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Treatment 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 wastewater 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 dc 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.

Keywords: Sewage sludge; Dewatering; Electrokinetic geosynthetics

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 engineering [1] and all existing methods have severe limitations. These limitations may be attributed to the different physical states of water associated with the sludge and the manner with which they are bound to the sludge flocs. According to Smollen and Kafaar [2], water exists in the following physical states:

1. Free: water not associated with solid particles;
2. Interstitial, capillary: mechanically bound water which is trapped in the flocs;
3. Vicinal: physically bound multiple layers, held tightly to the particle surface by hydrogen bonding;
4. Chemically bound: water of hydration.

In addition, some sludges such as digested and activated sludges have a substantial intracellular component. Current dewatering methods are based on the use of mechanical pressure or centrifugation to cause the free water in the system to flow. This is performed by feeding a liquid sludge into a machine (centrifuge, belt press, etc.). This water can then be removed by mechanical means. More dewatering is achieved by exerting a greater and greater pressure. However, mechanical effects alone cannot achieve a sufficiently high potential to drive the interstitial water through the very narrow pore spaces and removal of interstitial water through mechanical means is extremely limited. Vicinal and chemically bound waters are not removed at all by mechanical means. Therefore, once a cake has been formed, however bad the quality, there are few ways of dewatering it further. Currently only potential gradients produced by thermal methods are sufficiently high to remove interstitial and vicinal waters, involving high capital and operating costs. 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).

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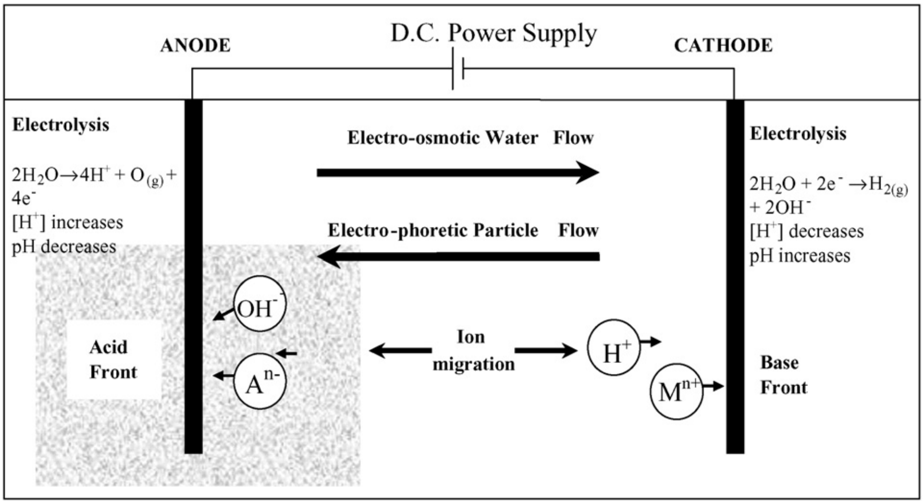

Fig. 1. Electrokinetic effects.

1.1. Electrokinetics

Electrokinetic techniques have been developed for treatment of clay soils, since their introduction as a construction technique in 1939. Electrokinetics, for these applications, may be defined as the application, or induction, of an electrical potential difference across a soil mass containing fluid, or a high fluid content slurry/suspension, causing or caused by the motion of electricity, charged soil and/or fluid particles.

Electrokinetic phenomena are the result of the coupling between hydraulic and electrical potential gradients in fine grained soils [3–6]. 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 [5].

Electrokinetic phenomena may be defined in terms of five categories. Of these, the three most relevant are defined below and illustrated in Fig. 1:

- Electromigration/ion migration: Applied electrical potential difference induces ion migration within the fluid phase of a charged particle matrix.
- Electrophoresis: Applied electrical potential difference induces movement of suspended colloidal particles within a fluid medium.
- Electroosmosis (E-O): Applied electrical potential difference induces fluid flow in a charged particle matrix.

