

## **Using Lime to Beneficially Manage Wastewater Treatment Plant Residuals: A Review and Assessment of the Practice for Producing an Exceptional Quality Product**

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### **ABSTRACT**

Lime is used to prepare residuals for safe beneficial use by preventing the biodegradation of organic material and either reducing the numbers (of) or eliminating any pathogenic organisms present. Lime acts in several ways including: elevating the pH and holding it at a high level for a period of time; and in some instances elevating the temperature of the residuals to a high level and maintaining it there for a specified period of time. The performance of any lime treatment system is, however, only as good as the quality of alkaline material selected, the dosage level applied, the mixing method selected and applied, the time allowed for all reactions to reach completion, and the monitoring methods employed for pH and temperature.

**KEYWORDS:** Lime treatment, alkaline treatment, exceptional quality biosolids, beneficial use.

### **INTRODUCTION**

Lime stabilization of wastewater treatment plant residuals or sludge came into common use in the United States during the 1970s. Then as a way of providing a high quality product it gained popularity in the 1980s. Its popularity, however, began to decline in the early 2000s because of issues with odor, product quality, and marketability. Alkaline treatment is viewed by many in the wastewater treatment industry as a low cost, easy way to meet the federal, state, and local requirements for beneficial use of sludge in agriculture, horticulture, and reclamation. While alkaline treatment can effectively disinfect and stabilize sludge when applied correctly, it is not a simple process, but rather one that must be properly designed and operated. This paper provides a better understanding of the practice's critical issues and an assessment of the current practices for producing an exceptional quality biosolids by lime/alkaline treatment. Then drawing upon that information it makes recommendations on how to move forward with the practice. The paper is organized into three sections: 1) A review and discussion of the key factors to consider in any lime/alkaline treatment system, 2) A detailed review of practices at numerous facilities utilizing different approaches to lime treatment including the N-Viro – like, RDP, and Bioset Processes, and 3) An assessment of the study's findings with recommendations for improved design and operation of lime/alkaline treatment systems.

**KEY FACTORS / ISSUES**

Prime reference materials reviewed include the USEPA’s 2004 Workshop and its later proceedings (USEPA, 2007), WEF’s 2009 MOP (WEF, 2009), WEF’s 2012 Solids Process Design and Management publication, and a relatively recent and comprehensive lime treatment of residuals presentation (WEF, 2012; Nicholson, 2013). The factors in the box below apply to all approaches to alkaline treatment and will be discussed in detail.

Need for EQ Product	Mixing Process
Regulatory Requirements	Monitoring Needs
Residuals to be Treated	Product Requirements
Lime/Alkaline Additive	Storage
Introduction of Lime into Residuals	Odor

**Need for EQ Product**

Exceptional Quality (EQ) Biosolids is sewage sludge or material derived from sewage sludge that meets the following criteria: 1) high quality pollutant concentration limits; 2) has undergone one of the Class A pathogen reduction alternatives; and 3) has undergone one of the vector attraction reduction options. If the biosolids are classified as EQ, they may be distributed for land application without site restrictions. Land application of EQ biosolids is not regulated by the US 40CFR Part 503 Regulation once the biosolids leave the control of the biosolids preparer. Therefore, soil blenders or other (non-preparer) users who take EQ biosolids may store the biosolids or mix the EQ biosolids with other (non-sewage sludge) materials without resampling the product. Conversely, if EQ biosolids remain within the control of the preparer, they are still considered biosolids and are still covered by the Part 503 Regulation. Like all Class A products, they must undergo microbiological testing at the last possible point before being distributed. In addition, if the preparer mixes the EQ biosolids with non EQ materials or otherwise changes the quality of the biosolids, the new material must again comply with pathogen reduction, vector attraction reduction, and pollutant concentration limits. EQ Biosolid derived product may be transported to soil blending operations to enhance the quality of the product.

**Regulatory Requirements**

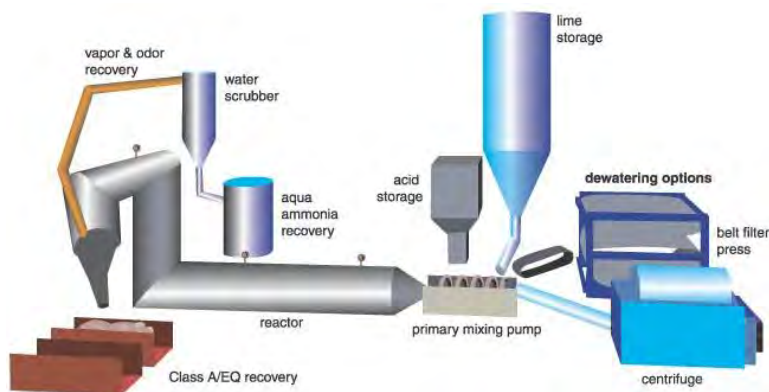
In 1993, EPA promulgated the US 40CFR Part 503 Regulation, “Standards for the Use or Disposal of Sewage Sludge” as minimum requirements (USEPA, 1993). Two classes of disinfection were described: A and B. Class A disinfection reduces the number of pathogenic microorganisms to below the detection level, while Class B disinfection accomplishes a two log reduction of bacterial pathogens and a one log reduction of enteric viruses and helminth ova. One lime based option was called out for Vector Attraction Reduction (VAR).

One of three alternatives are usually chosen for achieving Class A disinfection with lime treatment. Alternative One establishes time-temperature relationships as shown below.

Sludge	Temp, °C	50	55	60	65	70	75	80
Moisture > 7 %	Time, hours	316	63	13	2.5	0.5	0.10	0.020
Moisture < 7 %	Time, hours	120	24	4.8	0.95	0.19	0.04	0.008

Alternative Two is a pH-time, temperature-time, drying procedure. Basically, the sludge is held at a pH above 12 for 72 hours with a 12-hour period in which the temperature exceeds 52°C, followed by air drying to a solids content exceeding 50 %. Then under Alternative 6, sludge is treated by one of the proprietary processes listed below that were recommended as equivalent to a Class A, Alternative 5, PFRP Process by the USEPA (USEPA, 2003).

