]. Wastewater sludge was dewatered by belt filter presses in fourteen of the facilities. A vacuum filtration process was employed in one facility, and a unique filter press operation in another facility provided dewatered sludge at 36% solids content. The solids content of dewatered sludge varied considerably from 13 to 45%.

COMPOST OPERATIONS

Table 3 includes questionnaire results regarding composting operations for each of the sixteen biosolids composting facilities.

Plant I. D.	Compost Method Used	Major Amendment Material	Amendment / Sludge Mixture	Time under Aeration (days)	Curing Time (days)	Time under Cover (days)
O	IPS In Ves.	Yard W. & Recl.	Varies	Varies	30	Aer. Time
M	Aer. Stat. Pile	Wood Chips	2 / 3	27	30	60
I	Extended Aer.	Wood Chips	1 / 1	30	60	30
L	Royer In Ves.	Wood Chips	0.75 / 1	45	60	Always
A	IPS In Ves.	Saw Dust etc.	1.5 / 1	21-28	None	21-28
N	Aer. Stat. Pile	Wood Chips	3 / 1	21	60	21
C	Aer. Stat. Pile	Wood Ash	1.5-2 / 1	14-16	28	21-28
P	Taulman In Ves.	Wood Pallets	3 / 1	21	30-60	21
H	Aer. Stat. Pile	Wood Chips	1.5 / 1	30	90	None
G	Aer. Stat. Pile	Wood Chips	3 / 1	24-30	Varies	24-30
K	Aer. Stat. Pile	Yard Wastes, etc.	1.5 / 1	21	90-240	0
E	Aer. Stat. Pile	Wood Chips	3 / 1	31	30	0
F	Aer. Stat. Pile	Wood Ash	4 / 1	21	21-30	45
J	Aer. Stat. Pile	Wood C. & Recl.	3 / 2 / 1	21	30	21
B	Aer. Stat. Pile	Wood Chips	3-4 / 1	28	30	28
D	Aer. Stat. Pile	Wood Chips	3 / 1	30	30-5yrs	30

TABLE 3: COMPOST OPERATION PARAMETERS

The composting methods employed by the facilities surveyed are illustrated by Figure 4. The majority of facilities (12 out of 16) used the aerated static pile method of composting. Three of the facilities are using in-vessel systems with agitated bins, aeration and compost turning equipment (IPS & Royer). One unique facility is using a Taulman vertical silo continuous feed system.

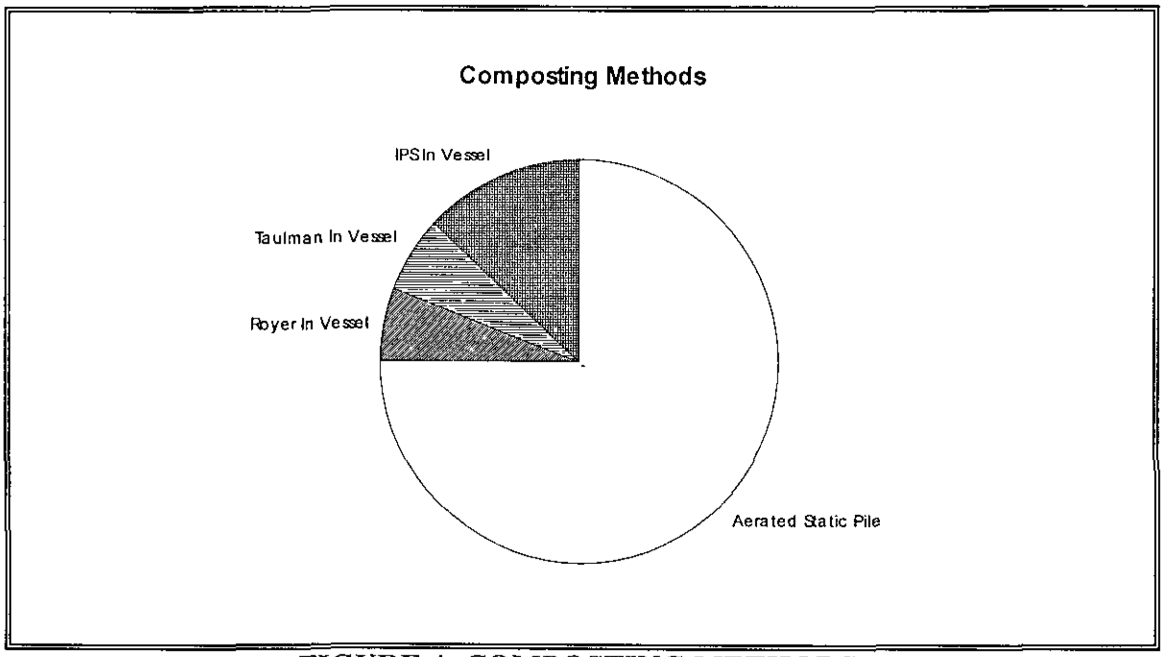

FIGURE 4: COMPOSTING METHODS

The distribution of amendment material (also referred to as a bulking agent) is illustrated in Figure 5. The majority of facilities, including nine aerated static piles and one agitated bin system, are using wood chips as a bulking material. Two of the facilities using aerated static piles systems are using wood ash as an amendment to control odors. Yard wastes are used by one agitated bin and one aerated static pile system. The facility operating the Taulman in-vessel system is using shredded wood pallets as a bulking agent. Sawdust is used as an amendment in one of the agitated bin systems.

