DEWATERING OF WASTE SLURRIES USING ELECTROKINETIC GEOSYNTHETIC (EKG) FILTER BAGS

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Abstract: Many industries produce waste in the form of slurries. These wastes are often transported to disposal sites and hence there is an economic driver to reduce the volume of these waste streams prior to disposal. Many of the current dewatering technologies, such as belt presses, require a homogeneous constant supply of sludge at a constant feed rate and for some industries this is not practical. The waste stream may be inconsistent in volume or heterogeneous in make-up. A possible solution for the disposal of small waste streams of this nature is to dewater using EKG filter bag structures. The basic EKG concept in dewatering waste slurries is to combine electrokinetic phenomena with the established functions of geosynthetics. This will have the effect of reducing the water content of sludge and slurry wastes in order to radically simplify their management and subsequent disposal. This paper will present the research work to date on these EKG bag structures, carried out at Newcastle University, and will demonstrate the results of this preliminary work in dewatering very fine-grained materials. The results of this work could have a marked positive impact on the industries that produce them, particularly in terms of disposal economic margins.

Keywords: electro-osmosis, electrokinetic dewatering, electrokinetic geosynthetics, hanging bag test, laboratory test.

INTRODUCTION

The treatment and disposal of waste slurry materials is one of the most problematic issues affecting developed industries worldwide. The traditional outlets for the disposal of these waste materials include deposition to landfill or incineration, spreading on agricultural land and in rare cases using the waste material as a product for a feed material to another industry. The majority of waste slurries are deposited in landfill or incinerated thus there is a significant economic driver to reduce the volume of these wastes prior to transport and disposal. Traditional dewatering methodologies require that the waste material is homogenous in nature or that it is a continuous process with a constant supply to the machine. Not all industries are able to follow these criteria thus a possible dewatering solution for those industries with a small heterogeneous supply of waste or those with batch process waste streams is the use of an electrokinetic geosynthetic filter bag (EKG). This paper shows that the use this technology, on two different materials, in a laboratory setting, has been successful.

Electrically conductive geosythetics

The concept of electrically conductive geosythetic (EKG) materials was introduced by Jones et.al. (1996). EKG materials are geosythetics which can be enhanced with the facility of electrically conductive elements in order to encapsulate the geosythetic fabric functions of filtration and containment along side an electrokinetic function. These materials may be constructed in 2D or 3D and can take the form of a single material which is electrically conductive, or a composite material, in which at least one element is electrically conductive.

Rationale for the concept of electroosmotic flow

The first observation of electrokinetic phenomena was made by Reuss (1809) and the distinction between electrolysis and electroosmosis by Napier (1846), it has been accepted that electroosmosis offers potential to dewater, consolidate and strengthen fine grained soils and slurries. Several researchers have shown that electrokinetic dewatering of sludges for example is more efficient than conventional hydraulically driven methods in ex-situ applications.

The historical application of electroosmosis in dewatering practices has had limited uses and success due mainly to the limitation of electrodes and the practical application of electroosmosis to existing dewatering technologies. The development and use of EKG materials eliminates these problems. Electroosmosis is the flow of water in a water-solid mixture in response to an applied voltage gradient. The flow rate is defined by Equation 1.

$$Q/t = k_e \cdot (V/L) \cdot A \qquad \text{Equation 1}$$

Where Q is the volume of water caused to flow in time t; k_e is the coefficient of electoosmotic permeability; V is the voltage applied and L is the distance across which the voltage is applied. This can be re-written as:

$$Q/t = I \cdot (k_e \cdot \rho)$$

Where, ρ is the resistivity of the material and I is the current passed through the material.

In the case of fine grained materials the effectiveness of electrosmotic flow can be illustrated by comparing the electroosmotic and hydraulic permeabilities of a range of soils (Figure 1). Figure 1 shows that the rate of electrokinetic dewatering of a fine grained material can be up to four orders of magnitude greater than normal hydraulic dewatering (i.e. $k_e > k_h \times 10^4$). Thus optimum conditions for electroosmotic flow are offered by materials with a high value of K_e. The effect of increased resistivity of material has a direct impact on the current drawn and thus the power consumption of the process.