- ATW, Inc., Santa Barbara, CA - Manchak process uses quicklime to simultaneously stabilize and pasteurize sludge. Quicklime, or a combination of quicklime and fly ash, is mixed with dewatered sludge at a predetermined rate in a confined space. An instant exothermic reaction is created in the product wherein the pH is raised in excess of 12 after two hours of contact, in addition, the temperature is raised in excess of 70°C for > 30 minutes.
- N-Viro Energy Systems Ltd., Toledo, Ohio - Fine alkaline materials (cement kiln dust, lime kiln dust, quicklime fines, pulverized lime, or hydrated lime) are uniformly mixed by mechanical or aeration mixing into liquid or dewatered sludge to raise the pH to > 12 for 7 days. If the resulting sludge is liquid, it is dewatered. The stabilized sludge cake is then air dried (while pH remains > 12 for ≥ 7 days) for > 30 days and until the cake is ≥ 65 % solids. A solids concentration of ≥ 60% is achieved before the pH drops below 12. The mean temperature of the air surrounding the pile is > 5°C for the first 7 days.
- N-Viro Energy Systems Ltd., Toledo, Ohio - Fine alkaline materials (cement kiln dust, lime kiln dust, quicklime fines, pulverized lime, or hydrated lime) are uniformly mixed by mechanical or aeration mixing into liquid or dewatered sludge to raise the pH to > 12 for ≥ 72 hours. If the resulting sludge is liquid, it is dewatered. The sludge cake is then heated, while the pH > 12, using exothermic reactions or other thermal processes to achieve temperatures of ≥ 52°C throughout the sludge for ≥ 12 hours. The stabilized sludge is then air dried (while pH > 12 for ≥ 3 days) to ≥ 50% solids.
- Schwing Bioset, Inc., Danbury, CT - The "Bioset" process (See below.) is to be used to

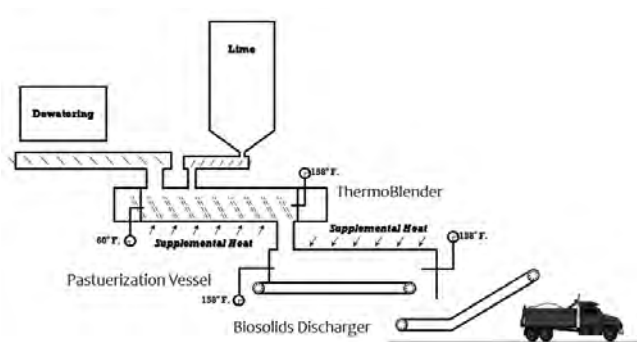


**Figure 1. The Bioset Process**

treat municipal wastewater sludge with a total solids concentration between 6 and 35% by weight and with a minimum ammonium concentration in the reactor discharge of 0.5 mg NH<sub>4</sub><sup>+</sup>/g dry weight. Dewatered sludge solids must be mechanically mixed with calcium oxide (quicklime) to achieve a pH of equal to or greater than 12 standard units.

Sulfamic acid must be mixed with the sludge/quicklime mixture to maintain the temperature of the mix at equal to or greater than 55°C. The process must be operated in a plug flow regime with a minimum operating pressure of 27 kPa (4 psi) and a minimum solids retention time of 40 minutes at a minimum temperature of 55°C.

*Comments.* An example of a process meeting Class A, Alternative 1 is RDP's EnVessel Pasteurization Process which is shown below in Figure 2. It is unique because it partially uses electrical heat to achieve the required 70°C for 30 minutes. Lime is added to sludge cake in an electrically heated mixer called a ThermoBlender. The 70°C and pH of 12.0 material is discharged from the mixer into an insulated and heated plug flow pasteurization vessel. Temperature is recorded at the inlet and discharge ends. This insures that every particle of sludge is at or above 70°C for 30 minutes. Class A, Alternative 2 is essentially the process offered by N-Viro Energy Systems Ltd., Toledo, Ohio and deemed equivalent by USEPA to a PFRP Process under Class A, Alternative 6.



**Figure 2. RDP EnVessel Pasteurization**

The Bioset Process shown previously in Figure 1, in addition to providing elevated pH and temperature, takes advantage of another disinfectant, ammonia. The high pH conditions of lime treatment convert  $\text{NH}_4^+$  to  $\text{NH}_3$ , a non-charged chemical species known to inactivate many organisms including *Ascaris* eggs. Further research showed that ammonia at temperatures near 50°C and a high pH near 11 could inactivate many pathogens (Pecson and Nelson, 2005). Studies at Tulane observed removal of viruses, pathogenic bacteria and *Ascaris* ova under closed systems at 55°C instead of 70°C due to the containment of ammonia in a closed system (Fitzmorris-Brisolara and Reimers, 2013). In the Bioset process, quick lime helps with both temperature and pH elevation while the small addition of sulfamic acid renders the lime sludge mixture thixotropic insuring complete mixing within the closed reactor. Data demonstrated the process' effectiveness at inactivating helminth ova within 30 – 40 minutes resulting in a greater than 2 log reduction.

All alkaline treatment systems meet VAR requirements with Option 6: Sewage sludge is considered to have undergone adequate vector attraction reduction if sufficient alkali is added to: a) raise the pH to at least 12, b) maintain a pH of at least 12 without addition of more alkali for 2 hours, and c) maintain a pH of at least 11.5 without addition of more alkali for an additional 22 hours. pH should be measured in a slurry

The American Society of Testing Materials (ASTM) issued a guide for the Alkaline Stabilization of Wastewater Treatment Plant Residuals in compliance with 40CFR503 (ASTM, 1998).

### **Residuals to be treated**

These can be primary, secondary or a combination of primary and secondary sludges. They can also either be raw or digested sludge, recognizing that anaerobically digested sludge is likely to contain a large amount of ammonia. Typically the sludges are dewatered to around 15-25 % solids when they enter the process.

