- CASE STUDY -

The Strategic Use of Liquid Lime in Sludge Treatment

ABSTRACT

Lime treatment of wastewater sludge has been in use for over a century. This paper describes the use of 'Liquid Lime' and hydrated lime suspensions as a sludge treatment process for the specific purpose of agricultural recycling. The introduction of 'Liquid Lime' treatment has enabled South West Water to achieve full compliance with the Sludge (Use in Agriculture) Regulations at a time when the major refurbishment of a number of existing anaerobic digestion installations had been identified to enable the final sludge product to be recycled to land. Initially considered as a short-term solution to transient problems, liquid lime dosing has been shown to be an efficient method of pathogen reduction and a cost effective alternative sludge treatment process for medium term applications.

A comprehensive review of the advantages and potential difficulties to be encountered when introducing liquid lime treatment at existing sludge treatment centres has been undertaken. The findings of the review have provided confidence that liquid lime dosing could be relied upon as a robust sludge treatment process and could play an important role in the company's sludge strategy. The role that liquid lime sludge treatment has played in the modification of the sludge strategy, and the savings in capital expenditure that have been realised, are discussed.

KEY WORDS

biosolids, sludge treatment, legislation, Sludge Regulations, HACCP, operating experiences, liquid lime, lime, sludge strategy

INTRODUCTION

'Liquid Lime' is a white or off white, fine suspension of calcium hydroxide $Ca(OH)_2$ in water with small quantities of calcium carbonate, magnesia and some trace elements. It has a relative density of 1.1 – 1.25 depending on its strength, a pH of 12.4 and exhibits a faint earthy odour. The product is used widely in the water, wastewater and chemical industries for acid neutralisation and pH control.

The use of lime to stabilize untreated sewage sludge is well reported and documented in a number of standard texts. However the lime treatment of sewage sludge prior to dewatering in order to produce a sludge cake that meets the 'conventional treated' or 'enhanced treated' status required by the Sludge Regulations is relatively new to the industry, with only 12 months experience within South West Water in particular.

Initial trials at a number of South West Water's sites had demonstrated that lime pre treatment using liquid lime, or liquid hydrated lime suspension, as the treatment chemical was effective at providing the *E.coli* and *Salmonella* reductions required to meet the Sludge Regulations. However, the temporary nature of some of the 'Liquid Lime' dosing arrangements had led to a number of apparent operational problems, which had, rightly or wrongly, been attributed to the use of 'Liquid Lime'. A study of the 'Liquid Lime' dosing and sludge mixing arrangements at the trial sites was undertaken together with an assessment of the impact of lime dosing on the wastewater treatment process and site operating regime.

The study investigated the following issues:

- Optimum lime dose
- Sludge mixing arrangements
- Odour
- Sludge cake dry solids content
- Sludge cake pumping
- Return liquor quality

In the first part, this paper reports the findings of a comprehensive assessment of 'Liquid Lime' dosing as an effective method of achieving a 'compliant' sludge suitable for land disposal. This has been achieved by using a variety of means: through site visits and feed back from the operators at the liquid lime dosing sites, discussions with the manufacturers and suppliers of sludge processing equipment and the analysis of HACCP related acquired data and other site specific data. The second part reports on the introduction of liquid lime dosing as a strategic sludge treatment process and the capital savings that have been generated through the revision of the SWW Sludge Strategy brought about by the use of liquid lime.

LIME-SLUDGE MIXING EFFECTIVENESS – THE THEORY

The dosing of lime into sewage sludge is a complex mixing duty involving the blending of two non-Newtonian fluids to produce a homogeneous product. When dosing chemicals into sludge, or blending sludge from different sources, the rheological properties play an important part in the subsequent mixture quality.

Both sewage sludge and 'Liquid Lime' are non-Newtonian fluids. 'Liquid Lime' is a typical shear thinning fluid, whilst sewage sludge behaves according to the Herschel-Bulkly model where the sludge exhibits a shear stress below which no movement will occur (the yield stress) and is shear thinning once the yield stress is exceeded.

Importantly, the apparent viscosity of sludge increases with increasing solids concentration. The yield stress, which for thin sludge is very small also increases with solids concentration and can be substantial for thick sludge.

The mixing methods utilised at the trial sites in South West Water can be crudely split between those dosing into stirred tanks and those utilising injection into pipes.