Electroomotic flow is governed by the following equation:

$$q = k_e \frac{\Delta V}{\Delta L} A \qquad (1)$$

where q is the flow, V the voltage (or electrical potential), L the distance over which voltage is dropped and A is the area of material through which flow is occurring. k_e is termed the electroosmotic permeability and has units of m/s per V/m, or $m^2/V\,s$. This is analogous to Darcy's law for hydraulic flow through porous media:

$$q = k_h \frac{\Delta H}{\Delta L} A \qquad (2)$$

where q is again flow, H the hydraulic potential, L the distance over which hydraulic potential is dropped and A is the area of porous media through which flow occurs. k_h is the hydraulic conductivity, or permeability and has units of m/s per m/m, or m/s. The difference in the units between k_e and k_h is therefore derived from the difference in the units of the driving potential, rather than the units of flow. Therefore, they are considered to be directly comparable.

Historically, k_e has been reported in units of cm^2/Vs in the literature [5] and termed electroosmotic permeability. For the purposes of comparison with published data, and to avoid confusion when comparing hydraulic dewatering to electroosmotic dewatering, this paper will use the terms electroosmotic and hydraulic permeability and use units of cm/s.

Typically electroosmotic dewatering of clay soils is of the order of 1–4 orders of magnitude faster than hydraulic dewatering, with a typical value of electro-osmotic permeability (k_e) for a clay soil being 10^{-5} $cm^2/V\,s$, as opposed to hydraulic permeability which ranges from 10^{-9} to 10^{-5} m/s for silts and clays. Actual values of k_e and k_h for a range of soils are shown in Table 1. The greatest advantage to be gained from electrokinetic dewatering over hydraulic dewatering is when the ratio of k_e:k_h is high.

Table 1
Typical values of k_e and k_h (after [5])

Material	Moisture content	k_e ($\times 10^{-5}$ $cm^2/V\,s$)	Approximate k_h (cm/s)
Fine sand	49.7	4.1	10^{-4}
Clayey silt	31.7	5.0	10^{-5}
Kaolin	67.7	5.7	10^{-7}
London clay	52.3	5.8	10^{-8}
Na montmorillonite	170	2.0	10^{-9}
Na montmorillonite	2000	12.0	10^{-8}

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. Previous research (see Section 1.2), which has concentrated entirely on improving various dewatering machines, has showed that sludges are shown to vary in electrokinetic performance, but this was not backed up by characterisation of the fundamental electroosmotic parameters, e.g. k_e (electroosmotic permeability), with the exception of Yaun and Weng [7] who noted a k_e value about five times that of many soils.

1.2. Previous work

The idea of using electrokinetic techniques to dewater sludges is not new and has been investigated by several researchers [2,8,9]. The majority of these have concentrated upon the use of electro-osmosis to enhance the dewatering capabilities of a mechanical process and have incorporated, for example, electrically conducting rollers into a belt press. Other studies have concentrated on laboratory studies using cake materials.

The major drawback with these studies is their practical application. If E-O is to be used only in conjunction with mechanical pressure this severely limits its application within the overall framework of sludge and wastewater treatment. The requirement for mechanical pressure would mean that it could not be applied, for instance, to treat sludge lagoons in situ. Researchers who have investigated the effects of E-O on cake in the laboratory, have not suggested a means of full-scale, practical implementation.

Another major deficiency is that all studies have used metallic electrodes. Electrolysis of water at the electrodes always produces acidic conditions at the anode which contributes to rapid corrosion of the metallic electrode. Within a relatively short period of time, the corrosion reduces the electrical contact with the soil and electrical efficiency is reduced. The inability of a metallic electrode to act as an effective drain also means that only single polarity treatment is possible, so that the final product is extremely heterogeneous.

1.3. EKG concept

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 because the oxidation reactions at the anode are very much reduced, and designed so that the anode is effective over its intended design life (different for different applications). 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;
- formed as the fabric in a belt or filter press to improve dewatering performance.

2. Lagoon applications

Electroosmotic consolidation could be applied practically in real situations by adapting the technology known as prefabricated vertical drains (PVD) or wick drains. These are used routinely to consolidate soft soils in situ. PVDs work by creating short pathways for water to flow out of a low permeability substrate such as fine grained lagoon waste. Using the traditional PVD approach, water flow is caused by creating a pressure difference between the PVD and the material to be consolidated. This pressure difference is achieved by placing a load (usually in the form of a layer of sand and gravel several metres thick) over the surface of the material to be consolidated. This process can take many months or even years to complete and is limited by the hydraulic permeability of the materials and the rate at which the overlying load material can be placed onto a weak substrate (staged loading).

Electroosmotic PVDs or ePVDs utilise the higher flow rates that are achievable by E-O without any additional 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.