### **Lime/Alkaline Additive**

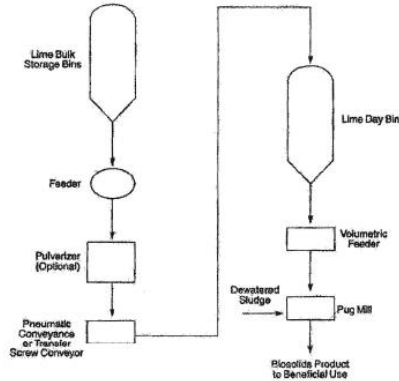
Both CaO and Ca(OH)<sub>2</sub> are frequently referred to as lime. CaO is manufactured from limestone (CaCO<sub>3</sub>) by heating it to a temperature of about 1093°C to separate and drive off carbon dioxide (CO<sub>2</sub>). CaO reacts with water to form Ca(OH)<sub>2</sub> and emit significant heat. The exothermic heat produced is 27,500 BTU/lb. mol (National Lime Association, 1990). A medium to highly reactive lime is needed to treat sludge and insure that CaO is fully converted to Ca(OH)<sub>2</sub>. Because of the cost of lime, other alkaline materials that contain small percentages of available or free CaO are frequently employed. For example cement kiln dust which contains about 3 to 5 percent available CaO and generally has low reactivity with water can be used. Similarly lime kiln dust with 25 to 40 percent available CaO and a low reactivity with water can be used as even can fly ash from the combustion of coal which contains anywhere from 1 to 40 percent CaO.

Ideally, sludge should be treated with a moderately or highly reactive lime to ensure that the CaO fully converts to Ca(OH)<sub>2</sub>. For the reaction to generate a high pH that migrates throughout the solids, there must be a continuous film of water throughout the material. Otherwise, the lime may not be fully hydrated or the hydroxide ions may not migrate throughout the solids. This can and does result in improper pH measurements, improper lime doses, and therefore, unstabilized solids. If calcium oxide must be pulverized, it is best to do the pulverizing at the point of application to prevent air slaking and ensure the desired reactivity.

Lime requirements vary greatly on type of sludge, anaerobically digested vs waste activated sludge for example, the temperature needed, and the solids concentration. Class "A" processes using the pasteurization criteria of 70°C for 30 minutes require a dosage of CaO of 13 to 20% on a wet weight basis. The RDP EVP process uses about 7 % on a wet weight basis with supplemental electric resistance heat, while the Bioset process uses 9-18 % CaO on a wet weight basis with a very small amount of sulfamic acid. The N-Viro Advanced Alkaline Stabilization with Subsequent Accelerated Drying (AASSAD) process uses 12-20 % CaO (or equivalent amount of CKD or LKD) on a wet weight basis to achieve 52°C for 12 hours, and additional by-product alkaline materials (CKD or LKD or fly ash) are added to achieve a final solids concentration of 55 to 65%, the amount added depending on whether air drying or heated-air drying is used. Usually where lime dose is high, the end product is best used as a liming agent and the calcium carbonate equivalency or CCE should be used to optimize load to the field.

### **Introduction of Lime into Residuals**

Dry CaO is added to dewatered cake. The lime typically is mixed with the cake via a pug mill, plow blender, paddle mixer, ribbon blender, screw conveyor, or similar device. Mixing is discussed in the next session. Figure 3 shows a typical lime feeding scenario. Quicklime,

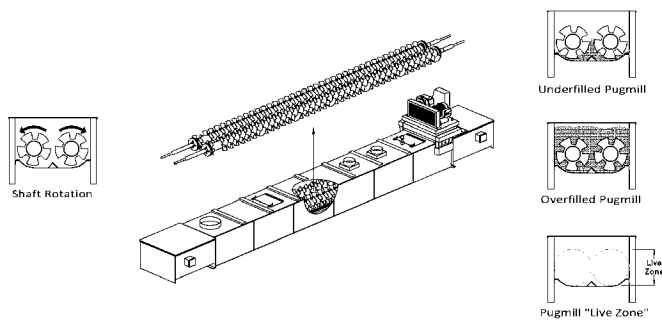


**Figure 3. Typical dry lime feeding scenario (Oerke et al. 1990)**

hydrated lime, or other dry alkaline materials can be used in this process. Quicklime is less expensive than hydrated lime, and the heat of hydrolysis released when quicklime is added to dewatered cake can enhance pathogen destruction.

**Mixing Process**

The heart of a sludge/lime treatment system is the mixing procedure. The mixing is generally done with a Pug Mill. The first known use of a pug mill dates back to 1824 where they were used to mix clay and water. Pug Mills are twin horizontal shafts that are rotated in concert to impart the required mixing action. The shafts are arranged to pull the product up through the middle and down on the outside, as shown in Figure 4. The counter rotating action is only effective when the proper bed depth is maintained in the live zone. Sludge/lime mixing pug mills need at least 60 seconds of mixing time in the live zone. They should be provided with a variable frequency drive to allow for changes in speed and mixing energy.



**Figure 4. Dual Screw Pug Mill Mixer (Christy, 2017)**

Dewatered cake and chemicals are added together at the “head” of the mixer. The proportioning of the alkaline material dosage rate to the rate at which cake is introduced is important. Good thorough mixing of the lime and sludge is critical to insure uniform distribution of calcium and pH throughout the sludge mass. Inadequate mixing or low dose rate can result in loss of pH control in storage and formation of putrescent odors. Over mixing can destroy the granular structure of the product. Uniform mixing of CaO or Ca(OH)<sub>2</sub> is much more difficult with

dewatered sludge. Non-uniform mixing will change the Calcium Carbonate Equivalence (CCE) of the product and impair its acceptance for beneficial use.

Factors to be considered in striving for good mixing are sludge solids content, type and grade of lime additive, mixer design, mixing energy and mixing time. Achieving the desired pH is not alone an adequate criterion for mixing efficiency. The procedure for measuring pH involves adding water to the treated sludge and then inserting the pH probe. Any unreacted CaO or Ca(OH)<sub>2</sub> will react with the added water and pH will increase. An indirect measure of mixing efficiency is NH<sub>3</sub> release. If NH<sub>3</sub> is not detected by the nose or by Dragger tube, then the bulk of the sludge is not experiencing high pH. DCWSA has developed a Ca test that has been shown to be effective in monitoring the completeness of mixing, and has allowed them to reduce their CaO dose significantly.

