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Dewatering of sewage sludge using electrokinetic geosynthetics

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ABSTRACT: The treatment and disposal of sewage sludge is one of the most problematical issues affecting waste water treatment in the developed world. The traditional outlets for sewage sludge are to spread it on agricultural land, or to form a cake for deposit to landfill or incineration. In order to create a sludge cake, water must be removed. Existing dewatering technology based on pressure can only remove a very limited amount of this water because of the way in which water is bound to the sludge particles or flocs. Several researchers have shown that electrokinetic dewatering of sludge is more efficient than conventional hydraulically driven methods. This involves the application of a D.C Voltage across the sludge, driving water under an electrical gradient from positive (anode) electrode to negative (cathode) electrode. However, there have been several reasons why this technique has not been adopted in practice, not least because the, normally metallic, anode rapidly dissolves due to the acidic environment created by the electrolysis of water.

This paper will describe experimentation using electrokinetic geosynthetics (EKG): polymer-based materials containing conducting elements. These have been used to minimise the problem of electrode corrosion and create a sludge treatment system that can produce dry solids contents in excess of 30%. It will suggest different options for the treatment of sludges both *in situ* in sludge lagoons and windrows, and *ex situ* as a treatment process.

1 INTRODUCTION

It is well understood that the dewatering of sewage sludge is one of the most challenging technical tasks in the field of wastewater and that current dewatering practice, based on mechanical pressure, is limited by the way in which water is bound to the sludge flocs. Electrokinetic techniques offer one potential cost-effective solution. The objective of the work described herein was to establish the susceptibility of a range of sludge materials to electrokinetic dewatering and to explore different means of application using electrokinetic geosynthetics (EKG).

Electrokinetic phenomena have been studied extensively in the context of dewatering/consolidation of fine-grained soils and are the result of the coupling between hydraulic and electrical potential gradients. These phenomena occur due to the presence of the diffuse double layer around the fine grained soil particles and involve the movement of electricity, charged particles and fluids (e.g. Yeung, & Mitchell (1993) and Mitchell (1993)). Of particular relevance is electroosmosis (E-O) where the applied electrical potential difference induces fluid flow in a charged particle matrix.

Typically electroosmotic dewatering of clay soils is of the order of 1 to 4 orders of magnitude faster than hydraulic dewatering, with a typical value of electro-osmotic permeability (k_e) for a clay soil being 10^{-5} cm^2/Vs, as opposed to hydraulic permeability which ranges from 10^{-9} m/s to 10^{-5} m/s for silts and clays.

Like clay particles, sludge particles have a pH dependent surface charge, which is frequently negative. For this reason they too develop a diffuse 'double layer' of water surrounding the particles with the characteristic zeta potential at the boundary between the fixed and mobile portions of this layer. Because the flow of water induced by an electrical potential difference is not limited by pore size, electro-osmosis has the potential to remove interstitial water from the sludge flocs, thus greatly improving dewatering efficiency. Indeed, Yan & Weng (2002) noted a k_e value for sewage sludge of about 5 times that of many soils.

EKG comprises conducting elements coated in a corrosion-resistant material, incorporated into a geosynthetic material. This patented design has overcome the problem of electrode corrosion. By encasing the metallic filaments in a relatively inert material, electrode corrosion is effectively managed or eliminated. By forming the electrode as a geosynthetic, EKG overcomes the problem of removing clean water by utilising the drainage and filtration functions of geosynthetics. Their ability to take on a wide variety of shapes and forms means that they can be manufactured to suit a range of different applications. It is envisaged that EKG could be applied in several ways:

- installed as vertical 'wicks' into sludge lagoons and used to draw water to the surface, removed by pumping, and discharged;
- installed as a combination of basal grid and fabric cover to increase dewatering rates in windrows; and
- formed as the fabric in a belt or filter press to improve dewatering performance.

2 LAGOON APPLICATIONS

Historically the predecessors of most UK water companies disposed of large quantities of sludge in unengineered lagoons, constructed on sewage works sites, because this represented the cheapest possible method for 'dealing with' this sludge. Until very recently it was in fact still legal to permanently deposit untreated sludge produced at a sewage works in a lagoon on that works, although it was not legal to do so with any imported sludge. Unfortunately these lagoons did not in fact deal with the sludge, they just postponed the time when it would have to be tackled properly. For some of these lagoons this time has now come, perhaps due to pollution of a watercourse or groundwater, or where the area of the lagoon represents the only possible space to expand the works, or in a few cases where there is development potential. The EKG system has the potential to dewater existing lagoons in-situ either to facilitate removal of the sludge as a solid or to strengthen the sludge in-situ to free development potential.

