THE DEVELOPMENT OF IN-SITU DEWATERING OF LAGOONED SEWAGE SLUDGE USING ELECTROKINETIC GEOSYNTHETICS (EKG)

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ABSTRACT

Once deposited in a lagoon sewage sludge in the form of a very thick liquid or cake is a difficult deposit to handle and most known methods to remediate or stabilise them are very costly or environmentally intrusive or both, EKG has the unique potential for dewatering sludge after it has been deposited in a tip or lagoon. The basic EKG concept is to combine electrokinetic phenomena with the established functions of geosynthetics. The patented electrodes known as electrokinetic prefabricated vertical drains or ePVDs include filtration and drainage functions to clean and remove the electroosmotically gathered water, engineered corrosion management and the design provide for good current distribution and electrical contact with the substrate. By functioning equally as cathodes or anodes the electrodes permit the use of polarity reversal, which is a crucial procedure in dewatering and controlling water quality.

A recent field pilot trial has demonstrated the effectiveness and efficiency of using ePVDs to dewater lagooned sludge by an in situ process. The trial demonstrated that the technology could dewater sewage sludge thus raising the solids content from 10.5% to 27% whilst at the same time producing a clean discharge filtrate water with BOD< 3.0 mg/l and a COD of 250mg/l. The power consumption was 43kWhr/m^3. These data represent the first field trial of this technique and indicate that it can provide a viable economic solution to treating in situ lagoon sludges. The trial also indicated that significant further improvements in solids contents and reductions in power consumption are achievable at full scale.

KEY WORDS

Dewatering, electrokinetics, electroosmosis, EKG, in situ dewatering, sewage sludge lagoon, ePVD

INTRODUCTION

The concept of using electrokinetic geosynthetics to perform in-situ dewatering of sewage sludge lagoons was introduced in 2003 by Walker & Glendinning [1]. They noted that the predecessors of many water companies deposited thickened and or dewatered sludge in lagoons as a method of 'dealing with' the sludge. One of the reasons for this approach was that space was available for this action and alternatives were considered too expensive. Such an approach is useful in climates which are hot enough to permit effective drying e.g. Idris, et al. [2] but in the UK the combination of temperature and rainfall means that this method will not work effectively or efficiently. The result is that nowadays there are a number of these historical features, which contain material, which is variable in nature and which presents a major technical challenge and economic cost to remediate.

DEALING WITH LAGOONS

There are several reasons why a lagoon owner would wish to deal with a lagoon: including seeking to reduce a pollution risk, expand the current treatment works, reduce the odour from a lagoon, or prepare the land for development.

A lagoon deeper than one metre will never effectively dry out in the UK climate. Generally a crust will form beneath which will be sludge of solids content of 12 – 15% stabilised on an annual basis by the effective balancing of evapotranspiration by rainfall recharge. 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. There are possible approaches, either to wet the sludge down until it can be pumped, or to add dry material until it can be shovelled, or to avoid stabilisation completely and cap or encapsulate the lagoon.

WETTING DOWN AND RE-PROCESSING (DEWATERING) THE SLUDGE

Wetting down sludge would use thin fresh sludge or final effluent. The material thus produced which would be of significantly greater volume would then need to be dewatered. On site treatment would assume that the existing system could accept the additional load and that any contaminants in the lagoon would also be acceptable. Such assumptions may not be met easily. Once dewatered the sludge may then be mixed ex-situ with lime or other stabilising material prior to final disposal, thus creating additional volume increase.

DRYING SLUDGE WITH AN ADMIXTURE

The other alternative approach consists of creating a dry sludge through the addition of a dry admixture that can be removed by excavator and taken to a licensed landfill site. Current legislation means that once the material in the lagoon has been disturbed it is again defined as a waste and cannot be re-deposited on the same or another sewage works site unless that site has a Waste Licence. Obtaining such a licence is unlikely to be a realistic or economic option for a single lagoon. From a stabilisation viewpoint the best materials to use as admixtures are those that can yield the best improvements in strength for the lowest increase in volume, examples including lime and cement. From an economic viewpoint however the best material for mixing into the sludge is clearly another waste product, ideally one for which the water company will be paid a gate fee. PFA is sometimes used as a material, which goes some way to meeting these requirements. It should be remembered that every extra tonne of admixture deposited in the lagoon must subsequently be dug out again and transported away. When mixed with the sludge, it will incur a gate fee and Landfill Tax at the higher rate on disposal.