Lime type and grade can greatly affect mixing uniformity. The basic reactions between CaO and Ca(OH)<sub>2</sub> and residuals are hydration and hydrolysis, both requiring interaction with free water in the sludge. The CaO is hydrolyzed to Ca(OH)<sub>2</sub> by combining with water, and the Ca(OH)<sub>2</sub> dissolves in water to raise pH. Both CaO and Ca(OH)<sub>2</sub> are relatively insoluble in water and since dewatered residuals/sludge do not contain much free water, intimate and immediate contact between the CaO or Ca(OH)<sub>2</sub> and them is critical. It is also important to keep in mind, that for Class A processes, which use CaO to generate heat, solubility of the formed Ca(OH)<sub>2</sub> decreases with temperature.

### Temperature and pH Monitoring

To measure the pH of an alkaline sludge cake is not easy and the procedure shown in the box below should be followed in addition to the following considerations. To get a proper pH reading at the high end of the pH scale, the reading must be taken at the standard temperature, 25<sup>0</sup>C, or corrected to 25<sup>0</sup>C, using the formula shown below.

$$\text{Correction factor} = [0.03 \text{ pH units} \times (T_{\text{measured}} - 25^{\circ}\text{C})] / 1.0^{\circ}\text{C} \text{ where } T \text{ is in } ^{\circ}\text{C}.$$

$$\text{Actual pH} = \text{Measured pH} + \text{correction factor (factor can be + or -)}$$

While pH meters often have temperature correction controls. These controls correct for probe temperature and conductivity only. Changes in the concentration of the test sample due to solubility that changes with temperature are not compensated by these controls. Also when testing a liquid/solid mixture with a system designed for liquids (pH probe), care must be taken to keep flow of sample moving across the pH probe surface for accuracy. Clean the electrode frequently, paying particular attention to the reference electrode junction. Bits of adherent biosolids or alkaline agent can strongly alter the measured pH, resulting in erroneous values not representative of the entire mass of material.

The sample and the fresh standard solution used for calibration of the meter must both be at 25<sup>0</sup>C in order to obtain a correct reading. The pH electrode should be one that is recommended for alkaline condition (USEPA, 1995). If one reads the pH of a solution at other than standard temperature, then the pH meter reading will either be too high, or too low, depending on the temperature of the test sample, leading to an incorrect assumption that the levels needed for disinfection and stabilization have been achieved. In sludge containing significant amounts of

1. Weigh out 20 to 30 grams (wet weight) of limed sludge into a beaker. There should be no smell of  $\text{NH}_3$  in the sample before water is added. Ammonia will give a false high pH if present. So if ammonia can be smelled, then allow additional time for the reaction between the alkaline material and the solids to complete.
2. Add water to the sample in a 1:1 ratio (grams of sample to mL of water). Distilled or deionized water should be used.
3. Stir the sludge/water sample thoroughly and allow to settle. If all of the water is absorbed by the sludge, repeat the procedure with more water until there is a supernatant solution above the settled solids. Allowing the sample to stand for a period of time will also allow any  $\text{NH}_3$  to volatilize.
4. Place the electrode in the supernatant solution and record the pH after the reading has stabilized. If necessary correct the pH reading to a temperature of 25 C.
5. Rinse the electrode with distilled or deionized water between readings.

nitrogen, ammonia gas will be released when the pH rises above about 9, with almost complete conversion and release by pH 10. The pH reading of ammonia as it is “gassing off” may exceed 12, leading an uninformed operator to believe that sufficient lime has been added to meet regulatory requirements. But, as soon as the ammonia conversion is completed, the pH of the sludge mass will be at about 10 and not meeting regulatory requirements. At pH 10, bacteria will regrow and consume the unstabilized organic matter, possibly resulting in offensive odors. Measuring the pH of the fully mixed sludge, after ammonia has gassed off, assures that sufficient lime material has been added to achieve the regulatory pH of 12 or above, assuring stabilization and inhibiting regrowth.

Temperature monitoring is important. It is critical to know, for example, if you are achieving Class A status with a temperature of 70°C in all sludge particles for  $\geq 30$  minutes, when the temperature reaches 70°C and how long it stays at  $\geq 70^\circ\text{C}$ . So significant monitoring is needed for Alternatives 1 and 2 as well as Alternative 6.

### **Beneficial Use Plan**

Beneficial use implies a material is used as a supplement to a mined or manufactured product and that the application rate is consistent with crop need based on realistic yield expectations for a given crop on a specified soil in a defined geographic setting. EQ products are considered a product and site specific permitting for the end use application is not required, but land appliers should maintain records of distribution. If the preparer is the applier, farm maps are necessary to assure the product is applied onto appropriate sites. Information on beneficial use and appropriate loadings is available from local or county extension staff, from the natural resources conservation service, from the local Soil and Water Conservation Service office or from crop consultants.

Beneficial use projects have been implemented throughout the country. Results from one project in Coastal North Carolina are provided to demonstrate the benefits of optimizing the quality of



products applied with local needs. One custom soil blender compost producer has requested the lime stable product for several years and the crop yields and quality have improved.

Morehead City, North Carolina is located in eastern North Carolina and is surrounded by sensitive areas. Biosolids management has historically been through a Class B program. In 2011, the City developed an Enhanced Pasteurization Process (EPP) to blend lime and supplemental heat with dewatered biosolid to produce a Class “A” product. That was achieved through pH adjustment for VAR and heat for PFRP. The material achieved the PFRP designation, but did not receive as widespread a use as initially planned. In 2014, the lime dose to the product was reduced yet still complied with VAR requirements and the dried product was blended off site with Class “A” compost. The commingled material was tested and found to contain moderate levels of essential plant nutrients. This commingled product was applied to the established test plots of Bermuda grass, Sorghum, and turf fields. The plots have been used since 2011 and this allowed time series comparison between high lime and low lime material.

Soil materials and crops on each of the designated test plots or sites were tested prior to application of biosolid derived products to assure compliance with nutrient and lime requirements and at the end of annual growing seasons to assure crop quality and yield was assessed.