Electroosmotic consolidation could be applied practically in real situations by adapting the technology known as prefabricated vertical drains (PVD) or wick drains to treat historical sludge lagoons *in situ*. Electroosmotic PVDs or *e*PVDs utilise the higher flow rates that are achievable by E-O without the requirement for a surcharge load. The advantages of this approach are that it does not require the double-handling of large quantities of material demanded by the application of any load, and it is much faster. The speed advantage derives from the fact that electroosmotic permeability is higher than hydraulic permeability (for materials such as silts, clays and sludges), and that because no load is required, the full flow rate can be achieved immediately rather than needing to wait for gradual improvements in strength before additional load is applied as is the case with 'staged loading'. A staged approach is normally required as soft, lagooned materials are too weak to support a significant load.

2.1 *Laboratory testing*

Tests were performed on two similar samples (A & B) of a cold digested thickened lagooned sewage sludge. This sludge had been resident in the lagoon for approximately 3 years. Tests were performed to determine the ability of the materials to support E-O and the degree of consolidation that could be achieved by E-O. The coefficient of electroosmotic permeability, k_e, is used as an indicator of the ability of a material to support E-O; the 3 week consolidation test was used to determine the amount of volume reduction possible. All tests were undertaken using an applied back pressure of 50 kPa and an applied voltage gradient of 1 V/cm, using parallel copper disc electrodes in the apparatus illustrated in Figure 1.

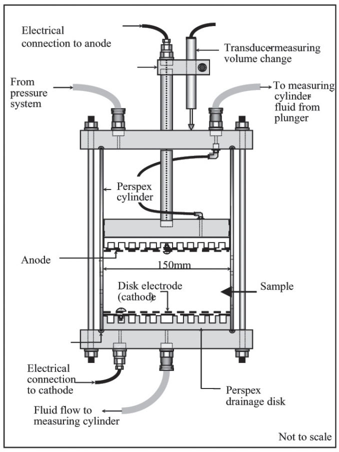

Figure 1. Electrokinetic test set up.

The sludge demonstrated a k_e value of 1.5×10^{-5} cm^2/Vs, which compares very favourably with the types of clay soils that are most amenable to this treatment. Results of the 21-day tests are summarised on Table 1, producing average solids contents of 27% (B) and 23% (A) and overall volume reduction of between 40% and 50%.

2.2 *Field trial*

The effectiveness of electrokinetic consolidation of lagooned sewage sludge cake by means of ePVDs was examined at pilot scale using two steel containers of 9.7 m^3 capacity with tailor-made butyl liners filled with approximately 8.5 m^3 of sludge. The sludge was

Table 1. Summary of long term consolidation tests.

	Test A	Test B
Initial moisture content	621%	574%
% dry solids	13.9% ds	14.8% ds
Test duration	21 days	21 days
Volume of extracted water	837 ml	1083 ml
% dry solids at cathode	31.8%	38.9%
% dry solids at anode	64.5%	72.5%
Total volume reduction	–40%	–51.7%

in a liquid state with a low shear strength (unmeasureable using a hand vane, but estimated to be approximately 1 kPa) and a solids content of only 10.6%. A before-and-after photograph is shown in Figure 2.

Figure 2. Skip trial before and after treatment.

3 WINDROW APPLICATIONS

At present some humic sludge is treated by thickening, pressing (in a belt or filter press) and then drying in the open air in elongated stockpiles, or windrows. Wood waste is added in the proportion of approximately 30–40% by volume to improve the mechanical handling characteristics of the sludge. The mixing of wood waste has a cost implication for acquiring the material, mixing and handling of the bulk product, which increases markedly in volume on addition of the wood waste.

The main objective of the study described herein was to examine the effects of E-O on the sludge with varying proportions of wood waste in order to explore if E-O dewatering would permit a reduction in the overall amount of wood waste needed to be added to the express sludge.

3.1 *Laboratory testing*

Tests similar to those described above were performed on ex belt-press humic sludge. E-O consolidation tests were conducted over a period of 21 days with a cell back pressure of 25 kPa and a voltage gradient of 0.5 V/cm with pure sludge samples mixed with varying proportions of wood waste (0%, 10%, 30%, and 50%). The k_e values ranged from 7.2×10^{-5} to 2.0×10^{-5} cm^2/Vs, indicating that the materials fully support E-O. This proved to be of the order of 500 times greater than the hydraulic permeability of the sewage sludge alone, but only 120 times greater that that of the sludge mixed with 50% wood waste.