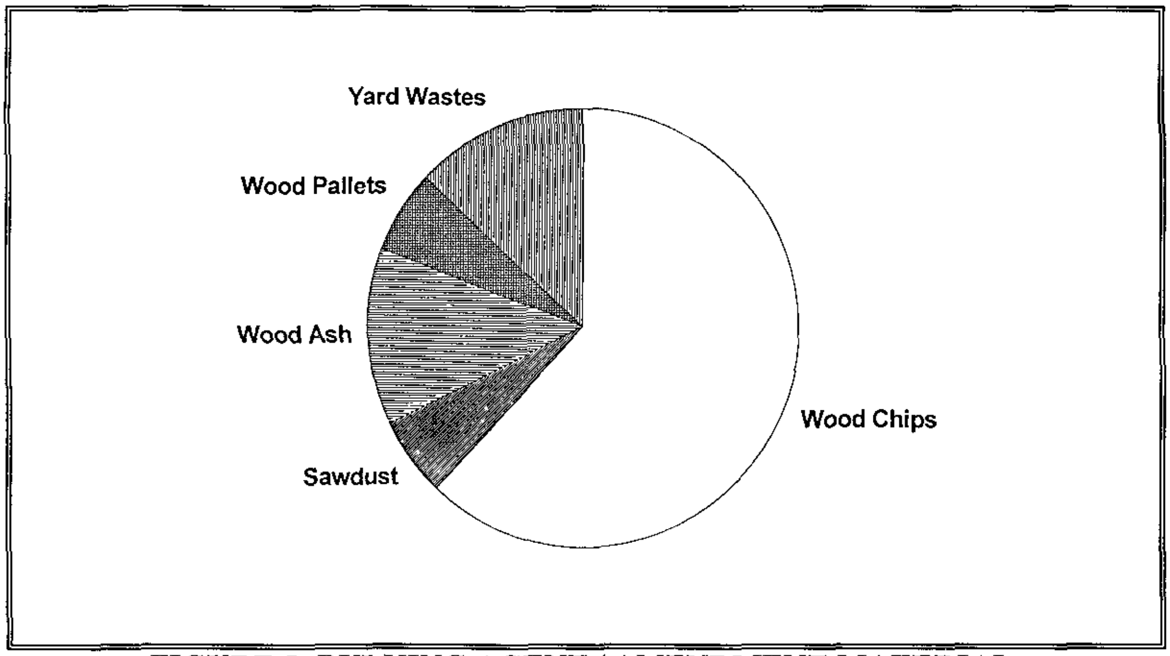

FIGURE 5: BULKING AGENT / AMENDMENT MATERIAL

The length of time utilized for active (aerated) compost processes varied from 14 to 30 days for various operations. In most cases an additional period of 30 days or more was allowed for curing of the compost prior to any distribution or land application. The location of composting operations (inside / outside) is illustrated in Figure 6. The majority of operations including two in-vessel and nine aerated static pile systems, aerated the compost indoors or under cover and cured the compost outdoors. Two in-vessel and two aerated static pile systems operated entirely indoors while three additional aerated static pile systems operated entirely outdoors. Outdoor operations were limited in their ability to control moisture due to rainfall. While aeration equipment could be configured and operated to reduce moisture, this procedure is costly and not entirely effective.