Based on the soil test results the biosolid derived product loads have been modified through time. The initial product contained lime only as the VAR compliance tool. Subsequent products contained a lower volume of lime when transported off-site for blending into a Class A compost. The material transported off site maintained the VAR/PFRP compliance at the time of use. The commingled biosolid derived products (Lime only or Enhanced Pasteurization Process and Class A compost) contained higher relative levels of N, P, K and secondary nutrients than the lime only material. Prior to the commingling operation, the biosolid derived product was applied at a rate of 3 to 4 tons per acre to satisfy the lime requirement of the soil, but this resulted in failure to meet other nutrient requirements. Following the commingling with compost, were applied at rates of 6 and 9 tons/acre on the Bermuda grass and Sorghum plots and at a rate of 6 tons/acre on the athletic fields to satisfy both lime and a more balanced nutrient requirement. The load to the athletic field was most sensitive because of the public contact on the sites. One of the fields is a “summer league” baseball field linked to the local semi-professional baseball team. On each of the athletic fields turf quality was critical because of the public scrutiny on these sites.

Plant tissue quality and yields have been measured through several growing seasons and correlated with soil test results and the biosolid derived product loadings. The soil test data show dramatic improvements in soil fertility indicators, particularly soil organic matter and other nutrients. Significant improvements in crop yield and quality associated with the beneficial use of these societal by-products are evident through assessment of the plant tissue quality and yield data.

Results from the 2011 through 2014 growing seasons are summarized in the tables below. These represent the changes in the quality of the biosolid applied when optimum beneficial use is considered as quality of the biosolid derived product applied, impacts of product application on crop yield and crop quality and finally improvements in soil fertility associated with optimization of the biosolid materials applied. The optimum quality resulted from addition of composted agribusiness residues containing high levels of essential plant nutrients with the lime-stabilized

products (LSP or Enhanced Pasteurization Process). The LSP generated initially utilized lime only for PFRP and VAR compliance, modification to the process initiated in 2014 utilized supplemental heat to achieve PFRP and required lower levels of lime to achieve VAR. This is the Enhanced Pasteurization Process material. The LSP and Enhanced Pasteurization Process when blended with compost yielded a more balanced source of essential plant nutrients than the LSP only. The commingled Enhanced Pasteurization Process material with the composted agribusiness residues resulted in the most beneficial impacts to crop yield and quality as evidenced through the doubling of yield depicted in Table 3.

The changes in processing and the commingling resulted in significant improvements in crop quality and yield. Utilization of the lime only amendment did result in elevation of soil pH to levels that may adversely impact crop management.

**Table 1. Biosolid derived product quality generated through commingling societal by-products (as percent except pH).**

Product	pH	CCE	N	P	K	Ca	Mg
LSP only	11	43	1.7	.3	.3	18	0.4
LSP+comp	10.2	35	2.1	.4	.9	12	0.4
EPP only	11	24	3.2	.8	.5	12	0.6
EPP+comp	9.8	21	3.0	.8	1.5	8	0.6

All waste, soil and plant tissue testing accomplished at NCDA Agronomic Service Laboratory.

The LSP materials met the Class A requirements at the time they were blended with the compost. The addition of the compost generated from agribusiness residues resulted in a plant nutrient source much higher in potassium than the lime only material. The potassium levels in these commingled products are well balanced with nitrogen and phosphorus.

**Table 2. Soil Test Results Following Application of Biosolid Derived Product (as NCDA index value) onto Biofuel Crops in Craven County, NC.**

Site	CEC	pH	PI	KI	Ca%	MG%	ZnI	CuI
LSP	16.8	7.4	79	67	92	7	189	101
LSP+Comp	24.2	7.1	113	115	90	6	172	90
EPP only	20.0	7.0	91	86	91	6	198	115
EPP+Comp	26.8	6.9	126	131	91	8	180	105
Control	13.6	5.5	57	41	80	9	129	72
Background	9.2	5.7	57	41	81	9	118	67

Addition of the lime-stabilized materials only did result in significant elevation of soil pH. The biosolid derived product generated through the Enhanced Pasteurization Process required lower levels of lime to achieve the Class A designation and the addition of this material to test plots had less adverse impact to soil pH than the lime only LSP. The addition of the blended lime products with agribusiness compost resulted in dramatic improvement in soil quality.

Measurable Benefits were documented in selected soil fertility levels as well as crop yield and quality following addition of the various biosolid derived products. Sample data collected during the initial phase of project and subsequently as the commingling of compost was added to the biosolid management scenario suggest the commingling results in production of a high quality

soil conditioner and nutrient source which improved quality of plant materials and soils in the community.

**Table 3. Biofuel Vegetation (Sorghum) Quality (as % or PPM) and Yield (as Tons/ac) Associated with Application of Biosolid Derived Product and from Control Area.**

Site	Yield	N	P	K
Lime only	7	2.3	.25	1.8
Lime+Comp	12	2.8	.3	2.3
EPP only	12	2.9	.3	1.7
EPP+Comp	15	3.1	.35	2.6
Control	5	1.9	.22	1.2

The beneficial use demonstrated has resulted in commingling product with soil and compost. Although the volume of material handled by the blender is greater than the volume of the lime only or the compost only, the mixing and blending has resulted in a custom blend most beneficial to plants and soil and least detrimental to underlying groundwater and adjacent surface water.

**Storage**

Federal and state regulations address storage issues in terms of the length of time that biosolids are stored. The Guide to Field Storage of Biosolids (USEPA, 2000) provides detailed technical information on storage methods and procedures. The Guide deals separately with the storage of Class A and Class B biosolids and addresses pathogen regrowth and transmission from stored biosolids, odor monitoring and mitigation, runoff control, and restriction of storage site access by humans, livestock and wildlife.

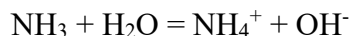
Lime and other alkaline materials can be stored in steel or concrete silos. Although standard steel can be used, silos must be both air tight and water tight. The steel silo with cone bottom is the most popular and comes in a variety of sizes. Silo capacity can be calculated from the dose rate of the process used and the biosolids produced. The decision to use several smaller silos rather than one larger one is a function of the process used. Processes using commercial CaO only need one silo, while the N-Viro process uses at least two silos to accommodate a variety of alkaline materials. A significant reserve capacity should be designed for alkaline sludge treatment to avoid process disruptions in the event of a supply breakdown. A recommended reserve is at least seven (7) processing days.