Part of the approach with ePVDs is the reversal of polarity to create homogeneous gains in material strengths between anodes and cathodes. EKG electrodes are designed to operate equally effectively as cathodes or anodes and are thus ideally suited to secure the advantages offered by polarity reversal.

2.1. Laboratory testing

Tests were performed on a cold digested thickened lagooned sewage sludge with an initial dry solids content of approximately 15%. This sludge had been resident in the lagoon for approximately 3 years. Tests were additionally performed on a similar sludge that had been resident for over 80 years. That work is presented elsewhere by Glendinning and Walker [10] and concluded

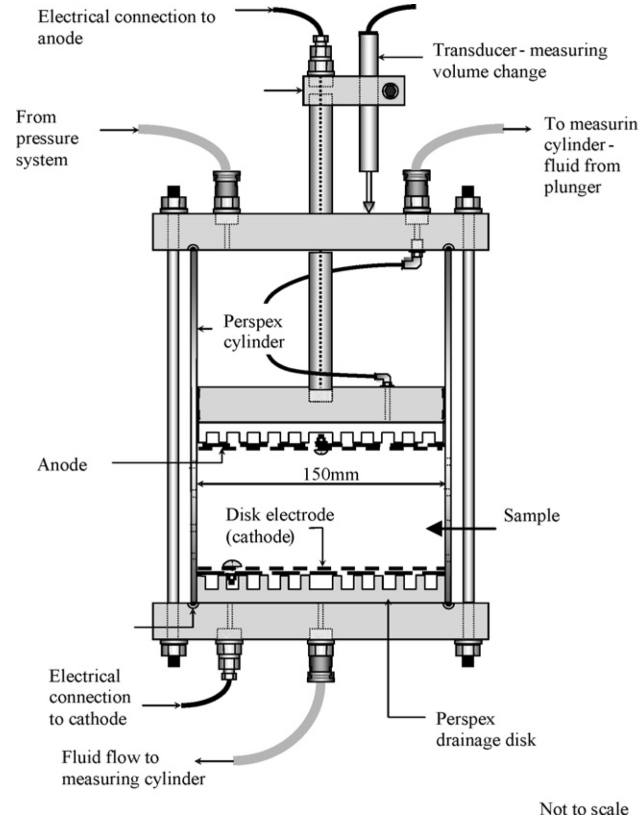

Fig. 2. Electosmotic cell.

that the dry solids content could be increased from about 19% to 42%, accompanied by a significant increase in shear strength from less than 1 to 29 kPa and a 57% reduction in volume.

Tests were performed to determine the ability of the materials to support E-O and the degree of consolidation that may be achieved by E-O. The coefficient of electroosmotic permeability, k_e, is used as an indicator of a materials ability to support E-O. The testing method used was non-standard and has been developed at Newcastle University. The k_e of a material is derived using Eq. (1) by measuring the flow of water caused by E-O (q in Eq. (1)) under constant electrical gradient ($\Delta V/\Delta L$ in Eq. (1)) with a constant supply of water to the anode under zero hydraulic head in the test cell illustrated in Fig. 2. The cell depicted consists of a Perspex cylinder with a fixed base plate and an internal movable piston whose movement may be monitored by means of a displacement transducer (LVDT). Provision is made for the location of disk type electrodes both on the piston and on the fixed base plate by means of cable glands that permit the passage of an electrical cable into the cell, without the loss of pressure. Additionally, the cell incorporates side ports through which porewater pressure and voltage gradient may be measured if required by means of a hypodermic needle tipped with a piece of porous ceramic or plastic. The chamber behind the moveable piston may be pressurised to apply a consolidation pressure to the soil sample. Back pressure may also be applied to the soil sample through tubing which passes through the piston and the base plate, this tubing also acts as a drain for any excess porewater pressure.

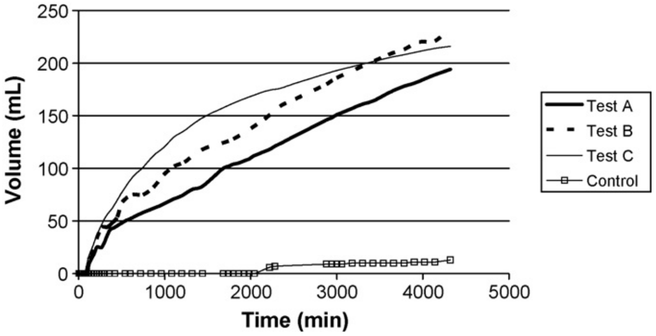

Fig. 3. Volume of discharge water during 3 day E-O consolidation test.