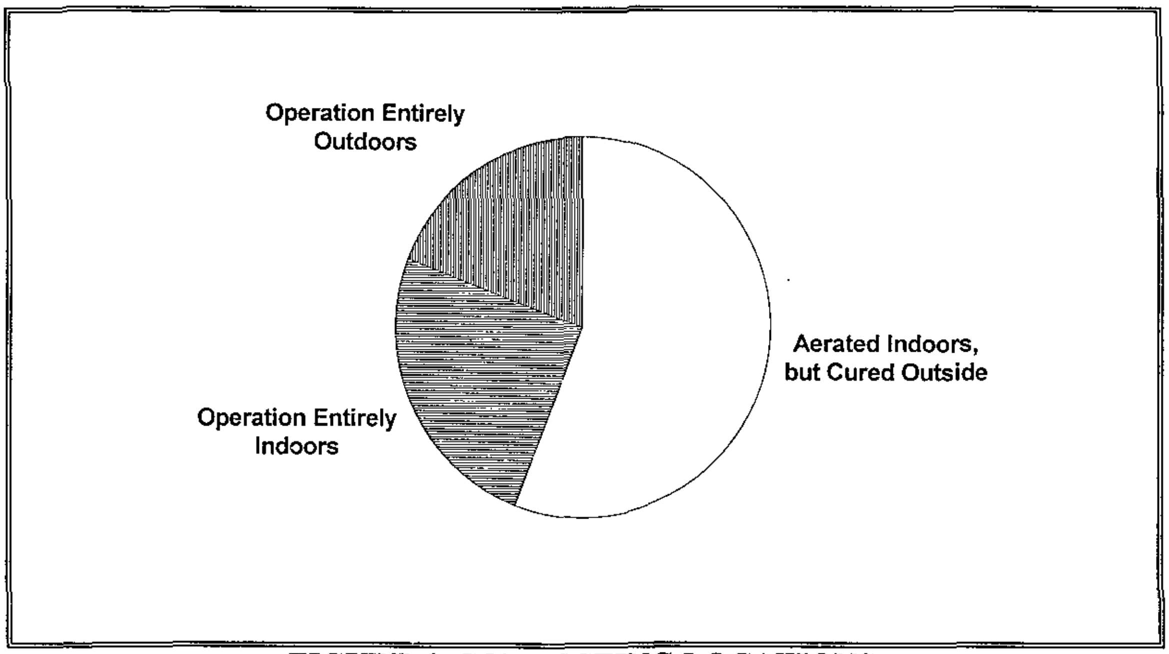

FIGURE 6: COMPOSTING LOCATIONS

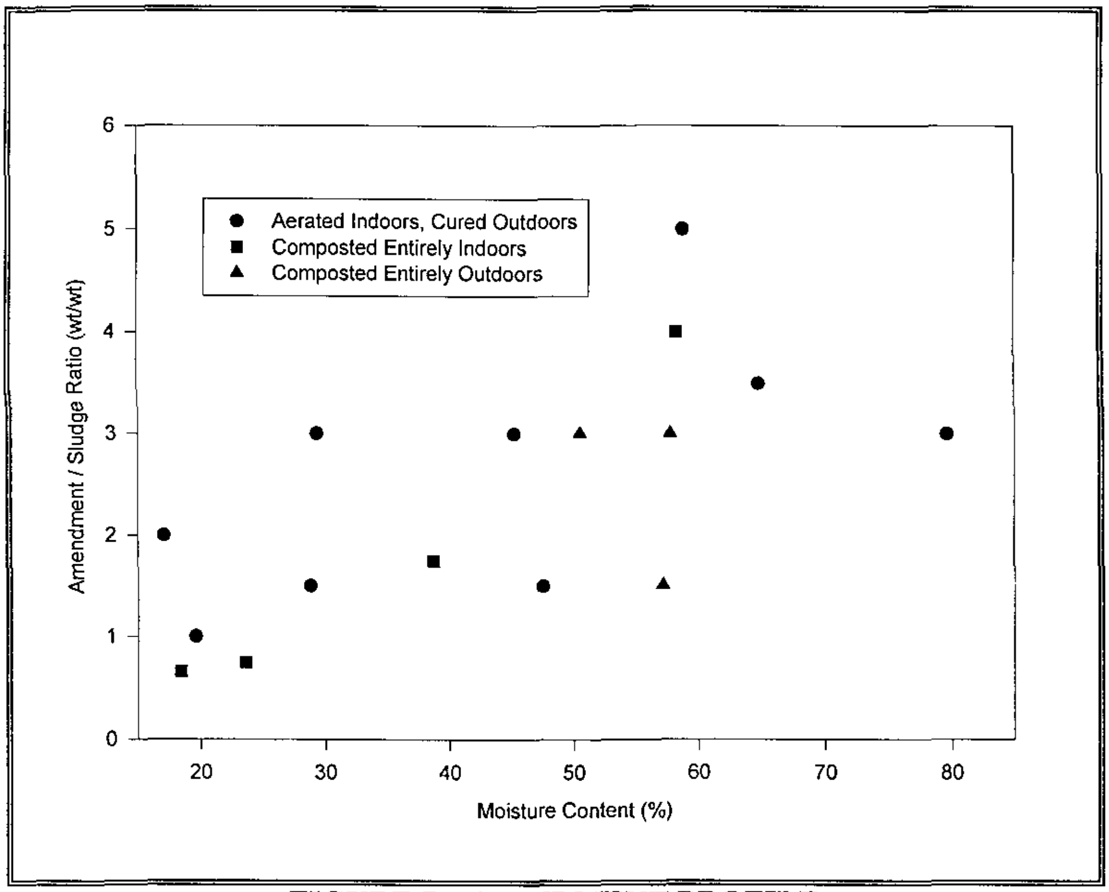

FIGURE 7: AMENDMENT PROFILE

An amendment material profile is shown in Figure 7, where the initial amendment to sludge ratio is plotted against the final compost moisture level. The location(s) of composting operations and amendment materials are also indicated in Figure 7. This figure suggests a mild trend where finished compost moisture content seems to be positively correlated to high initial mixture ratios. A correlation coefficient of r =0.67 was calculated. In addition, composts developed indoors tend to have lower moisture contents and lower mixture ratios. This trend does not appear to be due to differences in the type of amendment material used. Figure 8 is a plot of the same amendment to sludge ratios as a function of sludge dry solids content. A correlation coefficient of r = 0.24 indictes that there is very little correlation between these parameters.

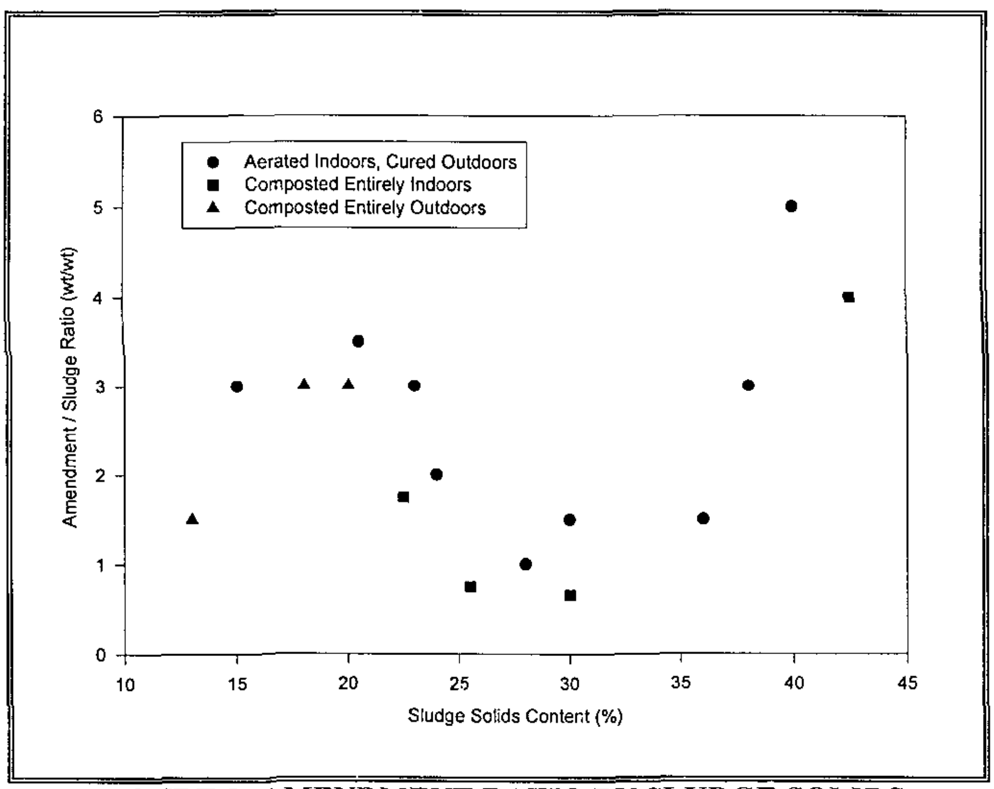

FIGURE 8: AMENDMENT RATIO BY SLUDGE SOLIDS

PROCESS MONITORING

Survey questionnaire results concerning temperature and moisture monitoring along with the determination and scheduling of aeration blowers, are included in Table 4. Temperature monitoring was conducted by all facilities on schedules which varied from every other day to continuous. Moisture monitoring, on the other hand, was only done by seven of the facilities on schedules ranging from one time only to twice a day. Aeration blower schedules were largely determined by temperature variations. Figure 9 illustrates the variation of average blower schedules as related to sludge solids levels. Where specific time intervals or blower direction were not specified, average values ranging evenly from negative to positive were plotted.