For stirred sludge tanks the type of mixers generally used within the water industry are of the submersible propeller type either with or without shrouded impellers. The mixing requirements in pipes are different in nature from those experienced in stirred tanks. Mixing in pipes relies on the inertia ratio of the additive flow to main flow, the shear developed along the walls and the turbulent energy within the bulk of the flow. The level of shear is dependent on factors such as the roughness of the construction material, the pipe geometry and the flow pattern.

These two mixing regimes exhibit very different requirements to provide a completely mixed product.

DOSING INTO PIPES

The rheology of sludge is such that, at the velocities used within pumping mains to minimise head losses, the flow regime tends to be laminar. Under laminar flow conditions, very little mixing will occur unless energy can be introduced into the mixing zone by increasing the momentum of the additive flow. Appropriate design of injection systems that introduce the lime suspension into the sludge pipeline as a high momentum jet, with or without a carrier water flow, will ensure that the sludge and lime are very well mixed within 30 diameters of the sludge pipe.

DOSING INTO MIXED TANKS

The stirring action of an impeller creates both flow and turbulence in the tank which promote mixing when a second fluid is added into the tank.

The intensity of mixing in a stirred tank is not constant throughout the volume of the tank and is dependent upon tank geometry. Mixing is intensive in the region of the impeller, but is moderate to poor in other regions.

The power input per unit volume of liquid can be used as a rough measure of the mixing effectiveness based upon the reasoning that more input power creates greater turbulence and greater turbulence leads to better mixing. Using this theory it is possible to estimate the velocity gradient (G) in the fluid and hence the mixing effectiveness.
For rapid mixing operations, the G value should lie between 250 and 1500 s^{-1}. To ensure a rapid dispersion of the lime, the liquid should be introduced at the impeller of the mixer to ensure that the dose enters the area of maximum energy dissipation within the tank.

It should also be noted that the liquid dynamic viscosity is a function of the sludge rheology and will change with sludge dry solids content. Therefore, a mixing system designed for a tank contents of, for example, 1 % ds (dry solids content) will provide approximately 30% of the shear at 2% ds and only 20% at 3 % ds as demonstrated in Figure 1.

THE EFFECTIVENESS OF MIXING IN PRACTICE

On analysis of site specific installations, it was found that the mixing conditions achieved in most sludge storage tanks being used for lime treatment could be considered as “poor”. The propeller type mixers normally installed to prevent sludge settlement were not sufficiently powerful to provide the rapid mixing necessary for the thorough blending of the two fluids.

Calculation of the ideal mixer power required to provide a completely mixed tank within 1 – 2 hours revealed that considerable capital expenditure would be required to improve mixing in tanks by increasing the mixer power. Some sites were overcoming the lack of mixing energy by allowing the sludge and 'Liquid Lime' mixture to mix for several hours prior to dewatering. Other sites did not have the luxury of abundant sludge storage capacity and were unable to provide the higher retention time. Final product samples from these sites often showed lime content higher than the optimum level.

The analysis of several hundred liquid lime dosed sludge samples has shown that a lime dose in excess of 0.12 kg lime/kg sludge ds is sufficient to produce an "enhanced treated" sludge product, but only if effective mixing is achieved. Poor mixing of the lime with the sludge has been shown to result in *E.coli* concentrations exceeding the 1,000 /g ds limit and the risk of *Salmonella* being found in the final product.

Figure 2 shows the *E.coli* concentrations in the liquid lime dosed sludge cake versus the lime dose achieved in the cake as measured by the total calcium content. It shows that the minimum recommended lime dose of 0.12 kg lime/kg sludge ds is an effective dose at producing an "enhanced treated" product with the exception of a few samples from Sites 3 and 4, where there were known problems with the sludge mixing arrangements. Reliable final product quality was only achieved at these two sites by applying a very high lime dose - approximately twice that of the minimum required.

This information demonstrates the need to ensure that the mixing arrangements are adequate to minimise the operational cost of liquid lime dosing. Very short payback periods can be demonstrated if improved mixing reduces the lime dose required to achieve the desired product quality.

A general recommendation was made to provide continuous dosing of liquid lime into sludge pipelines whilst filling the storage/mixing tanks. The dosing points were designed to provide a high momentum jet of lime suspension into the flowing sludge. This dosing/mixing option can be achieved at a fraction of the cost of providing larger tank mixers and at a considerably lower running cost.

