THE DESIGN AND COST OF CLASS A AND B TREATMENT OF BIOSOLIDS USING POST-LIME STABILIZATION AND PASTEURIZATION

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Introduction

Enacted in 1993, 40 CFR Part 503 regulations impose self-implementing requirements for the use and disposal of municipal biosolids and encourage their beneficial reuse. These regulations, coupled with rapidly dwindling landfill space, are forcing many municipalities to investigate new methods of processing biosolids.

Many municipalities apply bulk biosolids on agricultural land, an economical option that normally requires only Class B pathogen reduction. If biosolids regulations become more stringent, however, Class A pathogen reduction may be required for the same type of land application. The post-lime stabilization and pasteurization process can, with only minor operating modifications, economically generate either a Class B or Class A stabilized biosolids product that is readily amenable to various beneficial reuse options.

The US Environmental Protection Agency (EPA) recognizes this simple-to-operate technology as an acceptable process that generates Class B or Class A biosolids and satisfies pathogen reduction requirements for land application required by 503 regulations.

Post-lime stabilization consists of mixing dry, screened quicklime with dewatered solids cake to form a high pH and moderately high temperature biosolids environment unsuitable for survival of many pathogens. This process produces a Class B end product satisfying one of the five Processes to Significantly Reduce Pathogens (PSRP) listed in the 503 regulations. Hydrated lime is the product of this process, as shown in the following hydration reaction:

CaO	+	$\mathrm{H2O}$	=	$\mathrm{Ca(OH)2}$	+	Heat
1.0 lb Calcium Oxide (high calcium)		0.32 lb. Water in Solids		1.32 lb. Hydrated Lime		491 Btu

The highly caustic hydrated lime causes the pH of the dewatered solids and quicklime mixture to rise above 12.0, and the heat generated by this reaction typically raises the temperature of the mixture above 50º C (122º F). Supplementing the post-lime stabilization process with pasteurization carries the stabilization process one step further, raising the temperature of the solids and quicklime mixture to 70º C Maintaining this temperature for 30 minutes produces a Class A product.

This pasteurization satisfies one of the seven Processes to Further Reduce Pathogen (PFRP) listed in the 503 regulations. The higher 70º C temperatures can be achieved by overdosing with quicklime, by using a supplemental heat source in contact with the mixture, or by a combination of the two. In this study, overdosing means adding more lime than is needed to increase the pH to 12.0.

Advantages of the post-lime stabilization and pasteurization process include the following:

* Removes 0.32 pounds of water from the mixture for each pound of calcium oxide added, further discouraging growth of microorganisms and reducing hauling costs;
* Costs no more for capital equipment than other PSPR and PFRP processes;
* Costs generally less for operation than other PSPR and PFRP processes;
* Generates Class B or Class A biosolids with only minor operating modifications;
* Produces little odor, even during extended storage;
* Operates easily;
* Satisfies the 503 regulation for vector attraction reduction by attaining a high-pH;
* Avoids lime slurring and pumping equipment used for liquid lime processes;
* Reduces the likelihood of pH decay during storage;
* Produces a biosolids end product amenable to multiple beneficial reuse disposal options;
* Reduces fecal coliform densities at least as well as most other PSRP and PFRP processes; and
* Dilutes biosolids pollutant concentrations, thereby improving the likelihood of satisfying “clean sludge” pollutant limits.

Disadvantages of the post-lime stabilization and pasteurization process are:

* Potential for regrowth of microorganisms if mixing and heating are not uniform, because organic contents that promote the growth of microorganisms are not destroyed, and
* Mass of the dry solids increases with the addition of quicklime.

The objectives of this paper are to establish design criteria and estimate the costs of equipment and operation for both Class B and Class A levels of treatment using the post-lime stabilization and pasteurization processes.

Materials and Methods

Pilot Studies

Two pilot studies were conducted at the Taylorville, Illinois, municipal wastewater treatment plant using two different variable-speed, trailer-mounted mixers to process primary and waste activated solids. Characteristics of the feed solids are depicted in Table I.

