The Manufacture and Evaluation of an Artificial Soil (SLASH) Prepared from Fly Ash and Sewage Sludge

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KEYWORDS: Sewage sludge, fly ash, lime, pasteurization, soil amelioration, toxic elements

SYNOPSIS

Alkaline materials have, for centuries, been used for the treatment of sewage sludge with the primary aim of sterilization and reduction of odour. Recent advances pioneered by Burnham and others[1-5] showed however that by judicious formulation and processing, pasteurization with all its inherent advantages, rather than sterilization can be achieved.

This paper describes the use of sewage Sludge, Lime and fly ASH for the development of an artificial soil (SLASH).

The method used to produce SLASH renders a product with unique properties that can be beneficially used to address problems associated with conventional sludge disposal practice while simultaneously creating a new conduit for ash utilisation. SLASH produced during the investigation was utilised for the amendment of various types of soils. The findings show that substantial benefits can be derived. These are elaborated in separate papers (Rethman[6-7] *et al*).

INTRODUCTION

Given the large volume of coal ash that requires disposal, new application technologies are constantly being sought. The co-utilisation of fly ash and sewage sludge or biosolids to generate an artificial soil could prove to be a new opportunity for utilisation.

Due to the heavy metal concentration and pathogenic microbiological load, sewage sludge is classified as a toxic waste. It therefore requires extensive treatment to ensure a benign product, safe for land disposal.

With the introduction in 1986 of EPA regulations[8] allowing for the implementation of Processes for the Further Reduction of Pathogens (PFRP) interest in the alkaline treatment of sewage sludge was stimulated[2-4].

Spurred on by the availability of alkaline industrial wastes, Burnham *et al*[3] developed a process using either quicklime or cement kiln dust to effectively pasteurise sewage sludge. Pasteurisation is achieved either by maintaining the pH above 12 for at least 7 days or alternatively ensuring that a temperature between 52 and 62 °C is maintained for 12 hours and the pH exceeds 12 for at least 3 days. The resultant elimination of pathogens and the non-viability of parasitic eggs renders a product safe for land application.

The advent of South African regulations akin to PFRP raised the possibility of utilising fly ash as the alkaline medium to pasteurise sewage sludge.

ESKOM, the national electric utility produces 22 million metric tons of fly ash annually. With only a small fraction being utilised in the cement industry, the major portion requires disposal. This is costly since the resultant fly ash dumps require dust control and ultimate rehabilitation. Utilisation technologies that reduce disposal volumes are thus of direct financial benefit.

THE DEVELOPMENT OF METHODOLOGY

Exploratory tests on small quantities of sewage sludge mixed with Class F fly ash, the only type available in South Africa, indicated that the addition of free lime would be required to produce the heat pulse to ensure pasteurisation. The fly ash is almost devoid of free lime and no measurable exotherm was generated during hydration. In the absence of any viable sources of cement kiln dust commercially available quicklime was utilised as the supplementary material.

The focus of the initial investigation was to assess the efficacy of various ratios of quicklime and fly ash in providing conditions conducive to the pasteurisation of sewage sludge.

The materials used in the study were:

- Sewage sludge from Goudkoppies Sewage Works, which serves both a residential and an industrial area in Johannesburg. The sewage utilised was a mixture of raw settled solids and digester sludge which was belt dried to a filter cake containing 80-82% moisture. For each test series, sludge was collected the day before and stored in sealed bags below 10 °C. This ensured that the pathogenic activity was retained at the original level.

- The sludge was selected due to the expected heavy metal contamination. Since the ultimate aim was to produce an artificial soil it was considered essential to study the possibility of translocation of potentially toxic metals from the soil to the plant biomass.

- Class F fly ash from Ash Resources' Lethabo plant. The composition is given in **Table 1.**

- Commercially available quicklime from Pretoria Portland Cement. The lime, (91% available CaO) received in the form of lumps, was kept dry in sealed bags and crushed when needed.