Fine lime materials have inherent flow problems. Lime may absorb water and form a non-flowing cake in the silo, or may arch or bridge. Silos are equipped with external vibrators or air pads, as well as internal structures, to prevent bridging. Hopper bottoms must have a minimum slope from the horizontal of 60° to overcome the high angle of repose of CaO (50-55°) and Ca(OH)<sub>2</sub> (70°) (National Lime Association, 1990).

**Odor**

Lime treated sludge can be particularly odorous, and this has caused problems for use of this method with respect to processing and beneficial use. Ammonia is the major process odor

associated with lime treatment, but others include dimethyl amine (DMA) and trimethylamine (TMA), as well as odor compounds associated with sludge itself (hydrogen sulfide (H<sub>2</sub>S) and mercaptans, among others). Ammonia is odorous in the gaseous form, and the gaseous form is prevalent at pHs greater than 9.5. At lower pHs, ammonia reacts with water, as shown below, to form ammonium ion (NH<sub>4</sub><sup>+</sup>), which is highly water-soluble. The equilibrium pH for this reaction is 9.5, so at pH 9.5, 50 % of the ammonia is NH<sub>4</sub><sup>+</sup> and 50 % is NH<sub>3</sub> gas. Since pH is a



logarithmic scale, it means that, for every unit increase in pH the concentration of NH<sub>3</sub> gas increases 10 fold. Because of the high reactivity of NH<sub>3</sub> with water, NH<sub>3</sub> is not very stable in the environment. Ammonia is more of a worker issue during alkaline stabilization, when most of the NH<sub>3</sub> in the sludge is released into the working environment. Ammonia is rarely detected beyond distances of 10-20 feet at processing sites, so odor control measures at the processing site are rarely used. The most obnoxious odors associated with alkaline biosolids are the methyl amines, which have a strong fish-like odor, are highly persistent, and will absorb to clothing. The methyl amines can be easily detected hundreds of yards from the source and are not readily dissipated. Factors affecting the generation of odors with alkaline stabilization include:

- pH – as discussed above, primarily affects the generation of gaseous NH<sub>3</sub>.
- Temperature – escape of gaseous compounds from sludge increases with temperature, and very high temperatures can result in formation of burnt odors.
- Residuals/sludge type – the type of sludge (raw or digested) can affect the odor compounds formed. Anaerobically digested sludge has orders of magnitude higher NH<sub>4</sub><sup>+</sup> concentrations than raw, waste activated or aerobically digested sludge, and NH<sub>3</sub> processing odors are most severe with anaerobically digested sludge. Anaerobically digested sludge also contains higher concentrations of reduced compounds like H<sub>2</sub>S and mercaptans, while raw sludge contains higher concentrations of odor compounds associated with putrescence.
- Use of polymer – certain polymers that contain amino (-NH<sub>2</sub>) groups are chemically unstable under alkaline conditions and hydrolyze to form methyl amines. There are no hard and fast rules as to which polymers will form methyl amines under alkaline conditions, so all polymers proposed for use in lime treatment should be tested for their stability under alkaline conditions. Also sludge/biosolids should be treated as soon after dewatering as possible. Undue storage of dewatered sludge may lead to anaerobic conditions, with NH<sub>3</sub> and other odor generation, and to breakdown of polymer.
- Incorporation of biosolids by plowing or by injection - is recognized in 503 as a non-treatment option to meet VAR. With alkaline biosolids, however, VAR is usually met by high pH and incorporation is not required. Incorporation of alkaline biosolids is recommended, however, to more uniformly mix the alkaline material into the soil and avoid any odors that may develop as the pH of the residuals falls and anaerobic decomposition of the organics commences.

Specific odor compounds are usually not routinely monitored. However, measurement of NH<sub>3</sub>, methyl amines, and reduced S compounds (H<sub>2</sub>S, methyl sulfides, mercaptans) can be used to optimize the alkaline process and anticipate field odor problems. Disposable probes (Dragger tubes) are available for many of these compounds. They are not analytically quantitative, but can be used to give relative values. Air sampling, together with gas chromatography measurements, is the most quantitative means of assessing odor.

Some regulatory authorities have had issues involving Class B and Class A alkaline biosolids. These issues are primarily associated with odors with material stockpiled in the field. In some cases, NH<sub>3</sub> was voiced by the public as being objectionable when alkaline biosolids were stockpiled too close to residences and public areas like schools. In other cases, methyl amines (fish odor) were identified as the cause of complaints. Causes cited for the issues included the failure to dose adequately with CaO or other alkaline products, and to uniformly mix these materials with the residuals. Frequently the putrescible odors occurred when pH dropped. The minimum dose rate is determined by the process parameters. Class A processes that use the pasteurization criteria of 70 °C for 30 minutes require a range of CaO or its equivalent of 15 to 75 % on a wet weight basis.

## REVIEW OF FACILITIES PRACTICES

The authors visited and spoke with personnel at approximately 50 facilities across the country, taking care to look at both *do it yourself type processes* and *proprietary ones* like N-Viro, RDP, and Schwing Bioset. An effort was made to collect the following facility and lime treatment information.