Pilot mixer #1 operated at relatively high revolutions per minute (rpm) for typical retention times of less than 1 minute. It was used primarily to develop pH decay relationships and to determine quicklime dosages required to obtain Class B pathogen reduction. Pilot mixer #2 operated at a relatively low rpm, producing 3-to-5-minute retention times. It included electric heating elements bolted to the mixing chamber. An insulation jacket around the heating elements directed heat into the mixing chamber. This mixer allowed determination of lime requirements to obtain Class B pathogen reduction and the supplemental heat requirements to obtain Class A pathogen reduction.

Dewatered primary solids cake, waste activated sludge (WAS) solids cake, and blends of primary and WAS solids cake ranged from 12-30% solids as they came off a belt filter press and were loaded into the inlet hoppers of each pilot mixer. Dry pulverized quicklime in 50-pound bags was metered into the mixer inlet hopper from an adjacent volumeter screw feeder inlet hopper. Calibrating the lime feeder prior to each run enabled relating the rate of quicklime feed to the lime feeder speed setting. The quicklime feed rate was changed so that several samples at different lime dosages could be collected. The mixer blended the dewatered solids and quicklime. Representative mixture samples were collected and analyzed for pH, temperature, fecal coliform, and percent solids. The remaining contents were poured in individual piles outdoors on sloping concrete pads and marked for future evaluation.

To achieve Class A pathogen reduction through pasteurization, the temperature of the solids and quicklime mixture in pilot mixer #2 was raised by increasing the quicklime dosage, activating the heating elements, or both. A 2.0 ft3 insulated vessel was used to collect and hold the discharged mixture in order to maintain 70º C for a minimum of 30 minutes. After 30 minutes, samples were collected from the vessel and analyzed for pH, temperature, fecal coliform, and percent solids. The remaining contents were poured in individual piles outdoors on sloping concrete pads and marked for future evaluation.

Full-Scale Study

A full-scale version of pilot mixer #2 was installed at the Greenville, Illinois, municipal wastewater treatment plant, which went on line in November 1993. This study used WAS from the plant's oxidation ditch activated sludge system. Pumped to an above-ground storage tank, the WAS was decanted to attain 0.9% to 1.4% solids and then pumped to a belt filter press. Press cake was conveyed to the mixer, along with quicklime stored in a silo. A magmeter on the filter press pump discharge measured the rate of solids feed, a variable speed drive on the lime feeder controlled the lime feed rate, and a variable speed drive on the mixer controlled the solids and lime detention time in the mixer.

The drive on the lime feeder was field calibrated to determine the relationship between feeder speed and lime feed rate. During the study, the solids feed rate remained constant while lime feed rates and supplemental heat levels were varied. Samples for each run were collected and analyzed for pH, temperature, fecal coliform, and percent solids. The remaining contents were then poured in individual piles on the plant grounds and labeled for future evaluation.

Analyses

Analyses for the pilot and full-scale studies included pH, temperature, fecal coliform, and percent solids from each run after discharge and 1/2, 1, 2,3, and 6 months thereafter. Test methods included EPA-9045 (USEPA), 1992) for pH, SM-2450G (Standard Methods, 1992) for percent solids, and SM90221E (MPN) (Standard Methods, 1992) for fecal coliform.

Table I

Characteristics of Dewattered Feed solids

Location	Feed Solids	pH	%Solids	Temp(.C)	Fecal Coli.*	Mixer Tested
Taylorville	Primary Sludge	5.0	25	19	43,000	Pilot 1 & 2
Taylorville	WAS	7.1	16	19	200,000	Pilot 1 & 2
Taylorville	Prim/WAS Mix	6.5	24	19	Not analyzed	Pilot 1
Greenville	WAS	6.3	18	6	89,000	Full-Scale 2

*(MPN/gTS) - Most Probable Number per gram of Total Solids

Results and Discussion

Pilot studies were conducted during the fall of 1991, and the full-scale study was initiated in January 1995. The 6° C temperature of feed WAS in Greenville resulted from its storage in an above-ground tank for several days prior to stabilization. Lower-than-expected fecal coliform densities in the feed solids from both plants qualified those solids as Class B even without lime stabilization, based on fecal coliform density criteria Additional fecal coliform testing on the dewatered WAS will be conducted in Greenville during the spring and summer of 1995 to determine if seasonal fecal coliform density variations exist.

Variation of pH, Temperature, and Percent Solids Within Stored Samples

A visible difference existed between a 1-inch-thick crust, which was light-colored and hard, and the interior portion of each sample pile, which remained dark and pliable. Both were evaluated for pH, temperature, and percent solids.