CAPPING THE LAGOON

One approach to dealing with the problem has been to employ limited remediation, which avoids changing the material characteristics of the sludge (i.e. strengthening or stabilisation) in favour of capping or encapsulation of the lagoon. This method was adopted for a lagoon filled with dewatered sewage sludge cake at Dowley Gap near Bingley, Yorkshire. Whilst an effective method for dealing with an open lagoon, it does not permit further development of the site [3]. If the main economic driver for remediation is that of further development of the actual lagoon site then removal or stabilisation of the in-situ sludge or cake is required.

The present paper describes the development of electrokinetic geosynthetics for application to the remediation of historic lagoons on sites. This work was undertaken in by Electrokinetic Limited in partnership with Severn Trent Water. The paper will provide a summary of the development of EKG materials for use in sewage sludge and a subsequent field trial. This research has lead to the development of a potentially economical method of stabilising sludge and/or cake lagoons *in situ*, thus providing an additional option for the treatment of sludge lagoons.

ELECTROKINETICS

The ability of electrokinetic phenomena to transport water, charged particles and free ions through fine grained, low hydraulic permeability materials has been well established following their discovery by Reuss in 1809 [4].

Electro-osmosis occurs in materials, which have a negative surface charge. This comprises a large group of materials such as clays, organic and inorganic sludges and mine slurries. When a direct electrical potential difference is applied across a saturated mixture of solids and water ion migration takes place. These positive ions (cations), positioned in a boundary layer owing to their attraction to the negative surface charges on the solids, are attracted to the cathode and repelled from the anode. As the ions migrate they drag with them their water of hydration and exert a viscous drag upon the free pore fluid around them. Thus, the net flow of water is towards the cathode. The great advantage of electroosmotic permeability is that it can be up to 10^4 times greater than hydraulic permeability and the difference is particularly relevant in low permeability materials such as slurries and sludges.

ELECTROKINETIC GEOSYNTHETICS (EKG)

Electrokinetic geosynthetics have been developed to implement and thus exploit the benefits of electroosmosis and to couple this with the established functions of geosynthetics such as drainage, reinforcement, filtration, separation and encapsulation.

EKGs have several different forms depending on the application. For sewage sludge lagoon dewatering EKGs are a development of prefabricated vertical drains or PVDs. Electrokinetic PVDs (ePVDs) comprises up to six components including electrically conducting corrosion resistant materials combined with drainage and filtration elements.

The University of Newcastle and Electrokinetic Limited has Patents that cover the basic underlying concept, the physical configuration of the materials of EKG and the EKG structures that can be used for a variety of different applications. There are additional patents that cover specific applications, including: introduction of conditioning materials into the ground for a variety of ground-improvement processes; improved consolidation or reinforcement of a weak substrate; and combined dewatering, decompaction, pH control, aeration of natural sports turf.

The ePVDs used in the present trial were developed specifically for this application and represent a significant advance on ePVDs developed for the less aggressive environment of normal terrestrial soils.

LAGOON SLUDGE DEWATERING TRIAL

TRIAL SET UP

Two steel skips measuring 3.7m long by 1.8m wide by 1.6m deep and lined with butyl rubber were filled with digested sewage sludge from a lagoon. The sludge had an initial dry solids content of 10.5% when placed in the skips. Standing water on the surface of the lagoon from which the sludge was excavated served to lower the solids content of the sludge during the excavation and filling stage from that of the in-situ sludge. Two arrays of Mk5 ePVDs were installed by hand. Skip A had a rectangular array; Skip B had a hexagonal array (Figure 1). The spacing of the electrodes determines the voltage gradient required for treatment. Therefore both arrays were designed to have a 0.9m anode – cathode spacing so that the two tests were equivalent.