Table 1: Chemical composition of Lethabo fly ash (all values mass %)

Component	Concentration	Component	Concentration
SiO_2	52.8	MgO	1.1
Al_2O_3	34.1	CaO	4.4
Fe_2O_3	3.6	K_2O	0.5
TiO_2	1.6	Na_2O	0.4
SO_3	0.1	P_2O_5	0.3
C	0.8	Mn_2O_3	0.1

Initial Test Formulations

Various ratios of sludge, lime and ash were mixed in a revolving drum for 3 minutes. Any lumps present after discharge were broken by hand to ensure a relatively homogeneous texture. Once prepared, these 10 kg (22 lbs) mixtures were immediately placed into insulated drums. Thermocouples were inserted and temperature readings taken every 5 minutes over a period of 12 hours. The highest temperature achieved with the various mixes is listed in **Table 2**.

Table 2: Comparison of peak temperatures achieved with various SLASH mix formulations

Mix	% Sludge	% Lime	% Ash	Peak temperatures °C						Mean	Standard Deviation
1	25	25	50	94	111	106	117	98	112	106	8
2	25	35	40	149	158	93	139	295	210	174	64
3	25	40	35	172	184	106	244	259	242	201	53
4	35	25	40	110	94	65	94	111	103	96	15
5	40	25	35	94	98	95	91	116	95	98	8
6	45	25	30	107	96	94	93	109	94	99	7

The peak temperature achieved was used to compare the efficacy of different formulations. With the exothermic reaction between quicklime and the moisture in the sludge being the only source of heat it was expected that the temperature would increase along with lime content. This was verified by the trend exhibited in mixes 1-3. The variance in these values was however high. Lower but more consistent temperatures were achieved when higher amounts of sludge was used (mixes 4-6). The alteration of the ash content in these mixes did not influence the maximum temperature reached. In all cases the maximum pasteurisation temperature of 62 °C was exceeded.

Once the mixture had cooled to ambient temperature (15-18 hours), microbiological analysis was carried out. Samples were taken from each formulation and tested for:

- Total aerobic bacteria
- *Escherichia coli*
- Total coliforms
- Faecal streptococci

In all cases the bacteria and pathogens were completely destroyed indicating sterilisation rather than pasteurisation had taken place.

The erratic temperature distribution within the SLASH mix was investigated by preparing a batch containing 40% lime, 35% ash and 25% sludge. Thermocouples placed at various locations throughout the product were used to measure the heat distribution. It was found that the maximum temperature ranged from 160 – 276 °C.

This variation was ascribed to the position of the thermocouple relative to the hydrating lime particles. Compared to the other constituents the lime (<4.75 mm) is relatively coarse. When hydrating in a mixture containing limited amounts of water the quick lime particles will tend to erupt and release a heat pulse in their immediate vicinity. In the relatively dry environment heat dissipation is limited. A temperature probe close to such a particle will thus record a much higher value than one further away.

In mixes 4-6 where more sludge was used and the water content was concomitantly higher the eruption of lime was prevented. The additional moisture also improved heat dissipation and consequently lower temperatures with reduced variance were recorded.

AMENDMENT OF FORMULATION

In an attempt to reduce the heat liberated and achieve pasteurisation, the product was reformulated to contain 25% sludge 10% lime and 65 % fly ash. Temperatures measured in this batch ranged from 75 – 90 °C.

The texture of all the SLASH formulations produced up to this stage was however reminiscent of ash or cement rather than a soil. Only mix 6 of the original series of mixes (**Table 2**) resembled a soil.

It was thus decided to radically alter the formulation by substantially increasing the sewage sludge content mainly at the expense of lime. Six mixes containing 60% sludge, 10% lime and 30% fly ash were thus prepared. As expected, peak temperatures were substantially lower (mean 47 °C relative standard deviation 8%) indicating conditions more akin to pasteurisation. In addition, the texture of the product changed dramatically from those produced earlier to become more soil-like in appearance.

The results of the microbial analysis **(Table 3)** on this mix formulation indicates that under these conditions the pathogens were destroyed while some microbial activity was maintained. The survival of the indigenous microorganisms is regarded as advantageous to the use of SLASH in agriculture where they assist in establishing a soil ecosystem.