Run #2 was typical of the variations that were recorded. The pH dropped rapidly from 12.6 to 8.9 within the first 30 days. The pH of the interior remained above 12.0 throughout the study. This rapid pH decrease in the crust probably occurred because precipitation washed alkalinity from the surface. The percent solids of the crust for Run #2 increased rapidly from 25% to 79% within the first 30 days of storage. The percent solids of the interior increased gradually from 25% to 50%. The difference is probably a result of air drying. The temperature measured 2 inches into the pile dropped rapidly after treatment, while the temperatures measured 4 inches and 8 inches into the pile dropped more gradually and at nearly identical rates. This indicated that the outer several inches of a stockpile cool more rapidly than the interior.

Based on these differences between the outer several inches and the interior, each pile was sampled from the interior in order to obtain data representative of the pile. Data in this report reflects results from interior samples, unless otherwise stated.

pH

All lime dosages are expressed as a percent of dry solids. Figure 1 shows typical pH-versus-time relationships for stockpiles from the full-scale mixer using various lime dosages. Similar results were obtained during the pilot studies. The pH of the stockpiles with 39% and 48% lime dosages using pilot mixer #2 remained above l 1.5 beyond 90 days. The pH of stockpiles with 38%, 48% and 58% lime dosages using pilot mixer #1 dropped below 11.5 after 45 days. Pilot mixer #2 produced a mixture more resistent to pH decay because that equipment generated smaller mixture particles, implying that pilot mixer #2 mixed the quicklime more uniformly. The pH of stockpiles with higher lime dosages did not drop below 12.0 during the study. Although lime doses less than or equal to 15% from each pilot mixer raised the pH above 12.0, these pH values did not remain above 12.0 beyond one day.

Figure 1: pH vs. Time Full-Scale Mixer

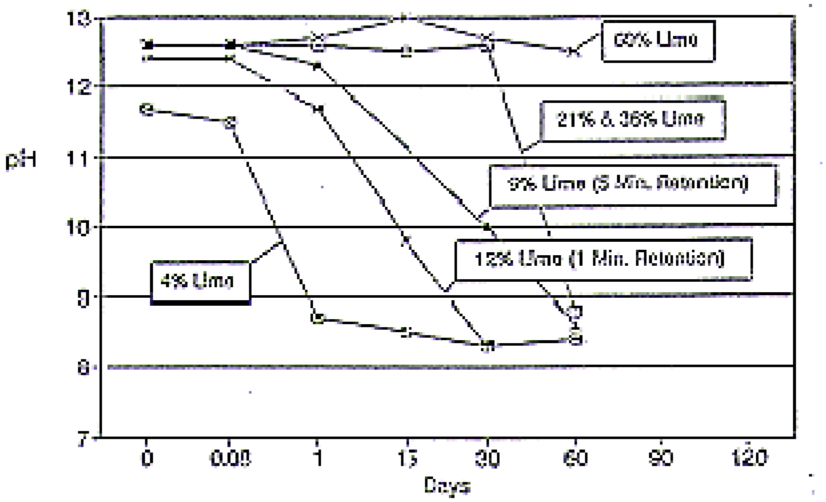
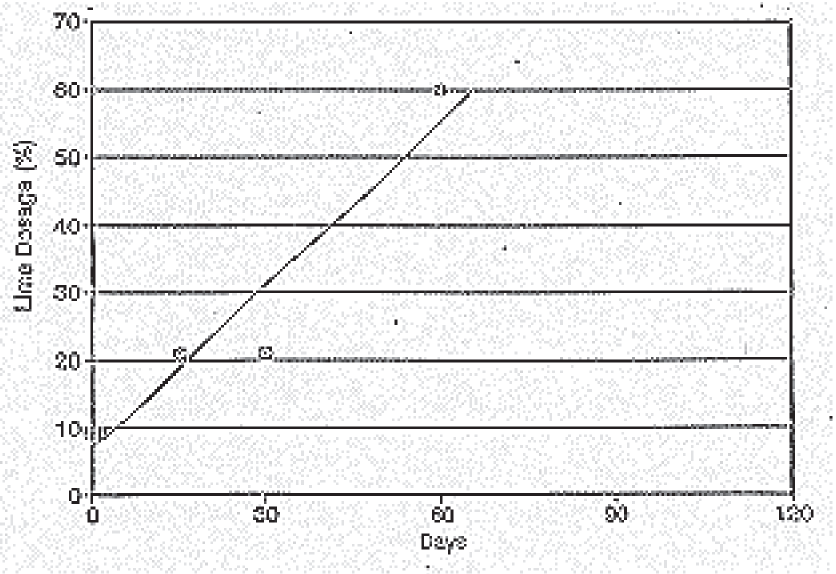