It is quite likely that the true minimum effective lime dose to produce an enhanced treated product is well below the 0.12 kg lime/kg sludge ds dose that has been stated above, but the lime dosing and sludge mixing performance would have to be almost perfect to enable a site to consistently operate at such low lime doses.

RETURN LIQUOR SAMPLING

To assess the potential impact of the introduction of liquid lime dosing at existing sludge treatment centres, and to determine whether lime dosed sludge liquors would adversely affect the wastewater treatment processes, a short sampling survey of sludge dewatering liquors was undertaken as part of the assessment. Samples of sludge dewatering liquors (centrate and press filtrate) were collected from sites using 'Liquid Lime' (or hydrated lime suspension) and from other sites dewatering digested and raw sludge to compare the effect of liquid lime addition on the liquor quality. Tables 1 to 4 present the results of the sample analysis and summarise the main findings.

RETURN LIQUOR SAMPLING STUDY FINDINGS

The following conclusions have been reached from the available data:

- 'Liquid Lime' improves (reduces) the COD to BOD ratio making the liquors more biodegradable.
- Generally, BOD and COD levels are lower in 'Liquid Lime' treated sludge than raw sludge liquor, possibly due to the oxidising effect of the 'Liquid Lime' and possibly due to better solids capture rate.
- There is higher ammonia content in 'Liquid Lime' treated sludge liquors than in either raw or digested sludge liquors.
- 'Liquid Lime' sludge liquors contain higher suspended solids concentrations than other sludge liquors – mainly due to the 'Liquid Lime'/lime particles and precipitated carbonates in the sludge. This is supported by the sampling results, which show that the ratio of volatile to non-volatile solids is similar to that of digested sludge liquors, and is less than the typical 4:1 ratio expected for raw primary settled sludge.
- In general, digested sludge dewatering liquors appear to contain the lowest concentrations of BOD and COD, and this should be taken into consideration when changing to the dewatering of raw or limed sludge.

- At sites pressing raw sludge, prior to quicklime treatment for example, converting the process to liquid lime dosing would offer a modest reduction in the total load returned to the wastewater treatment process in the return liquors.

THE EFFECT OF LIQUID LIME DOSING ON CAKE DRY SOLIDS CONTENT

In general, where the STC has switched from pressing digested sludge to pressing liquid lime dosed raw sludge, there has been a major improvement in cake dry solids content. Other sludge treatment centres have reported either no change or some difficulties in producing good dry solids content.

Figure 3 plots the dry solids content achieved in dewatered liquid lime dosed sludge against the lime dose for a number of sites.

The results would suggest that there is a correlation between lime dose and cake dry solids concentration with an increase in dry solids content as the lime dose increases. The correlation is strong at a number of sites (Figure 4), but not present at others (Figure 5).

On further analysis it was found that the sites showing little correlation between cake dry solids content and applied lime dose all had BAFF plants installed and were dewatering a mixture of raw primary settled and BAFF backwash sludge. In addition these sites were also reliant on chemical coagulants, especially aluminium salts, to aid primary settlement.

Under alkaline conditions, hydrated aluminium hydroxide is precipitated as a gelatinous mass. An excess of alkali causes this sequence to continue with the formation of soluble anions, which may destabilise the floc formation and hence cause poor dewatering. It is possible that this process is responsible for the lack of improvement in dry solids concentration with lime dose at these sites.

EFFECT OF LIME ON PRESS OR CENTRIFUGE THROUGHPUT

Some site operators reported the need to reduce the flow of sludge through the dewatering press to enable a cake with a good dry solids content to be produced. It is most probable that, where liquid lime dosing gives a negative effect on the cake dry solids content, the high pH is interfering with the polyelectrolyte action and is causing poor flocculation. Feed flow rates were reduced to maintain good cake dry solids content under such conditions. This effect was most notable on the trials of liquid lime dosing on digested sludge where modest elevation of the pH caused significantly poorer flocculation and dewatering performance.

EFFECT OF 'LIQUID LIME' ON ODOUR GENERATION AND ODOUR CONTROL

H_2S GENERATION

All sites that utilise liquid lime dosing within South West Water have reported that the release of H_2S has been either eliminated or dramatically reduced with a corresponding reduction in sludge odours.

However, at some sites, an increase in ammonia odour has been observed, especially in the dewatering press buildings. Severe ammonia release is believed to be a symptom of poor sludge mixing prior to pressing resulting in lime suspension and raw sludge coming into direct contact for the first time at the press. The ammonia is then released directly to the atmosphere rather than being either, dissolved in the liquid phase, or released whilst in the sludge tank. One of these sites in particular has also reported the detection of H_2S within the press building whilst dewatering liquid lime dosed sludge; this is a further indication of poor sludge/lime mixing. Rapid and effective mixing prior to dewatering should be sufficient to overcome the very high ammonia odours observed.