3.2 *Field trial*

A field trial was conducted on humic sludge mixed with 33% by volume wood waste. A trial windrow was constructed which was 26 m long, 5 m wide at the base, and 2 m high. EKG was installed in half of the length of the windrow, of which half was activated at 10 V. An intermittent voltage was applied for a period of 3 months. Post treatment exhumation of the windrow revealed significant differences in the properties of the different sections of the windrow. The active section exhibited significantly improved drainage and volume reduction and microbial activity.

4 PRESS APPLICATIONS

Many types of sludges are currently dewatered using mechanical means. Examples include both belt and filter presses. Sludge is firstly thickened using a polymer flocculant before being mechanically pressed. For reasons described earlier, the degree of dewatering achieved by these means is limited, at best achieving dry solids contents in the region of 15–20%. The remit of this work was to investigate the potential for applying electrokinetics to press technology to improve the dewatering of sewage sludge.

4.1 *Laboratory testing*

Similar tests to those previously described were undertaken, with the exception of the form of the electrodes, the thickness of the sample and the duration of the test. Electrodes were cut from woven polyester material and electrified with carbon fibre strips at spacings of 5 mm, 10 mm, and 20 mm. In this way these electrodes had very similar electrical and filtration properties to those that would be used in an operating press.

The sludge tested included the same ex-belt press humic sludge that was tested as part of the lagoon trial described earlier (15% dry solids) and ex-drum thickener activated sludge further dewatered by hand pressure (7.6% dry solids). The test set-up used two separate voltages of 15 V and 30 V applied to a 15 mm thick sample with a back pressure of 70 kPa for humic sludge and 25 kPa for activated sludge. The tests lasted for 20 minutes. The higher pressure was used to simulate typical pressure exerted in a belt press and the 20-minute duration was considered to be approximately two to three times the typical residence time of sludge in a belt press.

The percentage dry solids achieved by treatment of the humic sludge after 20 minutes duration for the different electrode configurations and applied voltages is shown in Figure 3.

This method calculates the dry solids in the material remaining in the cell from the volume of water collected. This calculation may underestimate % dry

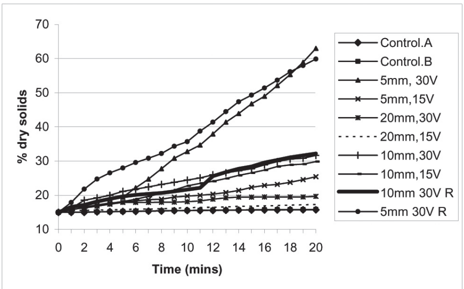

Figure 3. Humic sludge: % dry solids from discharge.

solids because some water removed by electrolysis is not accounted for and may therefore be regarded as conservative. The most effective of the tests were repeated (denoted with an R) to ensure repeatability of the dry solids achieved.

The results for similar tests on activated sludge are shown on Table 2.

Table 2. % dry solids after 20 minutes, activated sludge.

	Electrode design and applied voltage			
	2.5 mm 15 V	5 mm 30 V	10 mm 30 V	Control
Discharge (ml)	63.00	126.00	93.00	0.00
Displacement (mm)	–0.07	–1.89	–1.32	0.00
% dry solids (discharge)	10.28	15.89	12.36	7.60

These results, although apparently less encouraging than those for the humic sludge were achieved using a back pressure of only 25 kPa. This was necessary due to the very fluid consistency of the initial sludge material meaning that higher pressures forced the entire sample through the filter material. This low back pressure is of considerable significance here because it means that all the effective dewatering is attributable to E-O alone.

A recent trial was conducted using a full-scale belt press fitted with EKG belts in which significant increases in solids content were also achieved.

4.2 *Conclusions*

Results showed that the electrified belt materials acted as very effective electrodes and indicate that significant advantages can be gained in the dewatering efficiency of sewage sludge materials. Although the best improvements in solids content derived from testing electrodes with conducting elements spaced at 5 mm and a potential of 30 V the dewatering achieved appears to be more sensitive to applied voltage than to element spacing. These tests repeatedly produced solids contents of >30% after 10 minutes (the time representative of the residency within a belt press). It should be noted that this figure represents a conservative estimate of the solids contents. Tests on activated sludge produced solids contents up to 15.9%, again with the best results being produced from a combination of a 5 mm conducting element spacing and an applied potential of 30 V.

5 CONCLUSIONS

In this paper the application of electrokinetics to the dewatering of sewage sludge by means of electrically conductive geosynthetics (EKG) has been demonstrated through laboratory testing. Several different methods of practical application have also been demonstrated through the successful execution of field trials.

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