Plant I. D.	Temperature Monitoring Schedule	Moisture Monitoring Schedule	Blower Schedule (min/hr)	Blower Schedule Determination
O	Daily	None	by Temp	Temperature
M	Daily	Once	Negative 8	Temperature
I	2 x/day	None	Positive 10	Moisture
L	Daily	Before & After	Positive 2-10	Temp. & NH_4
A	Continuous	Random	Positive 1-36	Temperature
N	Continuous	Daily	Varies	Temperature
C	2 x/day	None	Negative 20	Temperature
P	Continuous	None	Positive 60	by Method
H	Daily	None	Varies	Temperature
G	2 x/day	None	Negative	Temperature
K	@ 2 days	@ 2 days	Positive	Temperature
E	Daily	None	Varies	Temperature
F	2 x/day	2 x/day	Positive 4	Temperature
J	2 x/day	None	Positive 20	Temp & Moist
B	Daily	Random	Negative	Temperature
D	Daily	None	Negative	Temperature

TABLE 4: COMPOST MONITORING

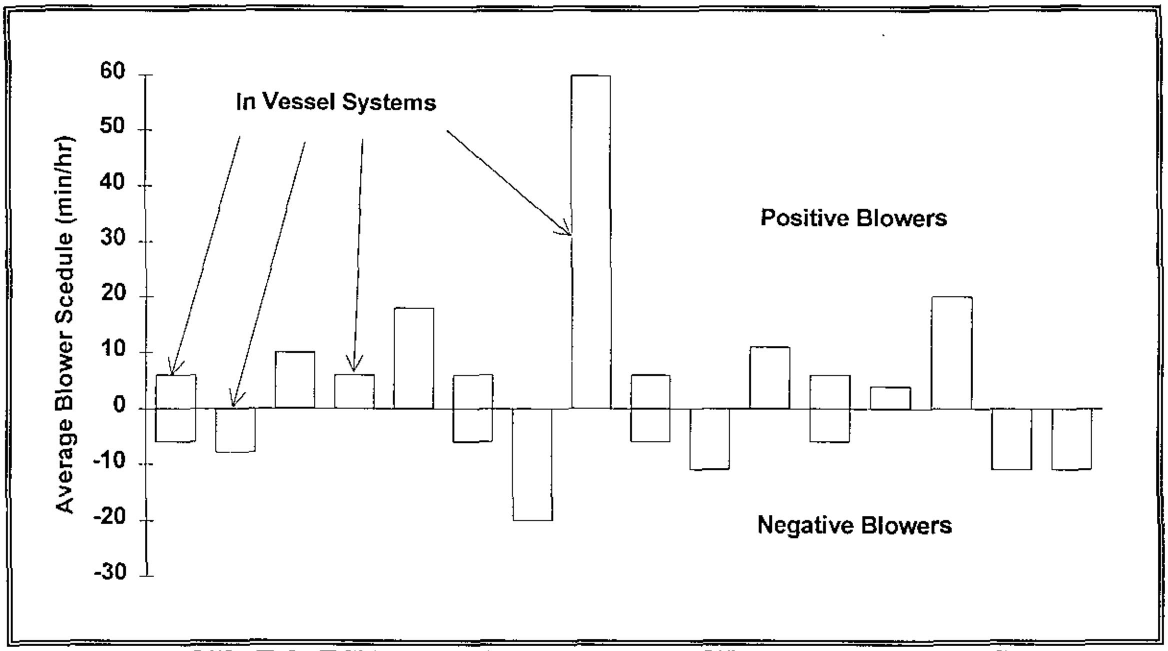

FIGURE 9: ESTIMATED AERATION CHARACTERISTICS

COMPOSTING MARKETING

Questionnaire results regarding EPA classifications, production and biosolids compost applications are compiled in Table 5. The distribution of EPA classifications is presented in Figure 10. The majority of facilities surveyed (9 out of 16), which included six aerated static pile systems and three in-vessel systems, obtained Class A ratings (EPA classification) based on the quality of their finished compost. Three aerated static pile systems obtained ratings of Class B. One aerated static pile and one in-vessel system had classification results still pending and two aerated static pile systems had not obtained any rating. Biosolids composting facility managers listed copper and cadmium concentrations among the standards which were difficult to achieve in the finished compost.