Despite an increase in ammonia released from sludge in the immediate vicinity of the dewatering equipment, there is general agreement that the sludge-generated odours are very much reduced at all sites using 'Liquid Lime'.

ODOUR CONTROL EQUIPMENT

Two major sites utilising wet scrubbing odour control systems have reported very considerable reductions in the consumption of odour control chemicals resulting in major operational cost savings following the introduction of liquid lime dosing.

Where existing biological odour control filter systems are in place, discussions with leading manufacturers would suggest that if the biofilter media and biomass were in good condition there should be no deterioration in the performance of odour control units if a treatment works were to switch to using liquid lime dosing and start to generate ammonia. Most biofilter manufacturers ensure that their units are designed to accommodate ammonia concentrations up to 50 ppm as standard.

MAIN FINDINGS OF THE STUDY

'Liquid Lime' (or hydrated lime suspension) dosing of sludge (raw, activated and digested) has been demonstrated to be an effective means of achieving either a "conventional treated" or "enhanced treated" sludge product at lime doses in excess of 0.12 kg $Ca(OH)_2$/ kg sludge dry solids. This lime dose is approximately 25% of the typical quicklime dose applied to dewatered cake to achieve the same product quality. This has a significant beneficial effect on the available land bank by reducing the total quantity of lime being spread. With such low lime content, it may be possible to apply liquid lime dosed sludge cake to the same land year on year rather than having to wait for a number of years in the case of a high lime content quicklimed sludge.

It has long been known that lime can reduce the generation of H_2S and other odours, and 'Liquid Lime' has been shown to have identical properties. Liquid lime dosing has resulted in dramatic improvements in air quality at certain sludge treatment centres and has reduced the sludge odours at other sites using this treatment method.

Both theory and observation in the field show that rapid, effective mixing of sludge and liquid lime suspensions is of paramount importance in achieving a product with good dry solids content and in preventing the release of ammonia into the atmosphere on dewatering.

Poor flocculation, possibly caused by the elevated pH following liquid lime dosing, is responsible for many of the problems reported with dewatering lime dosed sludge. Careful choice of dewatering polyelectrolyte is required when using liquid lime as a sludge treatment method.

The materials of construction typically used on the sludge treatment processes and dewatering equipment are unaffected by the elevated pH achieved following lime addition. The elimination of H_2S release that results from liquid lime dosing will have a beneficial protective effect on steel and concrete tanks.

Lime dosed sludge cake seems to exhibit a higher shear requirement than untreated sludge cake and coupled with improved dry solids content consequently generates higher discharge pressures in cake pumps and pipelines. This effect may not be immediately apparent to operators if cake dry solids content is not closely monitored. Boundary layer injection is recommended at sites exhibiting excessive pump wear and high pump pressures as well as at any new sites that have long or convoluted delivery pipelines.

Continuous dosing into sludge pipelines and automated control of lime dose is recommended for permanent treatment facilities. Equipment should be designed to deliver a maximum dose of 0.2 kg lime/kg ds and a minimum of 0.12 kg lime/kg ds to achieve an “enhanced treated” sludge product. Lower lime doses could be applied to achieve a “conventional treated” product, but this practice comes with the risk of sporadic product quality failure.

THE SOUTH WEST WATER SLUDGE STRATEGY IMPLEMENTATION

South West Water’s sludge strategy was introduced following the issue of the ADAS Safe Sludge Matrix and the Code of Practice. The company’s strategy is a commitment to treat sludge to the standards required for agricultural recycling at the least whole life cost. Implementation of the strategy comprised the refurbishment of several mesophillic anaerobic digestion facilities with the addition of treatment capacity at some sites. Major new regional sludge treatment facilities were envisaged in both Devon and Cornwall utilising either thermal drying or advanced quick lime treatment to produce enhanced treated sludge for agricultural recycling, and the installation of pre-pasteurisation technology at one large digestion site.

The approach was formulated at a time when there was still some uncertainty as to the prediction of the pathogen removal performance of existing mesophillic anaerobic digestion installations, windrow composting and some lime treatment processes. It was envisaged that advanced treatment systems may be needed to achieve even the lower “conventional treated” final product status at some sites.