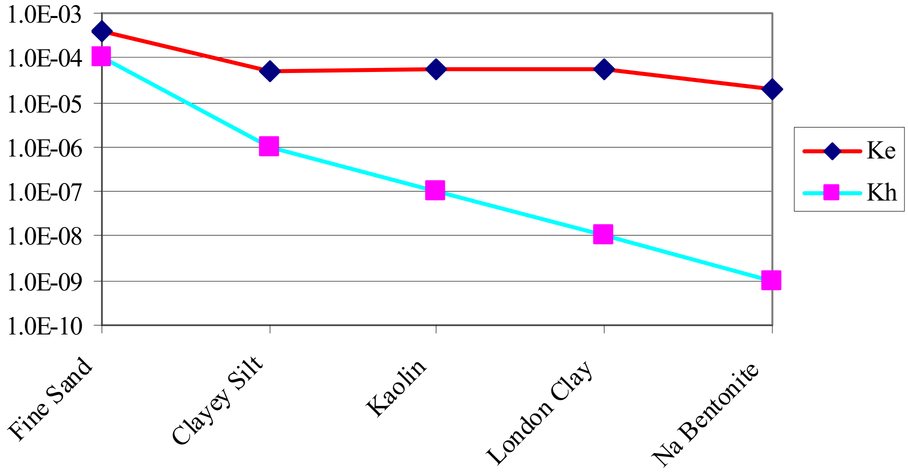

Figure 1. Comparison of the coefficient of electroosmotic permeability (k_e) and the coefficient of hydraulic permeability (k_h) (data from Mitchell and Soga, 2005)

AIM

The aim of this project, as described in this paper, is to establish if an EKG filter bag is a feasible technology to use to dewater waste slurries and warrant for further development. The objective was to establish if the prototype EKG filtration bag performed satisfactorily in terms of its filtration and electrical functions.

This paper presents details of the laboratory set-up and methodology, results and its interpretation and implications for a field trial application of this technology.

METHODOLOGY

Prior to conducting EK filter bag experiments identification of two waste slurries was required. The slurries selected were an inert kaolin clay slurry (symptomatic of quarry washings) and a waste slurry from the water clarification industry. These slurries were selected as characteristics of kaolin as an inert material and with a known responsiveness to electroosmotic flow is well understood and the water clarification slurry was selected as a material from an industry with this material as its main disposal problem.

Flocculation is used widely in the general commercial filtration bag set-up in order to both release free water and encourage a filter cake build up on the outside of the bag. The characteristics of flocculation and its effect on the materials electrokinetic potential are not readily understood therefore the kaolin slurry was selected for testing with and without flocculation as a direct comparison. These initially selected slurries were tested in the laboratory for their use as potential candidates for EK treatment technologies prior to hanging bag testing.

The coefficient of electroosmotic permeability, ke, is used as an indicator of the materials ability to support electroosmosis (EO) and is derived from Equation 1. and the resistivity measurements give an indication of the calculated power consumption should the technology be scaled up for commercialisation.

From the results in Table 1, these slurry samples are deemed to be suitable for EK geosynthetic filter bag treatment and thus a test methodology for EK filtration bags was set up at Newcastle University consisting of a hanging bag suspended from a framework complete with a load cell, calibrated to measure the mass change as dewatering proceeds. In addition continuous time-series information of bag mass and current data was be compiled.

The tests were conducted over 3 days at voltages of 12V, 36V and a 0V control for comparison. Voltage was applied both as a constant voltage and an intermittent voltage of 2minutes on followed by 1minute off (2/3 ratio) for the tests.