- Size of facility, types of wastewater received and method of processing
- Method of sludge dewatering and solids concentration achieved
- Method of feed conveyance
- Type lime added (CaO, Lime Kiln Dust, etc.) and method of addition (Storage silo, Rotary Vein, Transfer Augers, VFD)
- Mixing of lime and sludge: Plowshare Blender, Screw Blender, Pugmill, Heated Screw
- Curing practiced? Heat Pulse Bunker, EnVessel, Open Floor, Storage Bins
- Method(s) of Storage and Odor Control
- How beneficially used: Agriculture, Land Reclamation, Top Soil Blending Class A, or Landfill Cover

Examples of information provided by facilities utilizing the N-Viro, RDP, and Bioset Processes are shown in Figures 5, 6, and 7. Of the sludge processing facilities investigated and regulated as EQ biosolids producing ones, many were achieving pathogen reduction under Class A, Alternative 2, that is by a) Elevating the pH to greater than 12 and maintaining the pH for more than 72 hours; b) Maintaining the temperature above 52°C (126°F) throughout the sewage sludge for at least 12 hours during the period that the pH is greater than 12; and c) Air drying to over 50% solids after the 72-hour period of elevated pH. This is basically the N-Viro Process. Facilities using the RDP Process achieved pathogen reduction under Class A, Alternative 5, maintaining 70°C for ≥ 30 minutes. Bioset Processes achieved pathogen reduction under Class

A, Alternative 6, which meant maintaining 55°C for  $\geq 40$  minutes in addition to other conditions which were mentioned previously. All facilities inspected using an EQ alkaline treatment process met vector attraction reduction by using Option 6, adding sufficient alkali to: a) Raise the pH to at least 12, b) Maintain a pH of at least 12 without addition of more alkali for 2 hours, and c) Maintain a pH of at least 11.5 without addition of more alkali for an additional 22 hours. Further of the study's findings follows.

<p>Treats 2.2 of a possible 6 MGD of domestic and industrial wastewaters. Has primary and trickling filter processes. Sludges are 90 % primary, 8-9 % biological, 1 % septage, plus some activated sludge from another facility. All go to anaerobic digestion. Lime kiln dust is added to achieve EQ biosolids via Class A, Alternative 2. LKD is added via auger at about 50 %. Good mixing is said to be assured via pH and temperature measurements as well as visually. Untreated sludge is 60-80%; are 55-90°C with pH of 12.2. Product is stored in some storage of up to 3 years. That is now being resolved with a PR specialist on board. Biosolids are free to try and then \$15/scoop. See photos above.</p>		<p>measurements as well as visually. Untreated sludge is 60-80%; are 55-90°C with pH of 12.2. Product is stored in some storage of up to 3 years. That is now being resolved with a PR specialist on board. Biosolids are free to try and then \$15/scoop. See photos above.</p>
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**Figure 5. Information Obtained from Facility using N-Viro Process**

<p>Plant is attractive, very clean and has highly automated operation. Treats 2.1 to 3.57 mgd wastewater with primary and activated sludge processes. Effluent goes to a Creek and Reservoir and is P limited. Sludge goes into an aeration mixed holding tank. Sludge at 2-2.5 % solids is belt filter press dewatered to 19-21 %. 2300 # of lime kiln dust are then mixed with the 523 # of dry solids to produce via the RDP Process a 55 % solids product. Plant pays \$2/ton to farmers to take the product for corn, soy beans and landscaping. Spreading is largely done in Fall and Spring. RDP's Process employs a thermo blender, twin screw mixer and insulated pipe heated to 650°F. This movement of the sludge mixture through 20 feet of heated pipe guarantees the mixture will be at <math>\geq 100^\circ\text{C}</math> for 30 minutes. See photos. There was little dust and no lime-sludge balls visible in the soil like product. ....</p>	
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**Figure 6: Information Obtained from Facility using RDP Process**

**Lime Alkaline Addition**

Several plants using Alternative 2 used lime kiln dust to raise the pH and temperature and in addition some also used cement kiln dust and/or fly ash to either assist with temperature elevation or more often to help with product quality, making the product more granular and thus better in appearance and easier to use. Facilities using the RDP and Bioset Processes largely only added quicklime.

At some facilities visited introduction of the alkaline additive did not closely match, time wise, with introduction of the dewatered residuals. As such it raised questions about the level of treatment occurring. Mixing is always a major concern and is obvious upon both witnessing the process and looking at the product. You could see balls of material where the outside of the ball is coated with lime while the inside still contains raw or unreacted residuals. Similarly you could see unreacted lime particles.

Treatment Plant is a 48 mgd activated sludge one that utilizes pure oxygen. Waste sludge from the clarifiers is pumped to an equalization tank and then to belt presses where most of the remaining liquid is removed. The "cake" that comes off the belt presses at ~ 20 % solids is transferred by conveyor and high-pressure pumps to the Bioset Process. This process mixes dewatered biosolids with calcium oxide (typically 0.6 kg quicklime/1kg dry sludge) to achieve a pH of greater than or equal to twelve standard units. Sulfamic acid in solid granular form added to, and mixed with the sludge/quicklime to promote an exothermic reaction which increases the temperature of the mixture to equal to or greater than 55°C (131°F). The sludge/quicklime/sulfamic acid mixture is then continuously fed to a pressurized plug flow compact reactor (35' long X 4' dia.) using a twin-cylinder piston pump for a minimum solids retention time of forty minutes at a minimum temperature of 55°C (131°F). A pressure of 20 psig is maintained.



**Figure 7: Information Obtained from Facility using Bioset Process**

### Monitoring Needs

The requirements for insuring pathogen and vector attraction reduction are clear and apply to **ALL PARTS OF THE RESIDUALS**. For most of the facilities visited it was unclear how if at all assurance could be given that all parts of the residuals were meeting the temperature and pH requirements. See relevant photos in Figure 5. A conveyor belt was bringing the sludge cake to a lime or alkaline material feeder where the lime was deposited with the cake and both moved into a mixer with the combination then moving along with a conveyor to a windrow pile. The introduction of the lime material to the sludge, the mixing, and the movement out of the mixer all happens quite fast. How quickly the temperature and pH rose to required levels is questionable. In some instances steam was noticeable as well as the odor of ammonia, However, more often than not all that was noticeable was a fog of dust. pH and temperature measurements, if taken, were taken by sticking a probe into the center of a windrow and/or perhaps taking a sample of material from a single location in the windrow. So how uniform the pH or temperature was throughout the windrows is not known.

### **Dust / Cleanliness**

It was not uncommon to see at the facilities visited considerable dust in the air, sometimes accompanied by the odor of ammonia and wet residuals on the floor. From a public relations standpoint, these situations can be problematic.

## **DISCUSSION OF STUDY'S FINDINGS WITH SUGGESTIONS FOR IMPROVING DESIGN AND OPERATION**

Three major issues were identified in the course of the study: mixing, assuring that pH and temperature requirements are achieved, tackling problems of odor and dust, and planning for beneficial use of the biosolids. Each issue will now be addressed.