A series of investigations into existing sludge treatment facility performance (Ref 1) subsequently demonstrated that the digestion installations were capable of reliably producing a "conventional treated" product without the necessity of pre-pasteurisation or similar enhancements, provided that appropriate critical control points were maintained and sufficient secondary digester capacity was provided. Likewise, windrow composting was shown to be a reliable treatment process given sufficient operating footprint and compost retention time. These findings led to the modification of the scope of a number of strategic projects.

In particular, the monitoring of the existing quicklime installations was demonstrating that significantly lower lime doses than anticipated could be used to reliably produce an "enhanced treated" product. Furthermore, little correlation was found between the temperature achieved within the limed sludge cake and the final pathogen content of the product. It was evident that a chemical process was primarily responsible for the pathogen reduction rather than the thermal effects of the quicklime hydration.

'LIQUID LIME' TRIALS

A subsequent visit to the Dŵr Cymru Wrexham works reinforced South West Water's view that lime addition for pH adjustment alone could provide a robust and effective sludge treatment. As described above, with the assistance of Buxton Lime, a series of pilot 'Liquid Lime' dosing trials were set up to prove the process would satisfy South West Water's requirements of a sludge treatment process suitable of producing a sludge for agricultural recycling. Routine HACCP monitoring enabled the process performance to be closely studied.

The trials were so successful that a number of sites immediately moved to full-scale adoption of 'Liquid Lime' dosing as the sole sludge treatment process. Existing hydrated lime make-up and dosing facilities, originally intended for sludge odour suppression, were later converted to enable sludge treatment without the need for additional 'Liquid Lime' storage facilities.

ECONOMICS

Evaluation of the economics of liquid lime treatment by South West Water's Regional Sludge Manager showed that liquid lime dosing could be introduced to a site at a lower operating cost than the transportation of the untreated sludge cake to another STC for further treatment and recycling.

Two mesophillic anaerobic digestion sites, that were struggling to produce a "conventional treated" sludge product without further treatment being required, have been converted to 'Liquid Lime' treatment without major capital investment. This has enabled increased sludge throughput (an additional 30% at one site), improved cake dry solids and hence storage capacity, and the ability to produce an "enhanced treated product" which increases the options for recycling. This has been achieved with very little initial capital outlay.

Comparison of the 'Liquid Lime' dosing facilities with those sites having hydrated lime make-up systems further suggested that considerable savings could be made at certain sites by converting to hydrated lime dosing. It was found that savings could be made at sites processing in excess of approximately 1200 tds per annum, below this throughput, the chemical cost savings would not justify the capital expenditure required for a permanent installation of hydrated lime storage and make-up facilities.

ENHANCEMENTS TO STRATEGY IMPLEMENTATION

The implementation of the strategy was reviewed in light of the continuing industry wide uncertainty of the future of sludge recycling to agricultural land. Although supported by the EC, UK legislation (draft) and the regulators the public perception of sludge recycling to land remains uncertain and there is a perceived risk that public pressure could make the agricultural recycling route unsustainable in the long term. Considerable capital and operating expenditure would be required should agricultural recycling become unviable in the short term.

Committed to keeping whole life costs down, liquid lime dosing was clearly identified by SWW as a treatment process that could be installed at low capital cost at any works with sludge dewatering facilities without the need for major investment in infrastructure and the risk of plant redundancy. The main thrust of the enhanced strategy implementation is outlined below:

- Maximised utilisation of existing assets; in particular at major mesophillic anaerobic digestion facilities and those incorporating combined heat and power systems using digester gas.
- The continuation of liquid lime dosing at 12 sludge treatment centres incorporating the recommendations of the lime dosing assessment and economic review.
    - Rationalisation of the procurement of lime storage, make-up and dosing facilities.
    - Improvement of sludge mixing
    - Use of hydrated lime to replace 'Liquid Lime'
- The completion of selected approved capital schemes where shown to offer the best value solution.

CONCLUSIONS

- The introduction of liquid lime treatment has enabled South West Water to achieve full compliance with the Sludge (Use in Agriculture) Regulations. This was achieved at a time when the major refurbishment of a number of existing anaerobic digestion installations had been identified as essential to enable the final sludge product to be recycled to land.
- Liquid lime dosing has increased the percentage of SWW's sludge production that can be treated to the "enhanced treated" standard – from 19% to 52%.
- The introduction of 'Liquid Lime' (or hydrated lime suspension) dosing for the treatment of sludge has ultimately enabled South West Water to make major capital efficiencies.
- Analysis reveals that the enhancement to the Sludge Strategy implementation could realise a 33% saving in the whole life cost of sludge treatment.