Table 1. Summary of electrokinetic feasibility laboratory results

Type of slurry	**Initial Moisture content (%)**	**Coefficient of electroosmotic permeability (k_e) (m^2/sV)**	**Resistivity (Ωm)**
Kaolin (non-flocculated)	20	2×10^{-8}	52.4
Kaolin (flocculated)	20	1×10^{-5}	34.5
Water clarification sludge	16	$5 – 7 \times 10^{-9}$	5.3

MATERIALS

The initial dry solids content (Equation 2) was 20% and 16% respectively for the kaolin slurry and the water clarification sludge.

Dry solids (%) = 100 / (1 + (water content / 100)) Equation 2

However the respective material characteristics varied greatly (Table 2) as the water clarification sludge was sticky, gelatinous and semi-solid at 16%ds in comparison to the milky white thin slurry of the kaolin at 20%ds (Figure 2).

Table 2. Material Characteristics of the tested slurries

Material slurry	**Visual description**
Kaolin slurry (non-flocculated)	Milky white water
Kaolin slurry (flocculated)	Floccs of kaolin binding together and settling rapidly in the mixing tub.
Water clarification sludge	Very soft, very sticky black silt with a distinct metalliferous odour

Bag set-up

The EK filtration bags used for the tests consisted of standard hanging bag base weaves, determined by the ability to hold the material slurry. The cathode element chosen was dependant on the weave of the bag selected and comprised of 1mm diameter stainless steel electrode elements stitched into the base fabric at 20mm spacing (Water clarification sludge) or alternatively a stainless steel expanded mesh stitched to the side of the bag (kaolin experiment). The anode comprised six 10mm diameter steel rebar sections, 1m in length arranged into a hexagonal shape and suspended from the supporting framework.

A maximum potential of 36V was applied across the sample of approximately 380mm in thickness (radii of the woven EK filter bag). This maintained a voltage gradient of 0.094V/mm or 94V/m; in excess of the typical voltage gradients applied for electroosmotic applications in soils and slurries (more typically 50V/m). However this voltage gradient is not considered unreasonable for more conductive slurries and, for example, in belt press applications where voltage gradients of 2V/mm (2000V/m) may be applied across a sample.

Figure 2a. Water clarification sludge – gelatinous in nature

Figure 2b. Kaolin Slurry

Figure 2. Visual depiction of the initial condition of the materials at the start of the dewatering experiment

RESULTS

Dry solids

The initial and final dry solids contents for the tests conducted are shown in Table 3.

Table 3. Summary of dry solid percentage change for the materials tested.

Material tested	Test voltage applied	Initial dry solids content	Final dry solids	
			Homogenised	Best observed value*
Kaolin slurry (non-flocculated)	36V	22.1	54.3+	57.6
	12V	21.5	46.3+	46.3
	Control (0V)	20.5	37.9	39.9
Kaolin slurry (flocculated)	36V	18.4	53.1	61.0
	12V	20.4	49.7	51.8
	Control (0V)	20.2	46.8	48.1
Water clarification sludge	36V constant voltage	17.7	21.4	27.0
	36V intermittent voltage	16.0	22.4	27.9
	Control (0V)	15.2	16.7	17.0

* These values were taken from the anodic area of the bag where the highest anticipated changes would be expected.

+ These values were skewed due to problems and inconsistencies during initial sampling

As can be seen from these limited results, there are distinct dry solids improvements to be gained by using an EK filtration bag in place of an existing filtration bag. Figure 3 shows a visual depiction of the distinct changes observed in the mass characteristics of materials after the application of EK treatment. In addition, the extent that this change in dry solids represents with respect to the increased handleability of the material is also visible.

Figure 3a. Kaolin experiments on dismantling

Figure 3b. Water clarification slurry experiments on dismantling

Figure 3. Visual changes to the slurry observed after the constant 36V tests

Leachate management

The leachate was collected in a large container directly below the hanging bag test. The initial and final pH of the leachate was recorded (Table 4). The pH of the leachate is determined by the initial material however in these experiments the pH's displayed are not in the extreme of the scale and can therefore be managed on site.