Table 3: **Results of microbial for SLASH mixes (60% sludge, 10% lime and 30% fly ash)**

Test	Initial Count (colony forming units/ml)	Final Count (colony forming units/ml)
Total aerobic bacteria	1.2×10^{8}	5.9×10^{3}
Escherichia coli	2.4×10^{5}	6×10^{0}
Total coliforms	1.7×10^{6}	6×10^{0}
Faecal streptococci	4.8×10^{5}	Not detected
Parasites	2.0×10^{0}	Not detected

PRODUCTION OF TEST BATCHES

Given the encouraging results obtained with the 60% sludge formulation, a 1 ton batch of SLASH was prepared for agricultural tests. In order to homogenise the alkaline materials the fly ash and quicklime were pre-blended in a concrete mixer prior to the addition of the sludge. This reduces the likelihood of 'hot spots' forming when they are added to the sludge.

In preparing the product pre-weighed bags of sludge and the alkaline components were sequentially added to the input port of a screw mixer. The constituents took approximately 5 minutes to traverse the 3 metre (10 ft) length of the mixer before being discharged onto a concrete apron.

Visual inspection indicated that this mixture was not homogeneous. Auxiliary mixing in a concrete mixer was therefore implemented. A further 5 minutes of mixing ensured a homogeneous product. The SLASH was placed in a heap and covered with a tarpaulin to reduce the loss of heat from the surface during the pasteurisation process. Thermocouples inserted at various positions within the heap recorded the heat generated. **(Figure 1).**

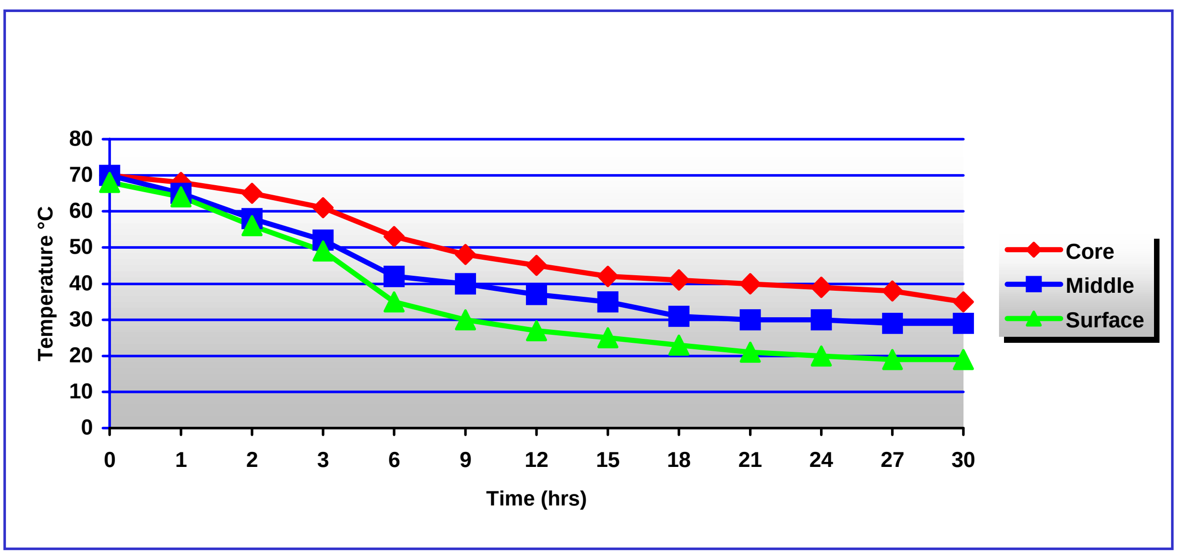

Figure 1: **Representation of the heat distribution at various locations**

Temperature readings indicated that the heat distribution was not uniform throughout the mass of the product. Due to the insulation of the SLASH itself, the inner region maintained a temperature in excess of 40 °C for approximately 20 hours longer than the outer surface.

After a maturation period of 56 hours, samples were procured from various regions within the heap and tested for pathogens. The results shown in **Table 4** indicate that with the retention of aerobic bacteria, pasteurisation had indeed taken place. The retention of microbial activity is regarded as advantageous to the subsequent use of SLASH as a soil ameliorant.