REFERENCES

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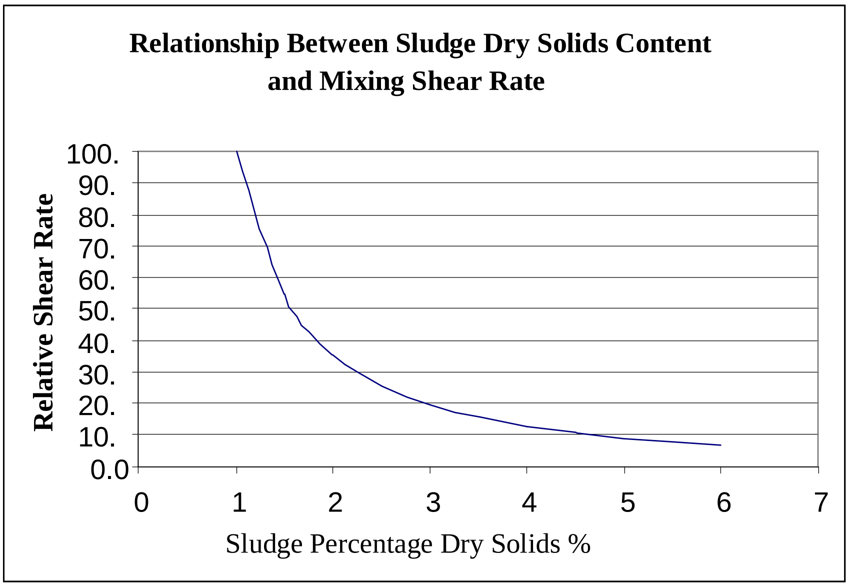