E-O consolidation tests were performed in a similar experimental apparatus, with the water supply to the anode switched off, i.e. operating under ‘closed anode’ conditions. An initial test of 3 days duration was performed, followed by a longer test of 3 weeks duration. All tests were undertaken using an applied back pressure of 50 kPa and an applied voltage gradient of 1 V/cm. The control test had zero applied voltage.

Both sets of tests were performed using parallel copper disc electrodes. Three repeat tests (A–C) were performed due to the variability of the initial material dry solids.

2.2. Results

The sludge demonstrated a k_e value of 1.5×10^{-5} cm^2/V s, which compares very favourably with the types of clay soils that are most amenable to this treatment (see Table 1).

The results of the 3-day consolidation tests are shown in Fig. 3. This illustrates the volume of water extracted from the sample with time and demonstrates the very marked difference between the control (with no voltage applied) and the samples subjected to an electric field.

At the end of the 3-day test the control sample had a dry solids content of 16% with virtually no change in volume of the sample; the maximum dry solid content of the E-O treated samples was 27% (at the anode) accompanied by an average 10% reduction in volume over the sample. Results of the 21-day tests (on A and B samples only) are summarised on Table 2, producing average solids contents of 27% (B) and 23% (A).

The tests concluded that the sludge is a suitable substrate for effective E-O dewatering, which proved considerably more effective than hydraulically driven dewatering alone. Treatment

Table 2
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%

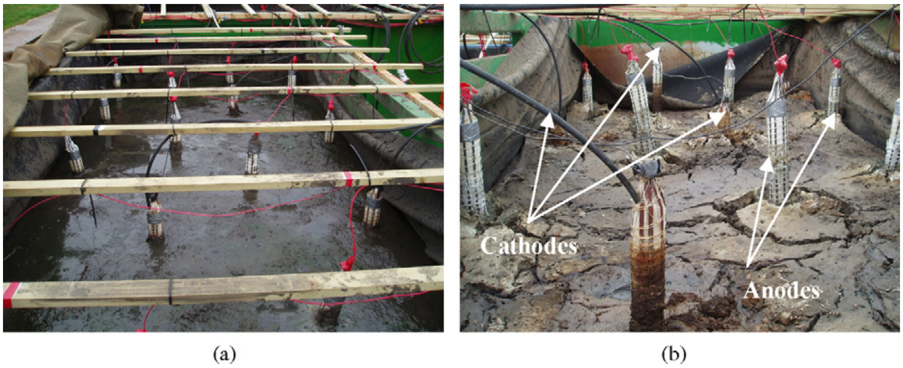

Fig. 4. Skip trial before (a) and after (b) treatment.

could produce an overall volume reduction of between 40% and 50% over a period of 21 days.

2.3. 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 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%. The skips were covered during the test to eliminate the potential for rainwater ingress. Two electrode arrays were evaluated:

- Rectangular array with anode–cathode spacing of 0.9 m and anode–anode or cathode–cathode spacing of 0.4 m.
- Hexagonal array with spacings of 0.7–0.9 m (in practice an equilateral spacing would be chosen; here the hexagons were distorted to suit the containers).

The electrodes were composite EKG Mk5 ePVDs, which comprised six different components including a central perforated drain, filter fabric, primary and secondary conducting elements, and integral and binding knitting yarns. The arrays were run at 30 V, providing a voltage gradient in the order of 33 V/m.

Sixty-three days of treatment, applying an intermittent voltage resulted in a reduction in volume of 23% for skip A and 30% for skip B. It is considered that the potential for reduction, however is much greater as the method used to remove water from the cathodes was not particularly efficient and significant quantities of water collected at the surface of the sludge adjacent to the cathode from where it flowed back to the anode and effectively recirculated around the system. The effect of evaporation was considered to be negligible as the sludge had been taken from the near-surface a lagoon that had been open to the atmosphere, allowing all potential atmospheric drying to have taken place. Evaporation had been further reduced by the presence of the covers.

Shear strength was measured using a hand shear vane in a regular grid pattern across each skip. The average shear strength for skip A was 7 kPa and 16 kPa for skip B. A before-and-after photograph of skip B is shown in Fig. 4. Again, it is felt that higher strengths can be achieved in the same time once the problem of water removal caused by the poor performance of the siphons is corrected.

