THE APPLICATION OF ELECTROKINETIC GEOSYNTHETICS IN THE ADVANCED CONDITIONING AND COMPOSTING PROCESSING OF SEWAGE SLUDGE

Chris White[1], Stephanie Glendinning[2], John Lamont-Black[3], Colin Jones[4] & Tom Taylor[5]

[1] *Newcastle University. (e-mail: chris.white@ncl.ac.uk)*
[2] *Newcastle University. (e-mail: stephanie.glendinning@ncl.ac.uk)*
[3] *Electrokinetic Ltd. (e-mail: john.lamont-black@electrokinetic.co.uk)*
[4] *Electrokinetic Ltd. (e-mail: c.j.f.p.jones@ncl.ac.uk)*
[5] *Yorkshire Water Services Ltd. (email: tom.taylor@yorkshirewater.co.uk)*

Abstract: The safe and economic recycling and disposal of sewage sludge that is a by product of waste water treatment has become an ever increasing problem for the water treatment industry. In an effort to increase the reuse of sewage sludge, Electrokinetic Ltd. is working in partnership with Yorkshire Water Services Ltd. on the application of electrokinetics in the conditioning and composting processes to turn what is a constant problem into a valuable and cost effective source of nutrients and organic matter. This study was focused on comparing the improved dewatering and conditioning of sewage sludge mixed in a 1:1 ratio with recycled shredded green waste by using a number of hybridised windrow designs that permit a voltage gradient to applied across the material mass resulting in a faster and more controlled rate of conditioning and homogenisation. Electrokinetic treatment has been shown to result in increased dewatering and the production of oxygen at the anode. With the anodes and cathodes both being made as geosynthetics, the ability for filtration and drainage as well as increased gas movement are also facilitated. This application of electrokinetics has shown positive results both in laboratory and field scale testing in the production of both treated conditioned sewage sludge and when used in conjunction with sludge phyto conditioning to produce enhanced treated status in accordance with the ADAS Safe Sludge Matrix, lowering pathogen numbers, breaking down polymer and increasing air spaces to produce a more friable compost/soil like material.

Keywords: electrokinetics, electro-osmosis, electrokinetic geosynthetics (EKG), sewage, oxidation, electrically conductive vertical drains

INTRODUCTION

Historically sewage sludge, which is produced as a by product of the waste water treatment process was encapsulated in a landfill cell or used in agriculture through spreading onto fields.

In the last three years water companies have been forced to change these established disposal routes by the following identifiable drivers,

- Introduction of the ADAS Safe Sludge Matrix in 1999/2000 (ADAS 2005)
- Increased public perception of food safety with a fear of public backlash against recycling
- Introduction of the landfill directive
- Increased cost of landfill disposal

Composting and conditioning is growing in profile as a cost effective means of disposing of sewage sludge when compared to other alternatives such as incineration, which is difficult with low calorific value sludges, and digestion, which can have initial high capital costs. Conventional composting and to an extent conditioning can be labour intensive and on the quantities of material produced the major challenge is that it also requires a large amount of storage space. By incorporating geosynthetics that enable the induction of an electrical energy it utilises both the established physical strengthening and stabilising qualities of geosynthetics, which can also act as pathways for water and gas movement, with the additional chemical conditioning benefits that an applied electrical current can induce; Electroosmosis (EO), Electrolysis (EL) and Joule Heating or thermal effects (JH).

COMPOSTING PROCESSES AND CLASSIFICATION OF THE PRODUCTS

Raw materials used for composting are dewatered sewage cake and recycled green waste. A field trial is currently underway where in the treatment of sewage sludge the dewatering of the filtrate from 0.55% dry solids (ds) using a set of centrifuges produces a sewage cake of around 17 – 19% ds. The centrifuges on the site have a capacity of 30 litres each and can produce 60m^3 of sewage cake per day. The sewage cake at this point is a very soft, dark brown/black gelatinous material with an odour. The sewage cake is mixed with locally recovered green wastes, which comprise mechanically shredded trees, grass and various organic matters. The two ingredients are mixed in a 1:1 ratio by volume.