Figure 2: Minimum Lime Dosage Required to Maintain pH > 12
vs. Storage Time - Full Scale Mixer



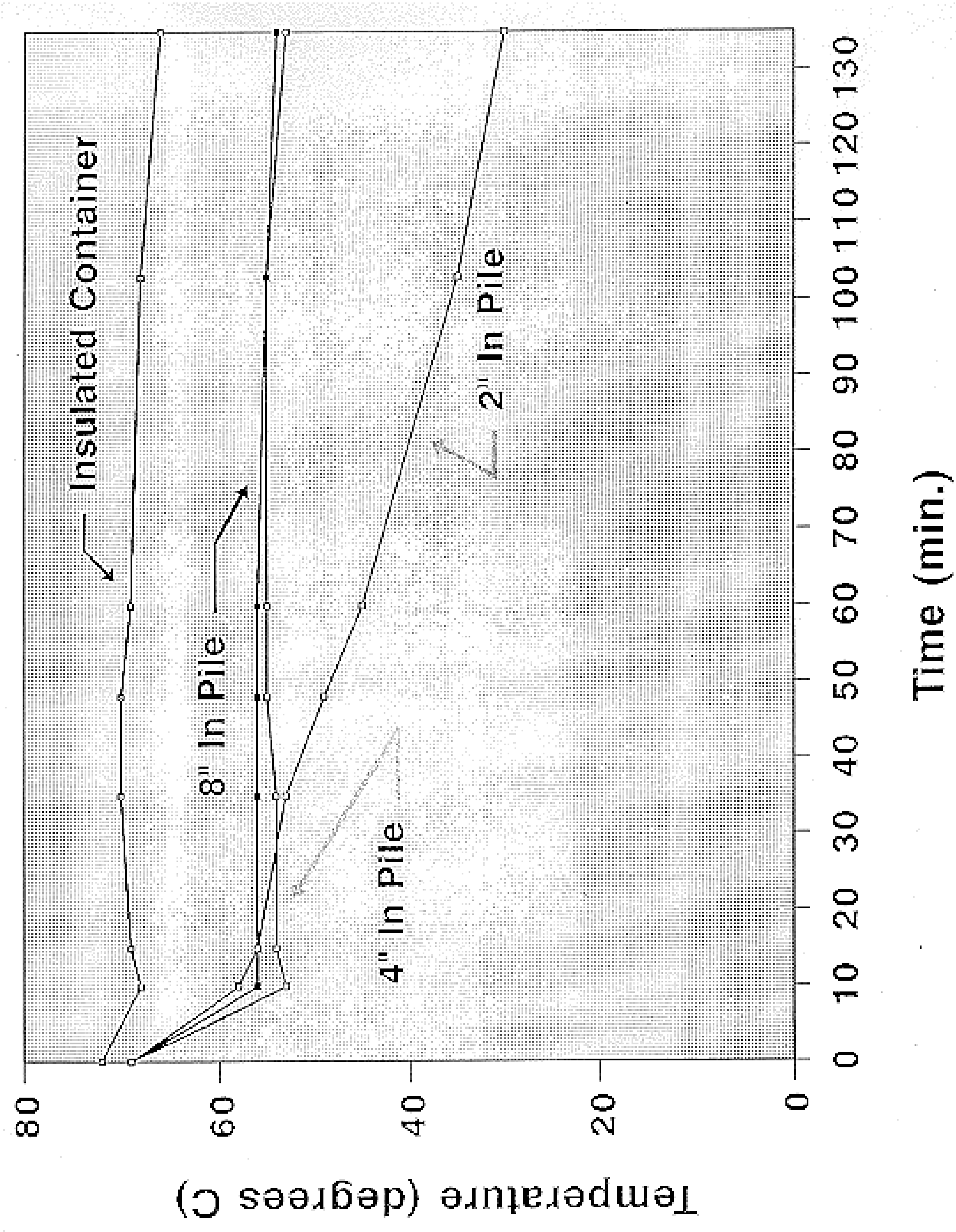

Insulated Container
8" In Pile
4" In Pile
2" In Pile
Temperature (degrees C)
0
20
40
60
80
Time (min.)
0
10
20
30
40
50
60
70
80
90
100
110
120
130