Power consumption was calculated for the entire treatment period, from the readings made of current and voltage, with the lowest demand for power resulting from the electrode configuration in skip B averaging 128 kWh/m^3 of wet sludge. Power consumption was expressed in this way as it was considered to be the most useful way of providing potential end-users with the likely cost of dewatering lagooned sewage sludge using this technique. However, it is felt to severely overestimate the amount of power required to treat this volume of soil if the overall treatment area is scaled up. These figures can be adjusted downwards by quantification of the following factors:

- Ineffective removal of water, which would lead to (i) reduced volume reduction and thus longer embedded lengths of electrodes and thus higher power demand and (ii) longer than necessary treatment duration thus higher overall power consumption over the duration of the trial.
- Addition of water during the filling of the skips. At 10.5% dry solids the sludge was wetter that the sludge in the lagoon and it is highly inefficient to use electroosmosis to remove water which could have been pumped clear of the surface of the lagoon at the beginning of the trial.
- Edge effects including (i) excessive current along the sludge/butyl liner contact (caused by water concentration due to ineffective water removal from some cathodes) and (ii) electrical field distortion meaning that the test arrays comprised a disproportionate number of electrodes that were at the edge of the overall array and thus part of 'partial cells'.

An initial quantification of these factors has allowed an estimate of the 'true' power consumption for effective treatment:

- Grading the performance of siphons, and comparing this to the current drawn through the associated cathodes, showed that effective water removal from all cathodes would have the effect of reducing overall current for the array by approximately 33%;

- Removing the surface excess water could produce a saving of 42–52%;
- Accounting for edge effects (using an example of an array of 100 × 100 electrodes) would yield a saving of approximately 7%.

Compounding these factors yields an overall power saving of approximately two thirds. This means that the initial estimate of 128 kWh/m^3 to reach a volume reduction of 30% could be adjusted to 43 kWh/m^3. This could be further refined as more effective water removal would create a faster rate of volume reduction and thus shorten the overall treatment time. It is further noted that electroosmotic efficiency (volume of water moved per unit charge) varies according to voltage gradient such that a higher voltage gradient produces more rapid flow but is less efficient. The voltage gradient used in the trial was low relative to historically common values [5] so there is scope to improve on the speed of treatment or to have a higher voltage over a larger electrode spacing to reduce the number of electrodes.

2.4. Conclusions

The laboratory testing has indicated that significant increases in shear strength and reductions in volume can be achieved by the application of E-O to lagooned sludges. The field trial has shown some improvement can be achieved by the application of E-O in situ using e-PVDs. However, some further development is required, particularly on the method of extracting the water from the cathodes before the full potential of E-O can be realised.

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 to the ex-belt press sludge in the proportion of approximately 30–40 vol.%. The addition of wood waste is carried out primarily to improve the mechanical handling characteristics of the sludge. The mixing of wood waste has a cost implication for acquiring the material, mixing it and handling 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 that needs to be added to the ex-press 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%). Control tests (with no voltage applied) were performed on the 0% and 50% mixtures.

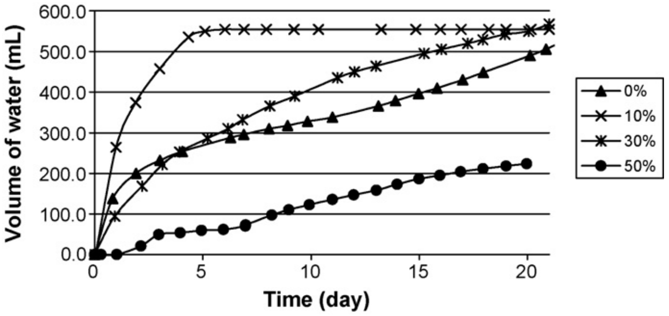

Fig. 5. Water discharged from E-O tests on ex-belt press humic sludge (mixed with varying proportions of wood waste).

3.2. Results

The k_e values ranged from 7.2 to 2.0×10^{-5} cm^2/V s, 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 than that of the sludge mixed with 50% wood waste because of its higher initial starting k_h. Fig. 5 shows the comparisons in the volume of water extracted with time from each of the E-O tests. Results from the control tests were not potted because so little water was extracted, typically approximately 150 ml of discharge was produced during the full 21 days of the test.