Plant I. D.	Compost Rating (EPA)	Most Difficult Regulation	Compost Production (cu. yd./mo)	Finished Compost Application
O	Pending	None	600	Landfill
M	Class A	None	400	Gardens
I	Class B	Copper	45	Landfill
L	Class A	Copper	75	Landfill
A	Class A	None	900	Landfill
N	Class B	None	150-300	Landfill
C	Class A	None	1200	Gardens
P	Class A	Cadmium	3000	Landfill
H	Class B	Cadmium	?	Stockpile
G	Class A	None	300	Soil Blend
K	Class A	None	400	Gardens
E	Pending	None	3	Stockpile
F	None	None	1100	Landfill
J	Class A	Copper	200	Landfill
B	Class A	None	500	Gardens
D	None	Metals	>2.5	Stockpile

TABLE 5: COMPOST CLASSIFICATION & APPLICATIONS

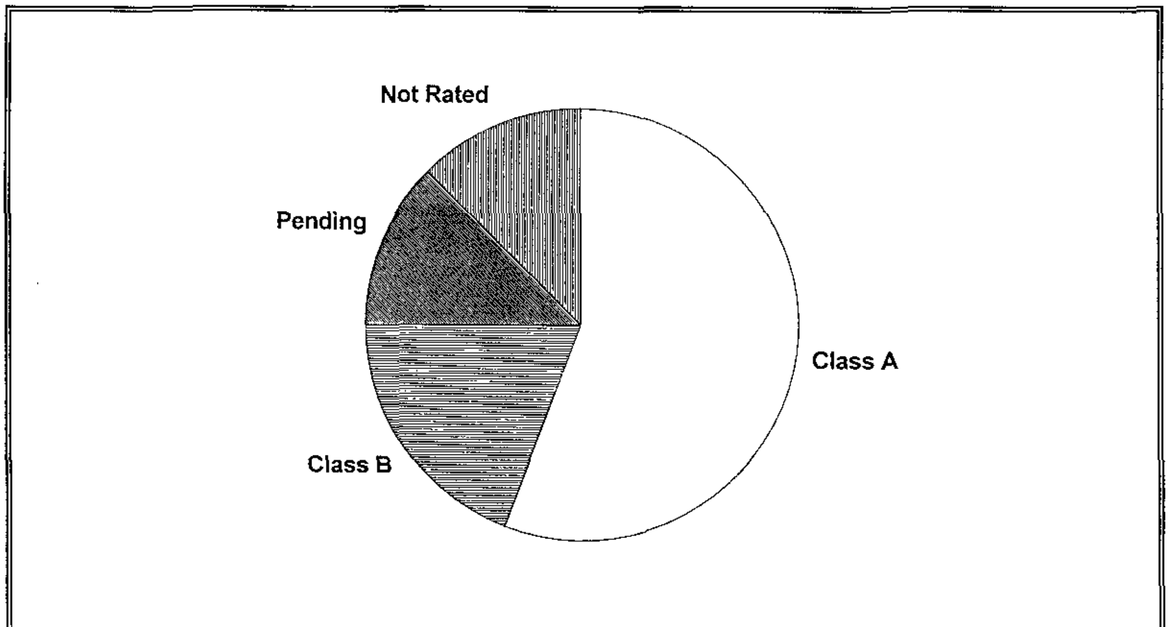

FIGURE 10: EPA CLASSIFICATION

Finished compost quantities varied widely between facilities from less than 2.5 to 300 wet cubic yards per month. The distribution of biosolids compost applications is presented in Figure 11. Four aerated static pile and all four in-vessel systems provided material for landfill application as both daily cover and final cover. Three facilities were stockpiling finished compost. Four facilities had found markets for their product as lawn and garden applications and one facility uses the finished compost for a soil blending process.

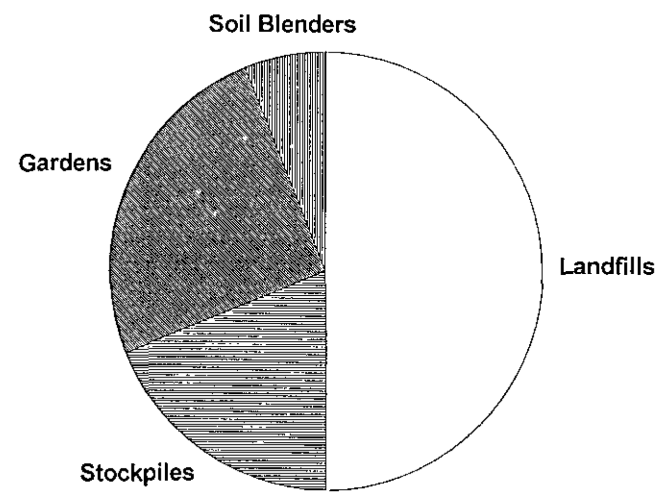

FIGURE 11: FINISHED COMPOST APPLICATIONS

LAB RESULTS

Table 6 provides a summary of the results obtained in laboratory testing of the biosolids compost samples. Moisture content of the finished compost samples varied from 17 to 80%. Estimates obtained by the Colilert method for both total coliform and *E. coli* concentrations are listed for each sample in each of three preparation types: A) existing coliform concentration, B) initial coliform concentration with seeded *E. coli* culture and C) coliform concentration seeded culture after five days of incubation. The estimation of total coliforms is not considered an indicator of pathogen concentrations, but is included here for completeness.

Plant I. D.	Moisture (%)	A) Existing Concentration Day 0 (log MPN/g)		B) With *E. coli* Added Day 0 (log MPN/g)		C) Incubated W/ *E. coli* Day 5 (log MPN/g)	
		Total	*E. coli*	Total	*E. coli*	Total	*E. coli*
O	17.1	5.04	3.38	5.66	4.04	6.66	4.04
M	18.4	5.04	<1.48	6.38	3.66	9.38	6.38
I	19.6	5.04	3.66	4.38	2.18	8.18	6.87
L	23.6	2.36	<1.48	5.04	4.66	1.60	<1.48
A	28.8	2.52*	1.48*	2.97	2.36	2.36	2.36
N	29.3	6.66	5.38	7.04	5.04	4.38	3.32
C	38.7	4.20*	2.91*	4.66	4.66	5.04	3.66
P	45.2	4.66	2.63	5.04	2.88	2.36	2.36
H	47.5	2.63	<1.48	3.38	2.63	5.81	<1.48
G	50.5	7.66	5.04	7.32	4.66	5.66	2.97
K	57.1	3.38	<1.48	4.04	2.63	2.18	<1.48
E	57.7	5.82*	1.48*	5.38	2.36	3.66	<1.48
F	58.3	1.48*	<1.48*	4.38	4.38	3.38	2.36
J	58.8	4.04	<1.48	3.87	1.60	<1.48	<1.48
B	64.8	6.66	<1.48	5.38	4.32	7.04	<1.48
D	79.6	8.38	6.38	>7.38	6.04	7.66	6.38

TABLE 6: LABORATORY TEST RESULTS

* Indicates the average of two measurements.