Table 4. Summary of leachate characteristics

Slurry	**Test**	**pH of leachate**		**Photograph of leachate discharge**
		Initial	**Final**	
Kaolin	36V	5.11	7.1	
Water clarification sludge	Constant 36V	6.2	5.4	

Reduction in volume / mass

A calculation was made (ignoring any electrolysis or material lost through the bag during initial development of the filter cake) of the projected mass and volume of material to be treated / disposed of from any given site. As can be seen in Table 4 these results are positive and with some economic projections could be attractive to potential waste industries as disposal charges and further treatment costs could be significantly reduced.

Table 5. Summary of mass and volume reduction as percentages of the total initial mass based on experimental results.

Test	Mass reduction after EK treatment (%)	Change in Volume after EK treatment (%)	Mass reduction after EK treatment (%)	Change in Volume after EK treatment (%)
	Kaolin (flocculated)		**Water clarification Sludge**	
Control	52	57	10	11
36V Constant	72	78	17	18.3
36V intermittent	Not carried out		29	31
36V Intermittent (anode area)			42	45.7

Based on the results presented in Table 5, and depending on the sludge nature, it is estimated that an EK dewatering bag may achieve a change in volume up to 31% for a 'real slurry' with the possibility of achieving upwards of 70% change in volume for very EK responsive material, as demonstrated by the inert kaolin slurry.

Power consumption and estimated treatment costs

As can be seen in Figure 4 the intermittent voltage, 2min on and 1min off, maintained a higher current throughout the experiments. This is consistent with the available literature (Fourie *et al* (2007), Yoshida (2000) and Shang and Lo (1997)) of increased dewatering and reduced power consumption seen for an intermittent power application.

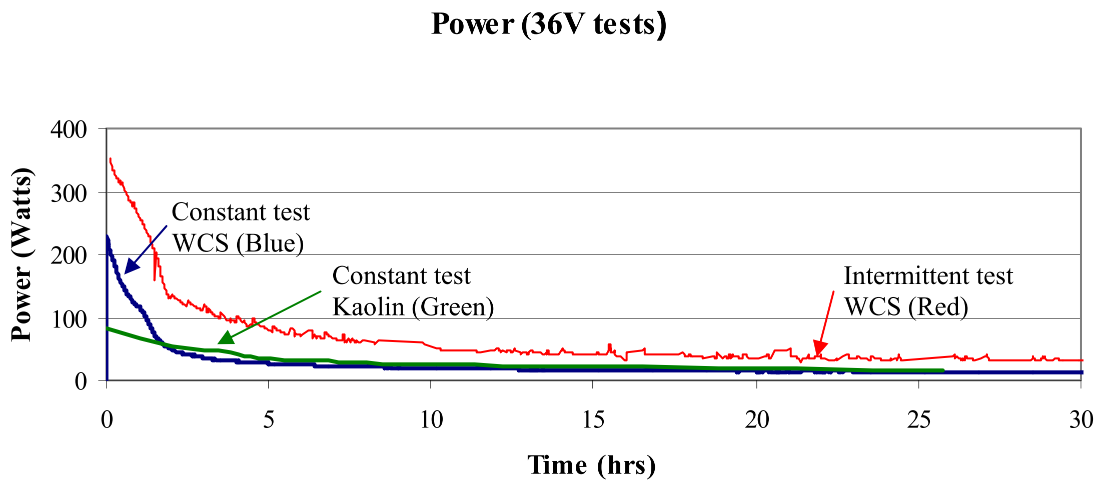

Figure 4. A graph showing the power consumption of the constant 36V and intermittent 36V test for the water clarification sludge (WCS) tests and the 36V constant kaolin test

The rapid drop off in the first 5hours of the current in the water clarification sludge experiments is attributed to an increased resistance build-up around the electrodes due to the material characteristics of this sludge on drying. This sludge material dries and relatively quickly becomes very friable and cinder-like in nature adding increased resistance to the system.

These results, based on a treated volume of 0.15m^3 and an electricity cost of £0.06/kWhr equate to estimated treatment costs as shown in Table 6. These costs do not allow for the electric input into the treatment system or any disposal / transport costs from site.