It is clear that the 10% wood waste mixture provided the best dewatering. This particular test showed a significant levelling off after 5 days, possibly due to the entrapment of gas produced adjacent to the electrodes. (In any test gas can be trapped due to the design of the equipment being particularly sensitive to minor blockages. This is not something particular to the 10% wood waste sample.) If this were the case, then further dewatering could be achieved in practice where gas is free to escape. The 0%, 30% and 50% tests appeared to be continuing to dewater after 21 days, although at different rates. The difference in the dewatering between the samples may be explained by considering the balance between the effect of the wood waste on the compressibility of the sludge and the effect of the wood waste on its electroosmotic permeability. Adding a small amount of wood increases the compressibility of the sludge, increasing the rate at which water is expelled from the sample through the action of sample compression. Adding increasing quantities of wood reduces the electroosmotic permeability to such an extent that elecroosmotic dewatering is reduced.

3.3. 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 a potential gradient of between 10 and 30 V/m. 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 (with voltage applied) exhibited sig-


(a) (b)

Fig. 6. Windrow trial, showing (a) increased settlement at crest and (b) increased drainage at the base.

nificantly improved drainage and volume reduction (as shown by the dip in the crest (a) and obvious flow of dark fluid from the base shown (b) in Fig. 6).

3.4. Conclusions

The broad relationships derived from the test programme show that E-O works best, theoretically and practically, for pure sludge, and its effectiveness decreases with additions of wood waste. A combination of E-O dewatering with a 10 vol.% mixing of wood waste appears to optimise dewatering and strength improvements, thereby offering significant cost savings over existing practices. The field trial has shown that significant improvements can be realised at full-scale for humic sludge mixed with 30% wood waste.

Although not explicitly tested in this programme, it also offers the potential of using green wood waste instead of dry wood waste. Currently this is impossible due to the high water content of green wood waste.

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, 10, 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 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 min. The higher pressure was used to simulate typical pressure exerted in a belt press and the 20-min duration was considered to be approximately two to three times the typical residence time of sludge in a belt press.

4.2. Results

In this application, the achievable dry solids content is significant as it is the measure used in the water treatment industry to describe the condition of sewage sludge. Therefore, the results are expressed in terms of percentage dry solids achieved rather than volume of water extracted. The results of the treatment of the humic sludge after 20 min duration for the different electrode configurations and applied voltages is shown in Fig. 7. This method calculates the dry solids in the material remaining in the cell from the volume of water collected. This calculation may underestimate % dry 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 3.

These results, although apparently less encouraging than those for the humic sludge were achieved using a back pressure

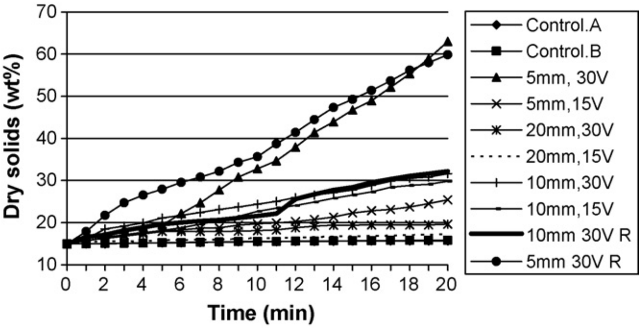

Fig. 7. Humic sludge: % dry solids from discharge.

Table 3
Percentage of dry solids after 20 min, 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

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 achieved. The belts were fabricated from woven polyester with metallic elements included to provide current discharge through the sludge and also a means of distributing current from the stationary power supply to the moving belts. A conceptual model of the press is pictured in Fig. 8

The sludge treated was a mixture of surplus activated sludge (SAS) and primary sludge. Under normal conditions belt press dewatering of this sludge was producing a sludge cake of solids content between 18% and 20% by mass. In order to maximise the dewatering performance the belt was slowed down such that the residence time in the parallel section of the belt increased from 5 to 9 min. At the same time the feed rate (and thus throughput) was reduced by 10% such that sample thickness was increased significantly from approximately 5 mm to approximately 10 mm.