Figure 2 consolidates the pH decay results into a general design curve that gives the minimum lime dosage required to maintain pH of the biosolids > 12.0 as a function of storage time. Based on this relationship, a minimum of approximately 10% lime dosage was required to maintain pH >12.0 for 24 hours. Because the relationship as shown is site specific it should only be used to approximate lime doses for similar feed solids. Where additional accuracy is required, bench pilot studies should be conducted using the solids to be treated.

Temperature

The temperature of biosolids from each run was measured immediately after discharge from the mixer. Material from runs #11 through #14 was also placed in an insulated container immediately after discharge from the mixer. The discharge temperature of the insulated material was easily maintained for at least 75 minutes without additional heat input. During the first 30 minutes in the insulated container, temperatures of the samples actually rose another approximately 4º C.

The relationship between lime dosage and the resulting change in temperature of the biosolids and the theoretical temperature increase as a function of lime dosage are given in Figure 3. Below a lime-to-solids ratio of 1, the temperature increase as measured agrees well with the theoretical temperature increase. Above this ratio, the theoretical method to predict temperature increase disagrees with actual temperature measurements. This relationship can be used to estimate the temperature rise of biosolids associated with a specified lime dosage for similar dewatered municipal WAS feed solids.

Figure 3: Temperature Increase vs. Lime Dosage - Full-Scale Mixer

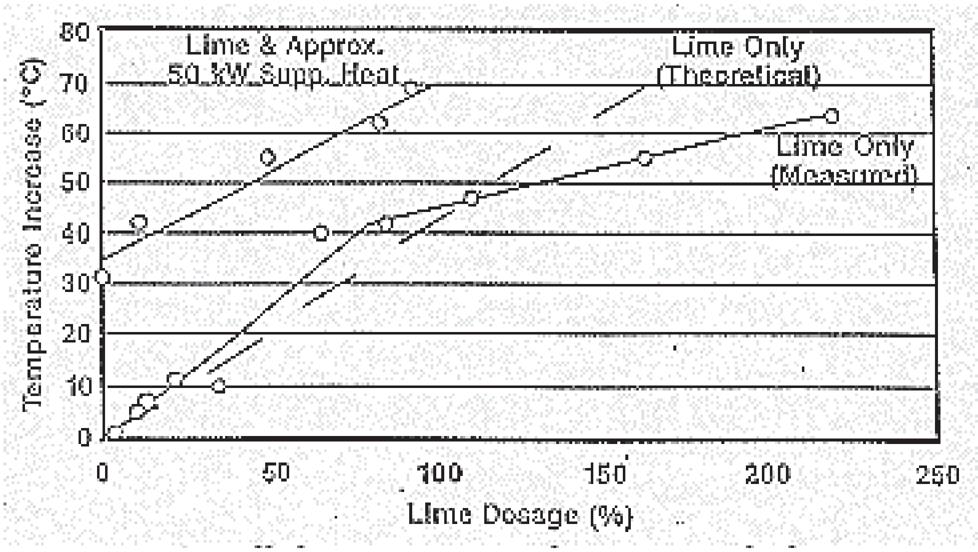


Figure 3 also shows the measured temperature increase corresponding to a theoretically determined supplemental electric heat input of 50 kilowatts. An electric heater efficiency of 75% was assumed. The Kilowatts used by the electric heaters of the full-scale mixer may be measured in the future to determine the their actual efficiency and allow a more accurate determination of the cost of using electric heaters for pasteurization.

Fecal Coliform

Without supplemental heat, an addition of 9% lime was the minimum required to reduce the fecal coliform density to less than 1000 MPN/gTS, the upper limit for Class A biosolids. All other runs reduced the fecal coliform density below 1000 MPN/gTS. The pasteurization criteria of 70º C for 30 minutes did not have to be satisfied to reduce the fecal coliform density below 1000 MPN/gTS. No noticeable fecal coliform regrowth occured in any of the samples.