Table 4: Microbiological analysis of 1-ton batch of SLASH after pasteurisation (60% sludge, 10% lime and 30% fly ash)

Sampling Position	**Microbial Analysis**				
	TPC	**EC**	**TC**	**FS**	**A**
Surface	230	< 6	< 6	< 6	nd
Inner	150	< 6	< 6	< 6	nd
Inner	150	< 6	< 6	< 6	nd
Inner	240	< 6	< 6	< 6	nd
Surface	170	< 6	< 6	< 6	nd
Inner	170	< 6	< 6	< 6	nd

TPC = Total aerobic bacteria
EC = *Escherichia coli*
TC = Total coliforms
FS = Faecal streptococci
A = Parasites
nd = Not detected

At this stage it became clear that the mixing time and equipment used would be vital to ensuring a homogenous product. In particular sufficient shear action is required to break up the sludge cake and continually expose a fresh surface for hydration.

To this end it was decided to use a three-screw feedlot mixer to prepare further large volume batches. This equipment allowed the mix to be retained for a sufficient period of time to ensure homogeneity.

During the use of this equipment over a period of time further adjustments to the formulation were made in order to:

- minimise the amount of quicklime required for pasteurisation. Being the most costly ingredient, lowering its content also improves the economic viability of the process;

- take cognisance of the variability of the sludge and its influence on the texture of the SLASH.

It was established that the lime content could be reduced to 6% and the amount of sewage varied from 50 – 63% (the remainder being fly ash) and still produce a pasteurised product with a soil-like texture. In particular the silt content of the sewage sludge was found to have a dramatic effect on texture. When this is very high the SLASH appears clay-like and difficult to incorporate into soil. The silt content is generally very high in the two days following severe thunderstorms when large volumes of storm water carry a heavy load of silt into the effluent treatment plant.

AGRICULTURAL EVALUATION

The various large volume batches of SLASH were utilised to ascertain the effect on different crops raised on various types of soil. The results, more fully elaborated in other papers [6,7], show immense potential for agricultural application. It was found that in sandy, loam and acidic soils the addition of SLASH enhanced the initial growth of corn. Analysis of the various parts of the biomass confirmed that potentially toxic elements were not translocated to the plant.

Where beans and potatoes were used as test crops the type of soil and supplementary fertilisation had a greater effect on plant yield than amendment with SLASH. Once again no evidence of translocation of transition metals could be found.

The addition of 5 – 10% SLASH was however found to significantly enhance the growth and vitality of both spinach and asters[7].

SUMMARY

Class F fly ash can, if suitably augmented with quicklime, be used to pasteurise a toxic waste like sewage sludge. The resultant product, SLASH is devoid of pathogens and can either be safely disposed in landfill or preferably used as a soil ameliorant.

The relative amounts of quicklime, sludge and ash used in the formulation is crucial to the achievement of pasteurisation.

Care must however be taken in the preparation of the product to introduce sufficient shear during mixing to ensure a homogeneous product. If this is not achieved ‘hot spots” can occur within the mix and the degree of treatment of the sewage can range between sterilisation through pasteurisation to no effect at all.

No exact recipe can be prescribed for SLASH. The formulation needs to take into account the variation in the nature of the sewage sludge so that besides pasteurisation being achieved the texture of the product enables easy incorporation into soil.

SLASH has significant agricultural potential. When used as a soil ameliorant it enhances the early growth of corn. In the case of beans and potatoes, the augmentary fertilisation obscured the effect of SLASH. In all cases no evidence was found of translocation of heavy metals to the biomass. High dosages of SLASH 5 – 10% considerably improved the vitality and growth of spinach and asters.

CONCLUSION

This research confirms the use of fly ash as an ingredient in the pasteurisation of toxic wastes like sewage sludges. Depending on the environmental requirements of the regulating authorities, this technology can be applied, not only to provide an innovative conduit for ash utilisation but a safe and cost effective means for the disposal of sewage sludge.

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