Trials were performed over a 5-day period, the belt press was manned continually and regular measurements of solids contents were taken. Data collected from the unactivated electrokinetic belt press indicated that the machine was producing a cake of approximately 22% dry solids in this configuration. This slight improvement on the normal value from the site (18–20%) was attributed to the installation of new belts and a slight reduction in the feed rate. Upon application of a voltage however, it was seen that the solids content steadily improved with applied voltage, increasing to a maximum value of approximately 30% with an applied voltage of 17 V.

Activation of the electrokinetic belt press over the course of a week showed that for an average throughput of 14 m^3/h at an average input of 2.5% dry solids, the power consumption yielded an additional electricity requirement of 19.5 kWh/dry tonne. This modest power consumption means that the technology is well placed to compete with other methods of dewatering such as centrifuges which would require between 35 and 55 kWh/dry tonne of additional energy to produce the same throughput.

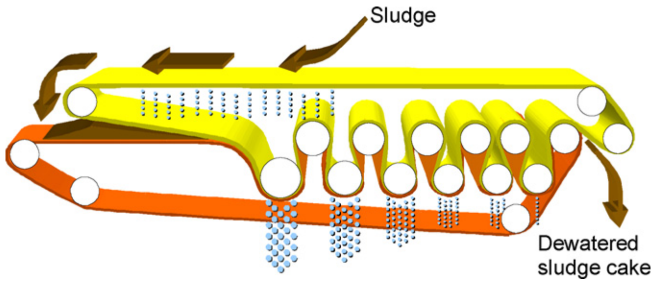

Fig. 8. Conceptual model of belt filter press. Upper belt is the anode and the lower is belt the cathode.

4.3. 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 min (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.

The results from the first field trial have indicated that EKG belt presses could offer a cost effective solution to improved dewatering of sewage sludge.

5. Discussion

Overall, the dewatering of sewage sludge will significantly reduce the volume of material either being deposited to landfill, or being transported for land spreading. Drying also increases the calorific value of sludge and offers greater potential for its use as an autothermic fuel. This work has shown that electrokinetic techniques can be used to dewater a range of different types of sewage sludge and points towards three different possible applications.

Dealing with an old sludge lagoons has generally meant removing the sludge altogether and clearing the site. Left to itself a sludge lagoon, deeper than say one metre, which has been deposited as a liquid, will never dry out. A crust will form on it, with plant growth that will dry out the crust to some extent. However, below this the sludge will generally not thicken beyond perhaps 12–20% dry solids, and may well be wetter. Transpiration and evaporation will be balanced by rainfall. Attempting to remove such material is difficult since it is too thick to pump and will contain tufts of grass, etc., and is too thin to shovel since it will slump completely. Prior to the arrival of the EKG process only two methods for stabilising a lagoon in situ were available; either mixing in more and more dry material until the lagoon was effectively solid; or employing a specialist contractor to mix quicklime or cement into the sludge to stiffen it. This second option is very expensive and would be unlikely to be economic unless the site of the lagoon had very important development potential. There is no method currently available for effectively drying lagoons in situ.

It is envisaged that EKG will be installed into lagoons containing this type of material by firstly creating a working platform over the surface of the lagoon using a stiff geogrid overlain by a granular capping. From this working platform EKG 'wicks' (perforated tubes, wrapped in a filter containing conducting elements) will be lanced vertically through to the base of the lagoon at 1–2 m centres. Water will be drawn to the cathodes from where it will be pumped and discharged. The design of an installation such as this will require initial laboratory characterisation of the sludge, followed by an on-site pilot-scale test. As such it offers a potentially economic solution to treating sewage (or, indeed any other waste) lagoons in situ.

EKG can be applied to the dewatering of compost windrows. The technique is to form and thoroughly mix the windrow then to insert cathode electrodes (similar to the wicks described above) across the bottom and insert anode electrodes near the top. The passing of the current would cause water to move downwards to the lower electrodes, which would form channels for it to leave the windrow. Results from the laboratory testing suggest that the amount of wood waste currently added to the sludge can be reduced by 80%. This, coupled with the faster rate of drying has the potential to significantly reduce the cost of these operations.

Significant improvements can be made to belt or filter presses by forming the belts as EKGs. In so doing, dry solids of greater that 30% appear to be achievable. This is a significant advance over previous proposals of electrified steel belts or drums as it overcomes the problems of filtration and longevity. The results show, within the limits of the above tests, that varying the voltage gives the greatest control over dewatering performance. Therefore, in an operating system this parameter will be of great value and may be optimised to suit the electrical and E-O characteristics of different sludges.

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