The function of electroosmosis is to move water towards the cathodes, therefore a method of extracting water form the cathodes was required. The system chosen was based on a siphoning process and comprised narrow diameter tubes with nylon ball foot-valves. These were inserted into the cores of the cathodes, connected to an external sump and then primed by adding topwater from the lagoon. The electrodes in each skip were then connected in parallel to a timed intermittent DC supply. The initial power-up sequence slowly raised the voltage to 30V over a two hour period, then the supply was left unattended for 24hrs a day, 7 days a week.

TRIAL PROGRESS

The trial lasted from April to June during which time there were several interruptions in the treatment, mainly due generator and fuel issues and problems with the siphons. Regular measurements were taken of current and sludge level. The quality of the discharge water was measured during a period of prolonged treatment to ensure that the water was representative of electroosmotic flow and discharge rather than siphon priming water. The effects of electroosmotic flow in the form of wetting near the cathodes and drying near the anodes was immediately and clearly visible when steady state current conditions had been established. Unfortunately, underperformance of the siphons caused a reduction in the overall dewatering efficiency and an improved method of removing water from the cathodes is currently being developed. This is illustrated in Figure 2 for the hexagonal array of Skip B midway through the trial.

RESULTS

The main result from the trial was the transformation of wet sludge into stiff cake as shown in Figure 3. The results presented below include data on volume, current and water quality during the test, and shear strength, conductivity and water content at the end of the test. Figure 4 presents the change in the volume of the sludge for Skips A and B determined by measuring the level of the surface of the sludge. This shows that the volume of the sludge in the skips reduced steadily throughout the test. Further, it is noticed that after mid May, when constant and steady current supply was achieved, then the rate of volume reduction was slightly increased (Figure 5). These data show that Skip A had a measured volume reduction of 23% and Skip B 30%.

Current drawn is shown in Figure 5. It is clear that the array in Skip A drew more current than Skip B and that the rate of decay of current was higher in Skip A. The establishment of steady state current conditions after mid May meant that electroosmosis was constant for both skips. This is reflected in a concomitant increase in the rate of volume reduction, which was especially evident in Skip B as shown in Figure 4.

The quality of the discharge water was analysed and is shown in Table 1. These show that in both cases the quality of the discharge water was high, especially so for Skip B, which produced suspended solids of <3.0mg/l and a COD and BOD of 250 and <3.0mg/l respectively. Of potential concern was the high pH level of the discharged water. Deviations of the pH away from the approximately neutral starting value of 7.4 were caused by electrolysis reactions at the electrodes such that the anode became acidic and the cathode became alkaline. It was demonstrated that, towards the end of the trial, a period of reverse polarity (cathodes are reconnected as anodes and vice versa) provided an important means of controlling the pH of the water.

Decommissioning of the trial was accomplished by removing the electrodes, sampling the dewatered sludge and carrying out detailed multileveled surveys of shear strength, water content and conductivity using a probe meter. These data are presented in Table 2. They show that Skip B had a slightly lower water content and sludge electrical conductivity than Skip A, but that the latter showed slightly higher values of shear strength and solids content.

Shear strength and solids content are generally related to each other and inversely related to water content and conductivity (although many other factors can influence these relationships). Therefore there is an apparent paradox in the data. With this in mind it is important to note that Skip A had a short period of reverse polarity near the end of the trial and this seems to have influenced the shear strength and solids contents measurements from Skip A such that these were slightly higher than Skip B, even though Skip B experienced a greater volume reduction. This can be attributed to the fact that all electrodes in Skip A had at some point experienced the drying effects of being anodes, whereas in Skip B some electrodes had only ever been cathodes. In addition the effects of poor siphon drainage (as shown in Figure 2) added additional variability to the results from both skips.