At present the conditioning processes in action on site produce both types of compost identified in Table 1 as being acceptable for re-use. The freshly mixed waste is stored in an initial holding area where the stacks, more commonly know as windrows, which are approximately 3 – 3.5m in height are left for a period of around 8 weeks depending upon results. It has been found that after this first 8 week period the material will achieve the targets set for a conventionally treated sludge (Ref. Table 1). To meet the enhanced treated standard a conventionally treated sludge is then stored in a 0.80m deep, one acre plateaux field plot on a concrete pad holding area and planted with a rye grass as part of a sludge phyto conditioning (SPC) treatment. The field plot will then be left for up to 50 wks or until it reaches the enhanced criteria. The time periods for the two products have been developed by Yorkshire Water and are not specified in the SSM. This method of treatment has been pioneered by Yorkshire Water (Taylor 2003). From it Yorkshire Water benefit from reducing their disposal costs and local farmers get a free supply of fertiliser.

Table 1. Acceptable compost products in accordance with the ADAS Safe Sludge Matrix (2005).

ADAS Recognised Product	Minimum Treatment Period (YW standard only)	*E.coli* Target Value No. cells per gram (dry)	Absence of *Salmomella*	Minimum Fallow Period after Application (grass land/grazing)	Minimum Fallow Period after Application (cereal and salad crops)
Conventionally Treated Sludge	8 weeks	Log 3 reduction	N/A	3 weeks (surface and deep injection)	40 weeks (surface) 30 weeks (deep injection)
Enhanced Treated Sludge	40 weeks	Log 5 reduction	0	N/A	10 weeks

COMPOSTING CHALLENGES

The traditional process for composting and conditioning has the following problems:

- The major constraint for the composting process is space.
- Composting is a biological process which is controlled by a number of variables and present significant challenges with respect to a strict time frame for treatment
- Rye grass, grown on the mixed waste in the enhanced treatment process as phyto conditioning, has two main advantages (i) the development of macro pores by the roots increases helpful bacteria growth (ii) This enhanced porosity aids the aerobic development of the mass. The field plots are restricted to a depth of 0.80m as this is the established limit that the roots will grow too. Anaerobic conditions prevail at a depth greater than 0.80m preventing deeper SPC treatment.
- To prevent deep anaerobic conditions developing, the traditional method is to regularly physically turn the material over, which can have a high visual impact due to the release of steam, dust and odour, which can all lead to perception problems and therefore poor public relations.
- Regular turning of the compost does have significant cost implications in terms of additional man hours.
- In the winter period a 1:1 mix proves to be unstable in wet conditions meaning that the material cannot be stacked as high. Therefore the mix has to be changed to 1 part sewage: 1.5 green waste. This reduces the effective amount of sewage that can be treated by composting by occupying more physical area.

APPLICATION OF ELECTROKINETIC GEOSYNTHETICS

So the short-comings of the traditional composting process are well understood and it was felt that the combined use of several types of geosynthetic material with the capability to generate an electrical gradient would provide benefits most importantly in controlling the treatment and providing an answer to the impasse that was preventing the expansion of composting and conditioning for wider use.

During 2007 using the results of previous work it, was planned that a large scale field trial would be undertaken in the second growing period around the end of the year and into 2008 at Yorkshire Waters' Esholt site. As a precursor to the field trial a scaled down laboratory trial was conducted to evaluate two different electrical arrays that had been generated through discussions within the research group.

LABORATORY TRIAL

The objectives for the laboratory trial:

- Identify the processes causing stratification and gas voids that had been observed in previous studies
- Record changes of dry solids, water movement and friability as the process proceeds
- Investigate two different electrode arrays/orientations
- Characterise the resistive behaviour to provide design parameters for up scaling

The reasoning behind investigating two different electrical setups is that it has been found that by applying an electrical voltage to a material, which can be for example a terrestrial soil, mine slurry or sewage sludge water is moved down the electrical gradient from the anode electrode to the cathode electrode. This mechanism is called electroosmosis (EO). Electroosmosis is driven by the applied voltage gradient and the properties of the material in question. The electrical behaviour of a material can be found by carrying out a number of simple tests. The important characteristics are the coefficient of electroosmotic permeability (k_e) and conductivity (σ) m.S/m. By establishing the material's characteristics, we can see through comparison with previous works if the material will respond to electrokinetics and if so, will it be an economical alternative? Too high conductivity will mean that the material will draw a high current meaning that both the size of the power supply and the energy drawn will reduce the usual significant cost advantages that electrokinetic treatment can give. In terms of the sewage sludge/ green waste mix the materials had a conductivity value of 200 m.S/m.