FIGURE 1

RELATIONSHIP BETWEEN SLUDGE DRY SOLIDS CONTENT AND MIXING SHEAR RATE

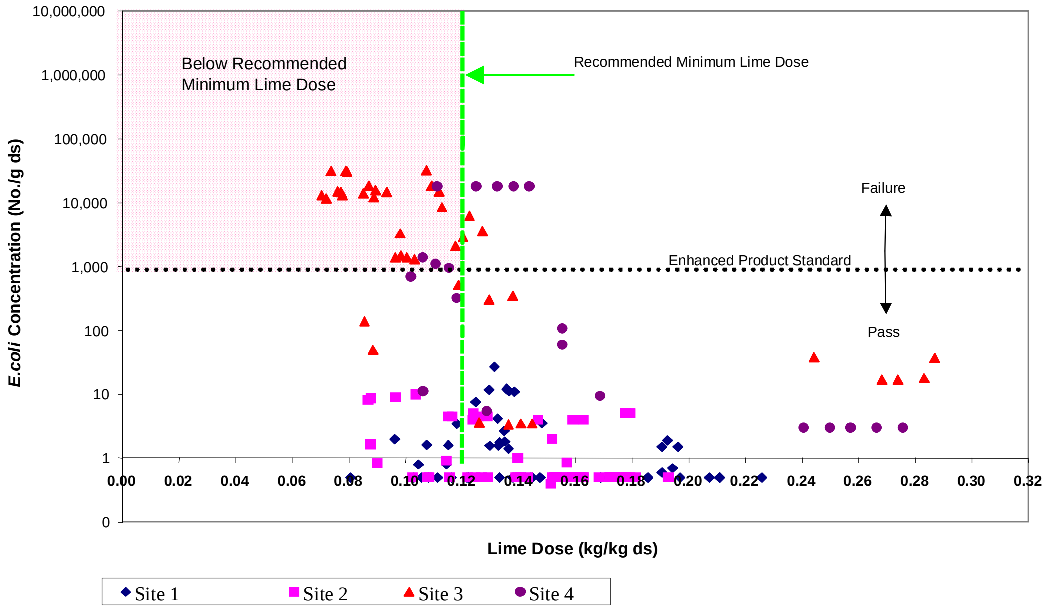

FIGURE 2

FINAL PRODUCT *E.COLI* CONCENTRATION VS. LIME DOSE

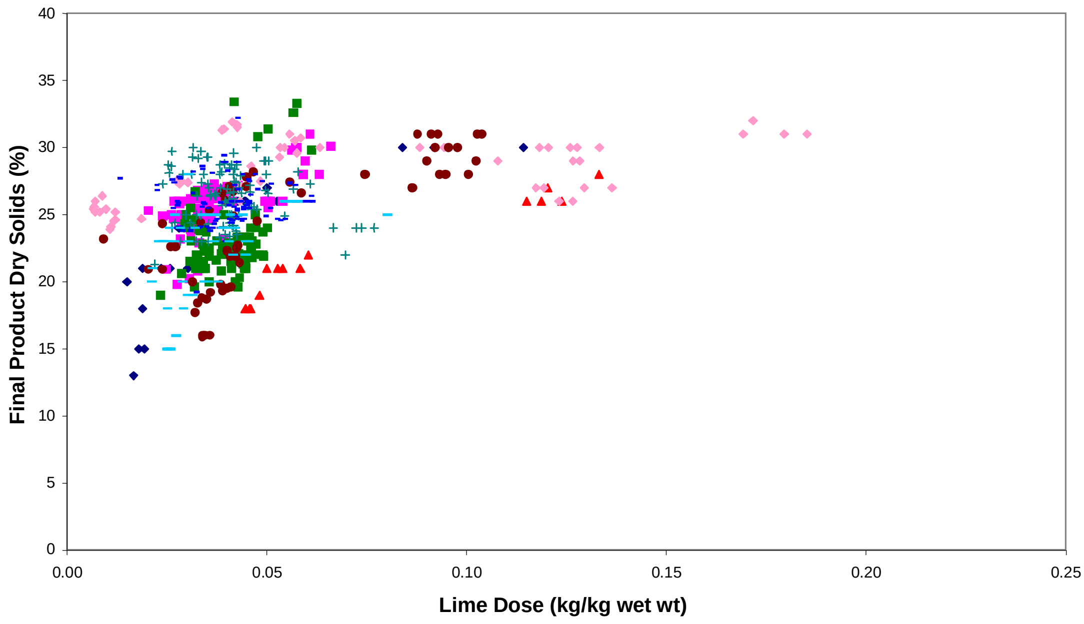

FIGURE 3

FINAL PRODUCT DRY SOLIDS CONTENT VS LIME DOSE

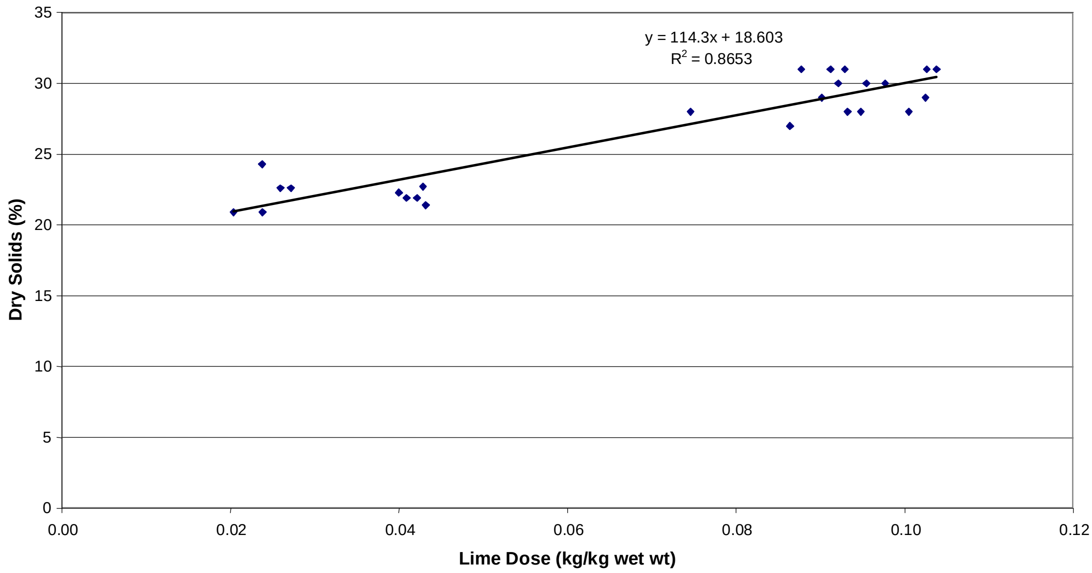

FIGURE 4

INFLUENCE OF 'LIQUID LIME' DOSE ON SLUDGE DRY SOLIDS CONTENT – SITE A

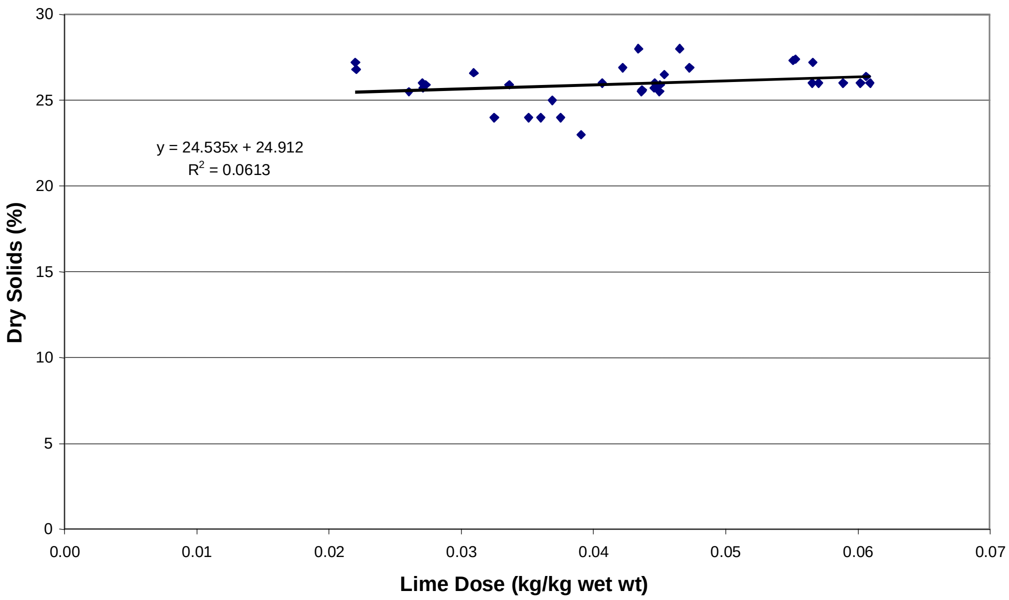

FIGURE 5

INFLUENCE OF 'LIQUID LIME' DOSE ON SLUDGE DRY SOLIDS CONTENT – SITE B

TABLE 1: SUMMARY OF RESULTS OF RAW SLUDGE LIQUORS

Raw	**Alkalinity at pH 4.5 (mg/l)**	**Ca Total (mg/l)**	**BOD Total (mg/l)**	**COD Total (mg/l)**	**NH_3 (N) Total (mg/l)**	**SS at 105°C (mg/l)**	**SS at 500°C (mg/l)**
Minimum	226	39	57	259	22	160	n/a
Mean	628	182	2,837	6,538	39	347	n/a
Maximum	1,064	324	7,150	16,600	61	534	n/a

TABLE 2: SUMMARY OF RESULTS OF DIGESTED SLUDGE LIQUORS