ANALYSIS

The data gathered showed that both electrode arrays proved effective at raising the solids content and reducing the volume of sludge under electroosmotic treatment. However the hexagonal array in Skip B produced faster dewatering, with greater maintenance of electrode current density and lower overall unit volume power consumption. In achieving a 30% volume reduction in Skip B a power consumption of 128 kWhr/m^3 (of wet sludge) was required. This figure 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%; and
- Accounting for edge effects (using an example of an array of 100 x 100 electrodes) would yield a saving of approximately 7%.

Compounding these factors yields an overall power saving of approximately 2/3. This means that the initial estimate of 128 kWhr/m^3 to reach a volume reduction of 30% could be adjusted to 43kWhr/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. Therefore, with present understanding of the system and using a figure of £0.055/kWhr it is estimated that the power costs for treatment would be £2.36/m^3. This does not include the power required to pump excess surface topwater from the lagoon prior to treatment. 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.

Besides the provision and operation of effective electrodes, the other major components to electrokinetic dewatering of sewage sludge lagoons include gaining access to the site, connecting the electrodes and dewatering equipment and dealing with the effluent. All of these latter components involved materials and processes, which are readily employed in civil engineering practices.

CONCLUSIONS

1. Electrokinetic prefabricated vertical drains appear to present a viable alternative for the in-situ dewatering of lagoons containing sewage sludge (or other difficult materials).

2. The cost of power for treatment is low at approximately £2.36/m^3 plus the cost of pumping excess water prior to treatment.

3. In addition to EKGs, all materials and practices required to perform such a treatment are already available amongst standard civil engineering practices.

4. Combining evidence from the present trial with that from previous laboratory trials, Walker and Glendinning [1] shows that the removal of topwater is likely to lead to improved electroosmotic dewatering and hence a higher final solids content and greater shear strength. They described laboratory trials on lagooned sludge from the North of England showed that starting with a solids content of 19%, this could be raised to 42% with an overall volume reduction of 57% and an increase in shear strength from 1kPa to 42kPa.

6.

5. The development of EKG in general and ePVDs in particular is opening the way to provide effective in-situ treatment of problem materials such as sludge lagoons and as such avoids the costly and environmentally intrusive alternatives, which involved removing and treating the sludge

REFERENCES

1. WALKER, J. & GLENDINNING, S. In situ dewatering of lagooned sewage sludge using electrokinetic geosynthetics (EKG). Proceedings of the 7th European Biosolids and Organic Residuals Conference, November 2002, Wakefield, UK.

2. IDRIS, A., YEN, O. B., HAMID, M. H. A & BAKI A. M. Drying kinetics and stabilisation of sewage sludge in lagoon in hot climate. Water Science & Technology vol 46 (9) pp 279-286. IWA Publishing 2002.

3. TENSAR INTERNATIONAL LTD. Not on solid ground, - extreme stabilisation with Tensar geogrids. Tensar International News http://www.tensar.co.uk/news 1 March 2003.

4. REUSS, F F. Sur un nouvel effect de l'électricité glavanique. Mémoires de la Societé Impériale des Naturalistes de Moscu, 2, 327-337, 1809.

5. MITCHELL, J K. Fundamentals of Soil Behaviour. 2nd Edn., Pub. John Wiley & Sons Inc, New York, USA. 1993.

TABLES

TABLE 1. WATER QUALITY OF DISCHARGE DURING ELECTROOSMOSIS

Sample	Ammonia mg/l as N	pH	Suspended solids mg/l	BOD (ATU) 5 Day mg/l	COD mg/l
Skip A	2100	12.4	13	170	690
Skip B	2100	12.4	<3.0	<3.0	250