Odor

Odor was never a problem during or after post-lime stabilization and pasteurization. All samples originally gave off a slight ammonia odor. It was only detectable, however, if the mixture was smelled from a distance of about 3 to 4 inches. Seven months after the pilot studies, only a slight musty odor was detectible and that only when the stockpiled material was smelled from a distance of about 3 to 4 inches.

Design Criteria and Cost Estimates

Cost estimates were determined after design criteria were established for full-scale post-lime stabilization and pasteurization systems that meet both Class B and Class A levels of treatment.

Class B by PSRP

Class B pathogen reduction by fecal coliform reduction was satisfied without adding lime because the fecal coliform density in the feed solids was already less than 2,000,000 MPN/gTS. At Greenville, the extended aeration nature of the oxidation ditch activated sludge process may allow enough endogenous respiration in the mixed liquor to reduce fecal coliform density below 2,000,000 MPN/gTS in the WAS. The near freezing temperature of the WAS may have also contributed to the low fecal coliform density.

Class B pathogen reduction by the post-lime stabilization PSRP process requires adding sufficient lime to the feed solids to raise the pH above 12.0 after two hours of contact. Illinois EPA also requires that lime stabilized biosolids measure pH > 12.0 before they can be land applied. Assuming biosolids could be land applied the day after treatment, the pH results for the full-scale study in Greenville indicate that a 9% lime dosage may be adequate to maintain pH > 12.0. A 21% lime dosage, however, adds a margin of safety to ensure maintaining the pH > 12.0 levels for at least one day. Therefore, a minimum 21% lime dosage requirement was assumed in order to estimate minimum operating costs to prepare Class B by PSRP bulk biosolids for land application. If treated biosolids must be stored and the pH must be > 12.0 at the time of disposal, Figure 2 can be used to estimate the required lime dosage.

Class A by PFRP

Class A pathogen reduction by post-lime stabilization and pasteurization PFRP process requires reducing the fecal coliform density to <1000 MPN/gTS, raising the temperature of the biosolids to 70º C, and maintaining that temperature for 30 minutes.

The fecal coliform density was lowered to less than 1000 MPN/gTS during all runs, except the 4% lime dosage. A 215% lime dosage without supplemental heat or 82% lime dosage with approximately 50 kw of supplemental heat were required to raise the 6° C dewatered solids to 70° C.

The mixtures in this study were overdosed with lime to raise the heat because heating equipment included controls to safeguard against overheating. Decreasing the lime dosage and increasing the supplemental heat, however, would have been a more economical method of satisfying the pasteurization criteria. Figure 3 was used to estimate the optimal lime dosage and supplemental heat combinations required to satisfy Class A by PFRP pasteurization requirements for a 20° C (68° F) feed solids using supplemental heat equipment. Based on Figure 3, 135% lime dosage without supplemental heat and 21% lime dosage with 198 kw of supplemental heat is the most economical combination required to satisfy the pasteurization criteria.

Table II depicts estimated equipment and operating costs for the post-lime stabilization and pasteurization processes to treat typical municipal wastewater treatment plant solids. Costs are included for Class B and Class A levels of treatment, and costs for Class A pasteurization are listed with and without supplemental heat. These systems do not require a full-time operator. The staffing cost estimates include equipment operation, clean up, and lab time for the pH measurements.

Class A level of treatment requires additional equipment to satisfy pasteurization criteria, including insulation around the mixer, an insulated pasteurization vessel for controlled-temperature storage, an additional conveyor, additional controls, and heating elements where supplemental electric heat is used.

Actual lime and electric costs are for 20° C feed solids.