A plot of the estimates of existing *E. coli* concentrations in order of final compost moisture contents is presented in Figure 12. The EPA Class A and B maximums for this parameter along with the reported ratings are also included in this plot. Five facilities were found to have existing pathogen concentrations in excess of the minimum Class A requirement, including one sample from a facility that has been rated as Class A. One facility had estimated existing *E. coli* concentrations in excess of EPA's Class B minimum requirement, but was not rated. *E. coli* concentrations below 30 MPN/g could not be detected by the sample preparation used in this study. No correlation between *E.*

coli concentration and finished sludge moisture content was found. However Figure 13, plotting *E. coli* concentrations as related to dewatered sludge solids content, shows a slight trend of higher values in composts derived from sludges with lower solids content.

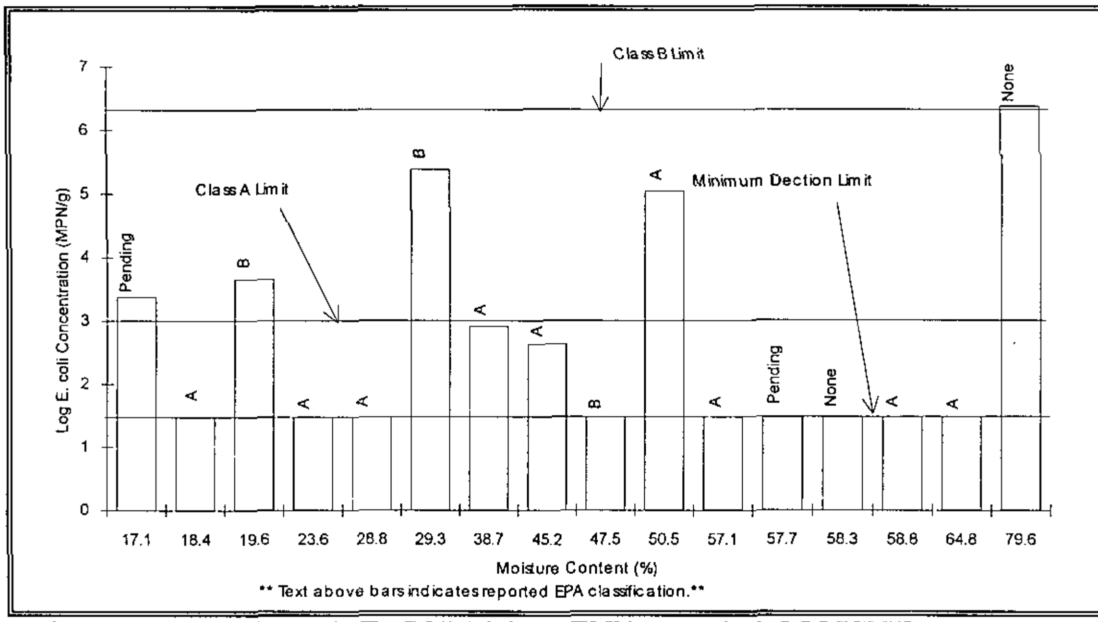

FIGURE 12: EXISTING *E. COLI* CONCENTRATION; MOISTURE PROFILE
Note: Text above bars indicates reported EPA classification rating.