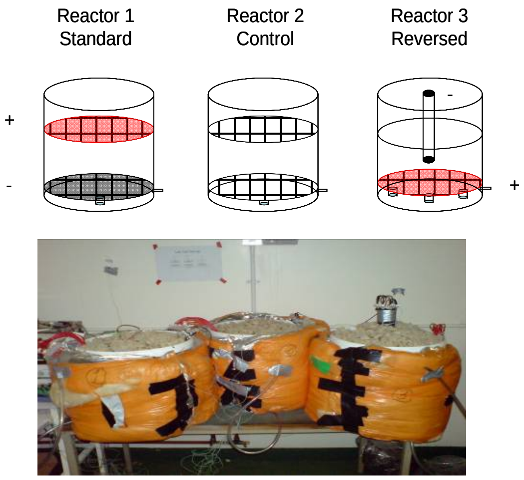

Figure 1. The laboratory trial set up showing the three separate reactors. From left to right reactor 1 is the 'normal' polarity set up, reactor 2 is the control & reactor 3 is the reverse polarity set up.

As shown in Figure 1, reactor 1 is a planar anode placed above a planar cathode. This set up is pushing the water down to the base of the reactor as a controlled discharge. Reactor 3 however, has a planar anode at the base and is forcing the water upwards, against gravity towards the vertical chimney type cathode. The cathode is formed as a permeable drain with external metal elements forming the electrodes. The reverse design came from the desire at Yorkshire Water to minimise basal drainage from the existing windrows, which is difficult to collect and control, resulting in health and safety implications. It also has a high visual impact and loading implications for the waste water treatment works since that flow would have to be returned for treatment. By moving the water upwards through electroosmosis it was hoped that its availability would be increased for dispersion through both evaporation, evapotranspiration (by wind action and taken up by the grass roots on the SPC) and by possible manual siphoning out of the centre of the vertical drain.

It has also been found that as the material is behaving as a resistor the electrical energy applied will also be used by two other mechanisms that can be measured in the field and can provide extra conditioning benefits. These are electrolysis (EL) and thermal or Joule heating (JH).

The anticipated effects of the three electrical mechanisms are summarised in Table 2.

Table 2. Arrangement of factors associate with electrokinetic treatment

Mechanism	**Physical/chemical Effect**	**Index/Measurement**	**Importance for composting/conditioning**
Electroosmosis (EO)	Drainage & dewatering	% Dry solids	Mechanical stability
	Consolidation	Crest height	Reduction in volume
Electrolysis (EL)	pH at electrodes	pH of solids pH of leachate	Influences biological processes and quality of leachate
	Aeration	Dissolved oxygen	Increases rate of aerobic microbiological activity. Sludge contains enteric bacteria, which originates from the digestive tract of the hosts gut some of which will be pathogenic.. By providing an aerobic environment, soil-type micro-organisms are encouraged and will compete for resources against the enteric bacteria, which will die off, thereby reducing the pathogen load in the finished product
Thermal effects/Joule Heating (JH)	Temperature rise	^{0}C	Increases rate of aerobic microbiological activity and vaporisation

As previously mentioned, the lab trial was a scaled down version of the planned field trial and it proved to be an excellent test bed for trying out different methods of data collection and an excellent predictive tool for identifying the key events that indicate that the treatment processes are active while also allowing refinement. By understanding the three main mechanisms; EO, EL and JH, we decided to monitor the following,

- The amount and timing of discharges
- Internal temperatures in the reactors at different points and the external room temperatures as a background reference
- The change in conductivity over time

- The consolidation in the rectors

The lab trial was run over a period of twenty weeks and the data collected was compared and contrasted for the three separate reactors. Upon completion of the test period the reactors were dismantled and the material was very carefully excavated out layer by layer to allow visual descriptions and sample to be taken that would give us information on how the homogenous material masses had changed in response to their different induced electrical arrays.