Table II

Equipment and Operating Cost Estimates(a)
Post-Lime Stabilization and Pasteurization Process

Capital Equipment	Class B, by PSRP	Class A, by PFRP- w/ Supl Heat	Class a, by PFRP- w/o Supl Heat
Lime Strg & Feed Sys	Yes	Yes	Yes
Unheated Solids Mixer	Yes	No	Yes
Heated Solids Mixer	No	Yes	No
Insulated Vessel	No	Yes	Yes
Biosolids Conveyor	No	Yes	Yes
Controls	Yes	Yes	Yes

Capital Equipment Cost

0.5 Dry T/Hr Capacity	$180,000	$435,000	$325,000
1.0 Dry T/Hr Capacity	$200,000	$485,000	$345,000
3.0 Dry T/Hr Capacity	$400,000	$1,400,000	$1,000,000

Operating Cost ($/Dry Ton)

QuickLime	$16	$16	$101
Electricity	$1	$14	$1
Operator Labor	$10(b)	$16(c)	$14(d)
Total	$27	$46	$116

(a) Based on 20° C (68 F) initial feed solids temperature
(b) Based on 0.3 operator hours per dry ton processed
(c) Based on 0.5 operator hours per dry ton processed
(d) Based on 0.45 operator hours per dry ton processed

Design and Operating Considerations

The final dewatered solids and quicklime mixture is typically a granular material with clumps of solids that vary in size and are coated or impregnated with lime. Smaller end-product clumps indicate a more uniform mixing of the quicklime and dewatered solids, resulting in better heat transfer and increased pathogen reduction. While end-product clump size depends somewhat on the characteristics of the feed solids, several steps can be taken to minimize the clumps. These steps, which should be considered during design, may include one or more of the following: conduct on-site experiments to determine the optimal bed depth in the mixer, increase lime dosage, although that will also increase expense; increase solids content of the dewatered feed solids; or relocate the quicklime injection point.

Controls for the lime feeder and mixer should be variable speed and located near the mixer where the operator can visually observe the mixing process. This helps the operator to adjust equipment speeds in response to the observed clump size.

A water source should be located nearby in order to clean the mixer after processing and before shut down, especially if the mixers are located outdoors where the mixture could freeze. If the units are not emptied and cleaned after use, or left running at a slow speed, the solidified or frozen mixture surrounding the mixer augers or flights makes the mixer difficult to start the next day.

Store the solids in conical-shaped piles to eliminate depressions where rain could pool. If the pile is mounded correctly, the dry crust that eventually forms seems to protect the inside of the pile from water intrusion and pH decay. Store the mixture in a location that allows drainage away from the piles.

Conclusions

These studies indicated a high predictability of the post-lime stabilization and pasteurization process. Lime dosages and supplemental heat levels repeatedly resulted in similar end-product characteristics, leading to increased confidence in the process and those design criteria established to ensure compliance with the 503 regulations.

The minimum lime dosage required to raise solids pH above 12.0 for 24 hours was 9%. A minimum 21% lime dosage is recommended to guard against potential pH decay and to provide a smaller, more granular, end-product clump size. If properly mixed, the final biosolids product can be stored at least for several months with minimal pH decay and without pathogen regrowth or odor problems.

The relatively low fecal coliform densities of the initial feed solids prevented the author from determining with certainty the minimum lime dosage required to reduce solids fecal coliform densities to below both 2,000,000 and 1,000 MPN/gTS.

Optimal end-product clump size was generally obtained when the mixer bed depth was kept below the auger midpoint. Better heat transfer and lower pH decay occurred, however, when the mixer bed depth was kept above the augers. Operators will need to weigh the tradeoffs between end-product clump size and process performance in deciding how best to meet their specific objectives.

United States Environmental Protection Agency, (1992) ‘`Test Methods for Evaluating Solid Wastes, Vol. 1A, Laboratory Manual - Physical Chemical Methods,” SW 846, 3rd Edition. Washington, D.C.

Due to the extremely cold feed solids temperature of 6º C and safety controls on the heating elements in Greenville, a full evaluation of supplemental heat could not be made. This forced lime overdosing to obtain pasteurization, resulting in higher-than-normal operating cost. Optimizing the use of supplemental heat and lime dosage and assuming 20º C feed solids, the operating costs to produce a Class A by PFRP pasteurization biosolids using supplemental heat can be expected to total about $46 per dry ton, as shown in Table II. This is about $70 per dry ton less than the cost of producing a similar product without supplemental heat.

The local farmer who land applies Greenville's post-lime stabilized and pasteurized biosolids feels it is an improved end product over the biosolids materials he previously applied. He is especially pleased with its consistency and spreadability.

Favorable results have led to confidence in the post-lime stabilization and pasteurization process as a reliable, economical solids treatment process capable of full compliance with disposal regulations.

Acknowledgements

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