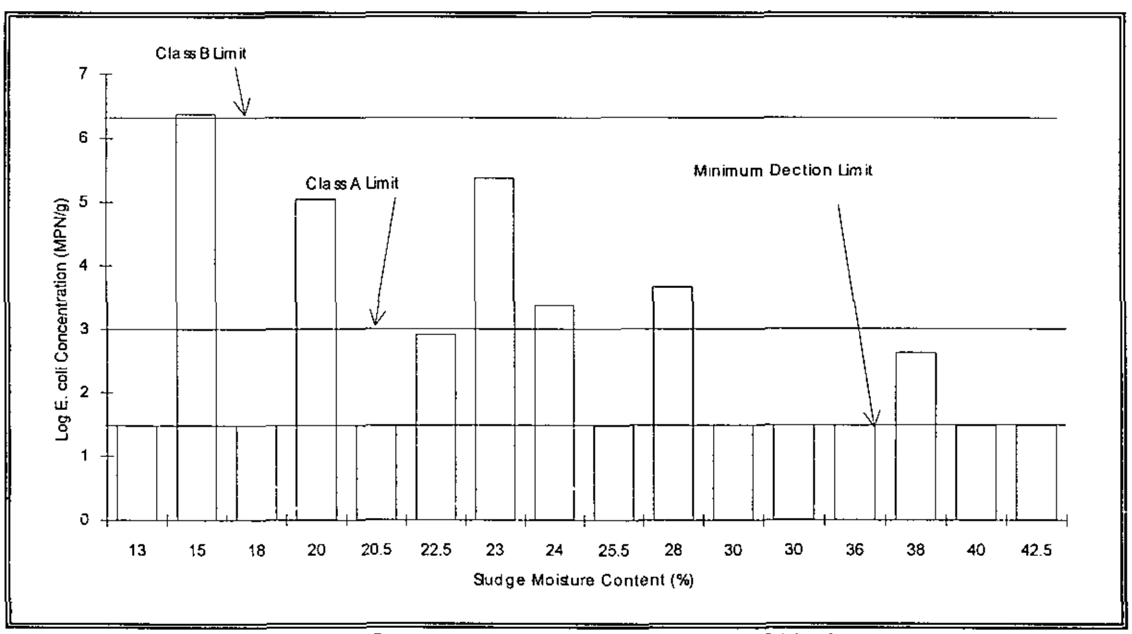

FIGURE 13: EXISTING *E. COLI* CONCENTRATION; SLUDGE SOLIDS PROFILE

Figure 14 plots the change in added *E. coli* concentrations after a five day incubation period in order of finished compost moisture content. This parameter is plotted on a logarithmic scale to depict the full range of values. Samples which had higher concentrations after five days are indicated on this figure as positive regrowth. The relative location and length of each shaded bar above the clear sections, indicates the initial and final concentration after five days, along with the change in concentration. While three of the samples tested indicated an increase in *E. coli* concentrations, two additional samples maintained constant concentrations (no change). These five samples had either low or extremely high moisture contents. The other eleven samples tested indicated decreases in *E. coli* concentrations during the five day incubation.

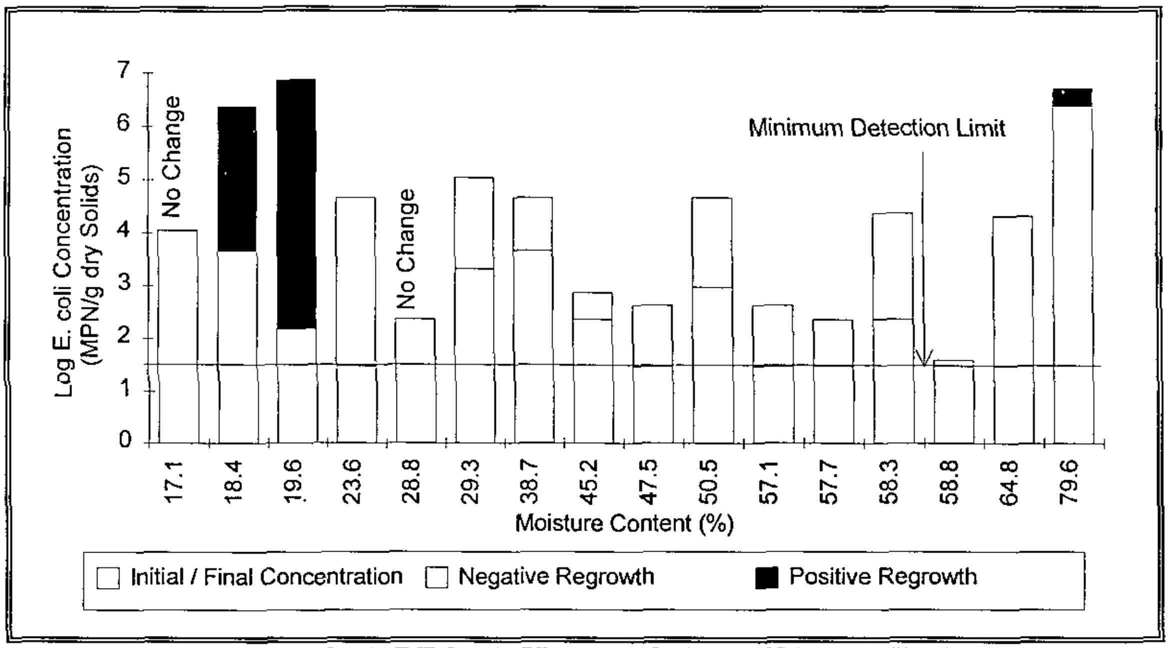

FIGURE 14: REGROWTH / MOISTURE PROFILES

OBSERVATIONS

During the tour of the sixteen biosolids composting facilities, interviews and observations provided additional information about operational conditions. Variations in the preparation and operation of aerated static pile systems included different blower systems and equipment. Many facilities used only wood chips around blower vents or as a cover for the piles. A few operations incorporated bio-filters or air scrubbing systems to treat the discharged air and reduce odors. Equipment for separating and recycling wood chips varied in the size of screen meshes from 1/4 to 3/4 inches. The finished compost was often aerated to remove moisture and facilitate wood chip screening. Additional amendment material such as recycled compost and other organics such as grease and food wastes were periodically added to the compost mixtures.

Some observations suggested potential problems. Many facilities used the same front end loader for both initial mixing and final removal providing on opportunity for recontamination with pathogens. In-vessel operations likewise, could not sterilize the agitating equipment between applications. Stockpiled compost was left outdoors for long periods without aeration, gaining moisture and providing opportunity for indigenous plant migration. Leachate formed in the aeration system was not contained. Extremely high temperatures were generated by in-vessel systems which were not controlled by aeration. Mixing of sludge and bulking agent was often performed with a front end loader on a cement pad, providing insufficient mixing. Equipment designed for farm operations performed poorly requiring frequent maintenance and delays. Many daily problems and practices occur which may contribute to the quality of the finished compost in terms of pathogen concentrations and regrowth potential.

Discussion:

It's important to consider, when evaluating these results, that the scope of this survey was somewhat limited. In the interest of obtaining results from all 16 facilities in Massachusetts, sampling and laboratory testing procedures were minimized. Grab samples obtained for laboratory testing were collected randomly from only a single location at each facility. Consequently the test results should only be used to suggest potential trends and variations in compost quality. Results obtained from the questionnaire also contain inherent inaccuracies. Facility managers may have reported operational conditions based on individual bias or uncertainty. Interpretation of questionnaire answers may have contained some inaccuracy or excluded some information. Data analysis of the combined survey and laboratory results do however suggest some trends.

A correlation between finished compost moisture content and the amendment / sludge mix ratio is suggested by Figure 7 as indicated in the results. Mixtures containing higher proportions of amendment materials might be expected to contain less water, due to more uniform aeration contributing to evaporation. Amendment materials also generally contain less initial water than dewatered sludge. However, moisture contents of the finished compost samples were generally higher when more amendment material was used. This trend is also apparent when only samples amended with wood chips are considered. Figure 8 plots the amendment / sludge ratio as a function of dry solids contents of the sludge. Where amendment material is often added to sludge as a bulking agent to reduce the moisture content of the mixture, the ratio of amendment to sludge would be higher for sludges with lower dry solids content. This correlation is not seen here. These variations may indicate the need for more carefully controlled operations.