2

3

4

5

Figures 2 to 5. Showing photographs of the reactors after decommissioning

The results of the lab trial were definitely encouraging. Reactor 1 normal polarity set up was shown to cause stratification in the reactor with the material showing distinct changes in its moisture content from a brown cohesive material above the anode to a light brown friable material immediately around the anode changing to a distinctly dark brown wet cohesive material at the base around the cathode. Reactor 2 the control had remained as a dark brown wet cohesive material with a very dark basal core and very strong odour. The material in the control exhibited little change from the start. Reactor 3 however showed that the reversed electrical array had had a big effect upon the material and its moisture by driving the moisture up to the cathode and in the area directly beneath the base of the cathode, between it and the planar anode, where the electrical field was at its strongest, causing a wet bulb of material. As Table 3 shows, the mass characteristics of the material in the reverse reactor had been significantly improved over the other two reactors showing a more complete treatment. There was also a visual increase in the fungal activity in Reactor 3 with a large amount of fungal hyphae present around the material in direct contact with the vertical cathode.

Table 3. Mass characteristics table form presentation

Reactor	**1 Normal Polarity**	**2 Control**	**3 Reverse Polarity**
Dry Solids % Top	46	35	39
Dry Solids % Middle	44	27	34
Dry Solids % Bottom	28	27	34
Dry Solids % Mass	33	31	38
pH	7.3	4.5	4.5

The results from the lab trial had shown that the reversed electrical array was successful in moving the retained water in the material up towards the vertical drain and increasing its availability. The reversed array had also provided a more homogenised treatment providing a brown cohesive bacterially active compost material. And although there was a small bulb of dark brown wet cohesive material still in the mass, it was distinctly smaller in volume than the deep anaerobic cores of dark material that were found in the control Reactor 2 and to a lesser extent still apparent in Reactor 1. Although it has to be mentioned that Reactor 1 had displaced the most discharge and had initially drawn the highest current it was also shown in the highest internal temperatures. Reactor 3 had experienced some basal discharge but by placing the anode at the base the oxidation created at the anode had caused a significant improvement in treatment.

FIELD TRIAL

The field trial was designed on the basis of the results of the lab trial with the results from the conductivity testing recorded throughout the trial being used to estimate the capacity of the power supplies and electrical consumables, which had significant cost benefits.

The trial windrow consisted of six cells each 6m wide and 8m long, which like the lab reactors, represented the three different electrical arrays. The windrow is a total of 54m in length, and 2.5m in height. The windrow was designed to be split in half to replicate the production of the two different types of end product; conventionally treated sludge, for the purpose of this test will be known as Non-SPC or more conventionally TCSS – treated conditioned sewage sludge, which is treated for 8 wks and the enhanced treated sludge which is further treated using SPC and for a period of 40 wks.

Using the laboratory trial data collected we were looking to identify the three main mechanisms; EO, EL and JH. The constant DC voltage and the current, which would vary over time would be logged constantly to provide a current profile over time of treatment and the physical data collected including consolidation using levelling techniques, internal temperatures of the cells, and this time chemical sampling of the sludge and leachate in a set monthly sampling schedule.

The shape and functionality of the bespoke combined geosynthetic used in the field trail was of great importance. The anode for both arrays would take the form of a planar electrode. The normal polarity set up required gaps between the yarns to allow grass roots to grow through and down deep into the mass to promote the SPC treatment. In the reverse polarity set-up it had to act as a basal to cloth to contain a filter medium to retain fines from washing out of the base of the windrow. It was very important for both cloths to support the regular closely spaced metal elements woven into the fabric, allowing a good electrical contact with the irregularly shaped mixed waste with its varying particle size.

The cathode for both the normal and reversed polarity arrays was to be composed of the pipe drain design with its integrated metal elements. In the normal polarity set up they would be placed width ways across the base of the cell with the electrodes having a length of 6m. In the reversed array the vertically placed electrode was 1.5m in length. In both uses the cathode drain would behave as a pathway for gas and water movement as well as allowing the efficient application of the electrical field.