Digested	**Alkalinity at pH 4.5 (mg/l)**	**Ca Total (mg/l)**	**BOD Total (mg/l)**	**COD Total (mg/l)**	**NH_3 (N) Total (mg/l)**	**SS at 105°C (mg/l)**	**SS at 500°C (mg/l)**
Minimum	522	82	18	209	61	296	107
Mean	624	88	20	287	73	324	118
Maximum	725	93	22	364	85	351	128

TABLE 3: SUMMARY OF RESULTS OF 'Liquid Lime' TREATED SLUDGE LIQUORS

'Liquid Lime'	**Alkalinity at pH 4.5 (mg/l)**	**Ca Total (mg/l)**	**BOD Total (mg/l)**	**COD Total (mg/l)**	**NH_3 (N) Total (mg/l)**	**SS at 105°C (mg/l)**	**SS at 500°C (mg/l)**
Minimum	3	255	445	902	21	189	58
Mean	1,328	755	2,190	4,128	116	1,132	380
Maximum	2,613	1,571	4,450	7,410	251	3,750	1,065

TABLE 4: ALKALINE TO AMMONIA (NH_3), COD: BOD AND VOLATILE SS: NONVOLATILE SS RATIOS

Ratios	Alkalininity/NH_3	COD/BOD	Volatile SS/ Non volatile SS
Raw	16.1	2.3	n/a
Digested	8.5	14.3	2.75
'Liquid Lime' dosed	11.4	1.9	3.0