### **Mixing**

The introduction of the alkaline material to the sludge cake starts the process. It is critical that that introduction is tied to the movement of the sludge cake. Usually this means the dosing is tied to the wet solids, typically ~ 18%, passing the dosing unit. The lime must be added as the wet cake moves under the dosing unit, not before or after.

Every opportunity must be presented for reactions to occur between the alkaline (Ca) product and the residuals/sludge. For this to occur available lime should be in small particles (promoting maximum surface area) but not so small as to create dust and the moisture content of the residuals should be between 80 and 85 %. The preference with most facilities is to buy a pulverized product. Seldom does pulverization occur at the facility. Reactivity of the alkaline material (available Ca) is also important and should be between medium and high (ASTM, 1998).

Manner of mixing including vigor as well as length of time mixing occurs are critical. Some research work has recommended a mixing period of 40 to 60 seconds with an operating speed of about 30 rpm. Ultimately, it is incumbent on the operator to conduct the necessary tests to assure that adequate mixing is occurring. Some guidance developed from mixing studies at DCWASA, USEPA-Region 3 and other locations (Murthy et al, 2000; Mangus et al. 2006) follows:

- Total Ca measurements throughout the lime-treated sludge is a good measure of mixing efficiency.
- Increased CaO dose over and above the minimum required to raise pH above 12 will guarantee that pH does not decline over a period of weeks.
- CaO or Ca(OH)<sub>2</sub> grades should be selected to give the highest possible lime content and fineness.
- Increased mixing time increases mixing efficiency. Increased mixing time is required for sludge with higher solids contents and for centrifuged sludge.
- Other measurable indicators of mixing efficiency include NH<sub>3</sub> and amine generation, fecal coliform reduction, and reduction of specific odor compounds such as sulfides and mercaptans.



- Screw conveyors can produce sludge masses that require longer mixing times to achieve uniform mixing.

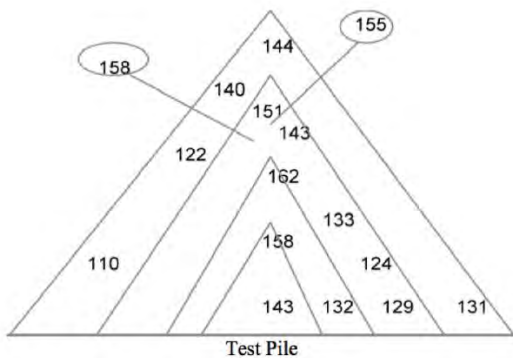
An approach is recommended for evaluating the distribution pattern of lime in the final mix and thus being assured of a proper mix. Take at least ten (10) 0.5 gm samples from the final sludge/lime mixed product and evaluate them for Ca levels. The variance can be used to evaluate if proper lime distribution/mixing and optimization of the equipment has occurred.

**Assuring that pH and Temperature Requirements**

The previous section addressed the need to insure a thorough distribution of Ca so that contact was made with all sludge particles. The difficulty occurs in knowing how fast all reactions occur. In most cases, though, with Class A alkaline treatment, enough lime will be added to insure that VAR is achieved.

This leaves as the critical concern that all particles of sludge meet the Class A time requirements for a 70°C, 55°C or 52°C temperature. In many of the utilities visited, following mixing, the combined lime-sludge cake product was on an open conveyor, where you could see steam coming off (cooling) as it moved to an open windrow. It is difficult to know what the temperature of the material is at any point in time. At least two equipment providers resolve this issue by a) having the conveyor move through an insulated channel where they can monitor when the temperature rises to the required level and note how long it stays at that level, or b) having the lime-sludge cake mixture move into a closed reactor where they can monitor the temperature and time.

An example of how temperature in a windrow can vary is shown in Figure 10. This temperature profile for this windrow was created with lime treated residuals and with daytime temperatures



**Figure 10. Open Pile Temperature Profile**

of 50 to 70°F (10 to 21°C). Facility wanted to achieve 158°F (70°C) throughout the windrow. You can readily see where this did and didn't occur. In an open environment it is very difficult to maintain temperature. Similarly it is difficult to maintain pH, when CO<sub>2</sub> from the air can enter the material and lower the pH.

This temperature profile is typical of many open pile systems including compost windrows. The profile demonstrates the need for effective contact with the high temperatures documented above to achieve pathogen reduction necessary to have a product designated as an EQ material suited for beneficial use.

### Tackling Problems of Odor and Dust as well as Temperature in a Windrow

The authors suggest consideration of an insulating membrane cover for the windrow(s). This would minimize heat loss to the environment and insure a more uniform temperature distribution throughout the windrow. Membrane technology has developed to the point where membranes are available that provide facilities a greater than 90% reduction in (escaping) process odors and VOC emissions including that of the beneficial disinfecting contaminant ammonia when compared to uncovered systems. Other attributes can include a greater than 99% containment of bio-aerosols. Membranes are now successfully used in composting systems.



**Figure 11. a) Membrane Covered Windrow, and b) Benefits of using Membrane (After GORE® Cover System-North America)**

### Beneficial Use of the EQ Biosolids

As was discussed previously in the paper, with any sludge management plan it is important to know where the final product will go. Stock piling is seldom an answer. A critical aspect of the program is securing the involvement of farmers who are interested in utilizing the EQ biosolids. The critical player for this job is the biosolids manager. Understandably his/her involvement will likely depend on the individual communities involved and their past experience with sludge application systems; and the overall public acceptance of the concept. The manager or his/her assistant has to be a good communicator and make the public aware of how the sludge is treated and the product of that treatment can be beneficially used by farmers/ranchers. The project could even be described in the local newspaper and the public invited to tour the operation on a particular day. Through the help of the local Soil Conservation Service or agricultural extension service agent the manager needs to get the word out to the agricultural community about the benefits of biosolids and at the same time enlist customers and see if they might be willing to pay anything for the product and or pick it up and spread it. Interested farmers could be invited to visit the sludge treatment operation and talk about what they are seeking most, for example lime or nutrients or perhaps both.

It was obvious in visiting facilities and talking with managers that where there was no plan, the well treated material just accumulated and accumulated, resulting in an unsightly mess.

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