Moisture is a important factor in aerated biosolids composting. Recommended procedures suggest that moisture levels of 40-65% be maintained throughout the composting process [16]. Moisture levels outside of this range will inhibit aerobic microbial activity. As water levels are reduced, ionic salts become more concentrated and osmotic pressure in the microorganisms is increased, often leading to their destruction. In addition, moisture is needed for microbial transport and access to nutrients. High levels of moisture result in areas that do not have any air or oxygen. Pockets within the compost can become anaerobic and require much more time to degrade organic material. Anaerobic processes also do not generally produce the heat needed for pathogen removal. The effects of both high and low moisture contents are suggested by the results presented here, as seen Figure 14. Moisture levels were not monitored regularly by many of the 16 facilities surveyed. Perhaps this parameter should be more carefully controlled.

Some of the operational practices observed may need to be more closely scrutinized. Equipment used for mixing or turning raw sludge may reintroduce pathogens into the finished compost. Quality control measures which assure relative stability and minimize pathogen regrowth potential may alleviate this problem. Drying operations conducted to facilitate removal and recycle of wood chips may inhibit the maturation stage of degradation, thus limiting the degree of stability. The mixture ratios and materials used for biosolids composting may need to more carefully selected. The determination of aeration schemes may be more closely related to temperature and moisture conditions. Apparatus for the addition of moisture and control of leachate might be considered.

Operational conditions may need to be more closely controlled to assure consistent quality of the finished compost in terms of pathogen survivability and regrowth. Operators of composting facilities have already developed methods for handling compost materials and equipment. Perhaps operators should attend specialized training sessions to insure a better understanding of composting operations in terms of compost quality and pathogen removal. Methods can be developed which account for variability in bio-mass and amendment materials while maintaining high quality safe biosolids compost. In general, more attention to operation seems necessary to insure a consistant product in terms of quality and safety.

Conclusion:

This survey provided information about the sixteen operational biosolids composting facilities in Massachusetts. Wastewater treatment processes which provided sludge for composting were mostly activated sludge systems with wastewater influent flows ranging from 0.03 to 43.4 MGD. The composition of the sludge used in composting varied from 13 to 45% solids. Biosolids were commonly mixed with wood chips, with some facilities using wood ash, ground wood pallets, sawdust and yard wastes. Compost mixtures varied widely in materials used and amendment to sludge ratios.

Most facilities operated aerated static pile composting systems, while four facilities were using in-vessel systems. In-vessel and most aeration operations were conducted indoors or undercover. Aerated static pile operations included a curing period of at least thirty days conducted mainly outdoors prior to distribution of the finished compost. Temperature measurements were taken throughout each process and used to determine blower schedules which varied in both duration and direction. Moisture level measurements were only taken by a few facilities. Nine of the facilities obtained Class A EPA ratings while three were rated Class B. Two facilities had classification pending and two were not rated.

Moisture levels of the finished compost were between 17% and 80% water. The results of laboratory testing for pathogen indicator levels indicated that five of the samples collected had concentrations in excess of 1,000 MPN/g (Class A maximum) and one sample in excess of 2×10^6 MPN/g (Class B maximum). Pathogen regrowth was measured in three samples, two of which had moisture levels below 30% water. The other instance of regrowth was measured in a sample that contained 80% moisture. A total of nine out of sixteen of the facilities had finished moisture contents out of the optimum range (40 - 65%) for effective composting.

Eight of the facilities use their compost for landfill applications while another three are stockpiling and only five have found markets which use the compost for agricultural applications. This may be indicative of the lack of consistent quality control in biosolids compost. Considerable variations in operating parameters were observed. While the specific effects of these variations may not be well understood, often conditions are not well monitored. Variations in the choice of materials and schedules should be incorporated in operational conditions [8]. Additional research and / or careful study of operational conditions, as to the effects of various parameters on pathogen concentration and regrowth potential, may need to be considered.

Biosolids composting technology has developed considerably, in part due to the installation of facilities like the sixteen included in this study. Massachusetts has chosen to pursue a leading role in the development of new techniques. Often the quality of biosolids compost is assured by the competence of the operators of municipal facilities. The development of marketing and distribution systems has been accomplished by individuals in the interest of serving their community. In order for the development and construction of new facilities to continue, marketing of the compost product must improve. This will depend on the consistant production of a high quality safe product. This study suggests that more attention should be paid to operation of the composting process.

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Appendix:

MASSACHUSETTS COMPOST FACILITY SURVEY:

What type of wastewater treatment plant do you have(e.g. activated sludge, trickling filter, etc.)?

What is the average daily influent flow at your wastewater facility?

How much compost do you produce?

What is the raw material used for composting (sludge; primary or secondary, septage, grease, etc.)?

In what proportions?

What type of de-watering equipment is employed?

What is the moisture content of the bio-mass used for composting?

What type of compost processing is used?

What material is used as an amendment or bulking agent (wood chips, yard wastes, compost, sawdust, bio-ash, etc.)?

In what proportions?

Are temperature and / or moisture levels of the compost measured during processing?

How often?

How often is the compost turned?

What is a typical blower schedule during compost processing (negative, positive, time variations, etc.)?

How is the blower schedule determined?

How long is the compost aerated for?

How long is the compost kept under cover?

How long and where is the compost cured?

What method is used for pathogen reduction?

What do you do with the finished compost?

What are the EPA and DEP ratings of the sludge and finished compost (Type 1 or 2, Class A or B)?

Which regulations are difficult to meet?

What is the estimated cost per weight for composting?