Table 6. Summary of estimated treatment costs for EK filtration bags

Test		Cost of treatment per m^3 of wet material into bag	Measured change in dry solids during experiment	Cost of treatment per % change in dry solids
Water Clarification Sludge	Constant 36V	£0.50	3.7	£0.34
	Intermittent 36V	£0.23	6.4	£0.09
Kaolin	Constant 36V	£0.44	34.7	£0.03
	Constant 12V	£0.03	26.6	£0.003

This information shows that there could be considerable economic advantageous to using both the EK filtration bag system but also in the optimisation of the intermittent power application.

DISCUSSION

From these results it can be seen that there could be significant economic advantages to using an EK filtration bag in order to manage waste slurries on site. However as with much research, these limited set of tests have identified technical challenges to be addressed in order to apply this product to market. These challenges may be classified into two main categories of:

- Anode design
- Bag construction

Anode design

As with many electroosmotic applications the main challenge is in maintaining an electrode contact with the material to be dewatered. This application is no exception and it was this phenomenon which was demonstrated plainly during the water clarification sludge experiments with the acute current drop off in the first 24hours as the material dewatered around the anode. The sludge characteristics on drying will depict how rapidly this current will degrade and the water clarification sludge was particularly friable in nature once dried thereby increasing the system resistance rapidly. On drying the kaolin slurries tended towards a more controlled desiccation around the anode and also demonstrated a degree of cementation to the anode (Figure 3) which may have improved the connectivity of the sludge and electrode.

In addition this problem was exacerbated due the rudimentary laboratory set-up and as the water clarification sludge had an initial shear strength, the initial contact between the electrode and sludge may not have been as desirable as the kaolin slurry was. Therefore alternative designs of electrode are being investigated to try and alleviate this problem in the future.

Bag construction

For larger applications in the field the bag must have both fabric strength and adequate seam strength in order to hold the volumes required. It is desirable, in order to maximise all potential drainage surfaces for the EO process, to have a vertically suspended bag. This has limitations available height and respective volume and thus it would be anticipated that a network of bags situated on site is an appropriate development of this technology.

Other factors to be considered

For further developments of this technology into a field application there are a number of other factors to be considered. These are summarised as follows:

Leachate management – from these experiments, leachate is identified as not being unmanageable on site. It may need further treatment before discharge however this is relatively easily achieved. No assessment has been made of the type of contaminants which may leave the system within the leachates during this study.

Flocculation – from this limited study, the effect of flocculation of the kaolin slurry did not appear to make any significant difference in the EO dewatering and final dry solids achieved. The initial hydraulic dewatering of the flocculated slurry was more apparent (measured as mass loss form the load cell data) over the first 150mins but the final EO dewatered product of the non-flocculated slurry appeared to be more uniform in nature on dismantling.

Heat generation – There is evidence in some of the experiments of a drying out of the material adjacent to the cathode (Figure 3b). This is not expected, as water during the EO process is driven from the anodic element towards the cathodic electrode however it is attributed to heat being generated locally along the metallic elements. This phenomenon was only observed on dismantling of the constant voltage tests on dewatering of the water clarification sludge.

CONCLUSIONS

From the results presented in this paper, it is apparent that EK filtration bags are a suitable technology for dewatering EK responsive materials. Although the experimental set-up in the laboratory was rudimentary, there is still enough evidence to allow a number of conclusions to be drawn. These are:

- The anodic areas of the material have dried out significantly in all EK cases.
- There is significant volume and mass reductions after EK treatment
- The leachate, although it maybe slightly acidic in some cases is not unmanageable as a waste effluent in most systems.
- Current drop off is significant within 24hours of the tests.
- There are potential economic benefits in using EK filtration bags as a treatment process, however the economic saving is, as expected, largely dependant on the responsiveness of the material to EK treatment
- The materials, once drier, are non-sticky in nature and thus it is easier to handle both by hand and with machinery if appropriate.

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