Figure 6. Windrow profile showing vertical and horizontal cathodes

RESULTS

The field trial was constructed in late December 2007 and started electrokinetic treatment in mid January 2008 and will be ongoing until the end of November 2008. This means that the reportable results so far are from the on going data collection including; logged current, chemical testing, physical monitoring, photographs and observations.

Results so far indicate that the process of conditioning through electrokinetics is active. The current for both the normal and reverse polarity cells initially started at between 109 – 130Amps for the constant 14Volts applied. This was maintained for the first four weeks as both consolidation of the masses created and the wet weather keeping the conductivity high. The conductivity has steadily reduced after this and in the lab trial this coincided with the start of the water discharge. Basal discharge can be seen from each of the cells with visual biofilms. The normal polarity cells that have basal horizontal drains show the more uniform discharge from the basal horizontal drains. The cells are consolidating with the heights changing from a start of around 2.5m to an average of 1.85m recorded on the 05/03/2008. The control cells clearly exhibit minor slumping in their profile with a very wet base of black soft material with a large amount of moss up to a height of 1.0m. When taking the chemical samples the material has retained the original strong sewage smell, dark wet cohesive nature and there is still the noticeable presence of polymer (residue from dewatering). The temperatures in the control cells are the lowest at around 6-14ºC. The normal polarity cells have maintained their original profile with the material around the middle anodes being noticeable drier and friable the internal temperatures are warmest in the material between the anode and cathode at around 8-19°C. The base material is wet cohesive and dark brown in colour. The reverse polarity cells have developed a 'compost like' smell with the highest range of temperatures 8-26°C. The material can be described as being cohesive and brown. It has been found that there is standing water in the vertical drains with an average of 26mm in the Non-SPC and 10mm in the SPC cells. In general the grass growth has been excellent with little visual difference in shoot length or density between the three cells. A small amount of excavation has revealed that the roots in the reverse cells are growing down to a deeper depth to the oxygen rich area around the anode at the edges. Chemical results have shown that the original materials levels of heavy metals are well below the minimum actions levels required by the Environment Agency of soils. *Salmonella* levels have reduced to zero for all the cells and all the cells have experienced a reduction in pathogen levels.

CONCLUSIONS

By concentrating on monitoring the three mechanisms; EO, EL and JH we can see that the treatment process of electrokinetics is being successfully applied to the material in the cells by the combined hybrid geosynthetics materials and as proposed it is having a positive effect on the composting and conditioning process. The observed effects are as a result of,

- The cathode drains are attracting and promoting water movement throughout the mass
- Recognisable increase in speed of treatment
- Increased depth of treatment, which will have overall capacity benefits for the site
- The lab trials have shown that the reverse polarity array is expected to produce the best mass conditioned material

By combining a geosynthetic with the ability to apply electrical energy, this study indicates that treatment benefits can be achieved. Further work is required to show the magnitude of those benefits and the economic advantage they can provide.

Acknowledgements: Special acknowledgement is due to Yorkshire Water headed up by Tom Taylor and Ian Fairless for their technological input, knowledge, interest in and funding of the project. We also thank the Civil Engineering and Geosciences Department of Newcastle University and its technical support staff.

Corresponding author: Mr Chris White, Newcastle University, Drummond Building, Newcastle upon Tyne, United Kingdom. Tel: + 44 191 243 0684. Email: chris.white@newcastle.ac.uk.

REFERENCES

ADAS, 2005. Safe Sludge Matrix

Duffin, W. 1980. Electricity & Magnestism. 3rd Edition. McGraw-Hill Book Company Ltd.

Helmoltz, H. 1879. Studien Über electrische Grenzscheihten, Wiedemanns Annalen d. Physik, Vol. 7, p 137

Mitchell, J.K. & Soga, K. 2005. Fundamentals of Soil Behaviour. 3rd Edition.

Taylor, T.L. 2003. Sludge Phyto-Conditioning: Low Technology Enhanced Treatment. Proceedings of the 8th CIWEM/AquaEnviron European Biosolids and Organic Residuals Conference.