TABLE 2. SLUDGE MATERIAL CONDITION MEASURED DURING POST TREATMENT EXCAVATION

Skip	Level in skip	Shear Strength (kPa)	Conductivity (mS/m)	Water content (% v/v)	% dry solids (determined on samples)
A	150mm (upper)	9.7	188	77	27.6
	400mm (middle)	12.7	208	79	
	700mm (lower)	13.3	218	79	
B	150mm (upper)	7.8	258	72	24.2
	400mm (middle)	10.9	224	72	
	700mm (lower)	13.4	213	73	
Initial values	Bulk sample from both skips	1.5	250	90	10.5

FIGURES

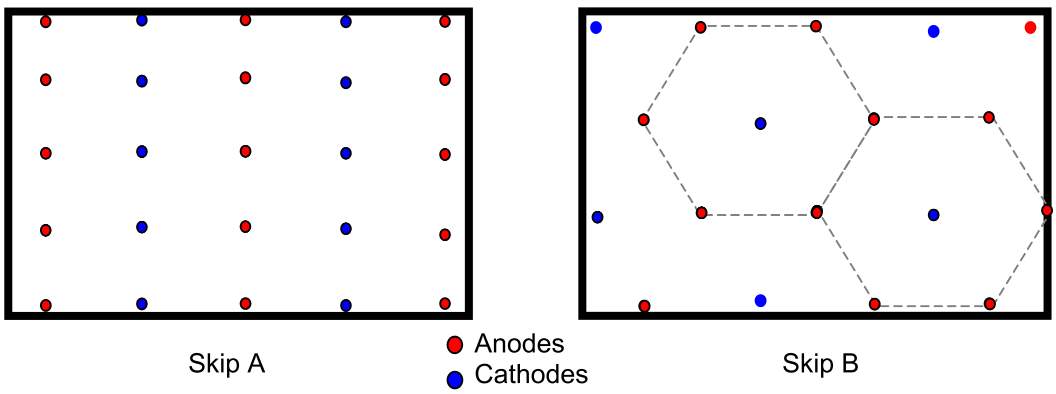

FIGURE 1 – ELECTRODE ARRAYS IN SKIPS A AND B

FIGURE 2 SKIP B HEXAGONAL ARRAY SHOWING EFFECTIVE SIPHON DEWATERING ON THE LEFT AND INEFFECTIVE SIPHON DEWATERING ON THE RIGHT.

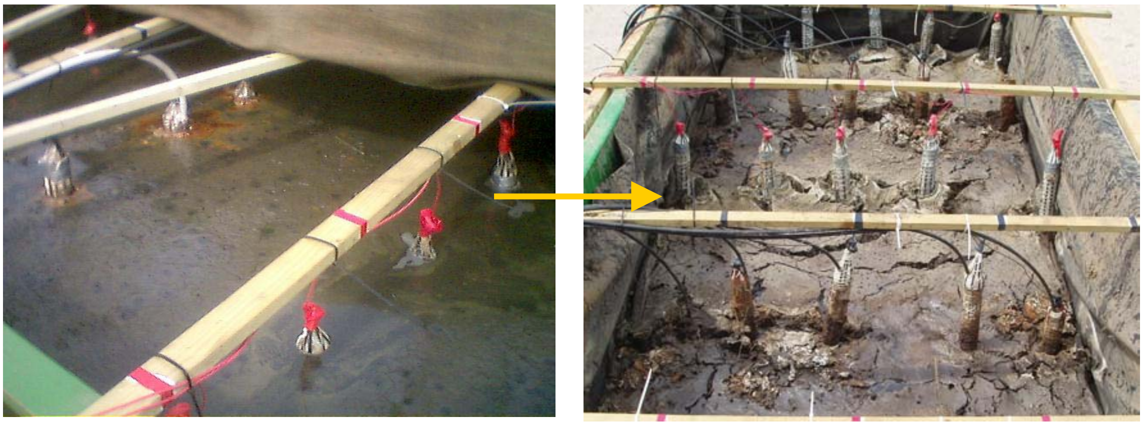

FIGURE 3 CHANGE IN CONDITION OF SLUDGE FROM 13TH APRIL (LEFT) TO 20TH JUNE (RIGHT)

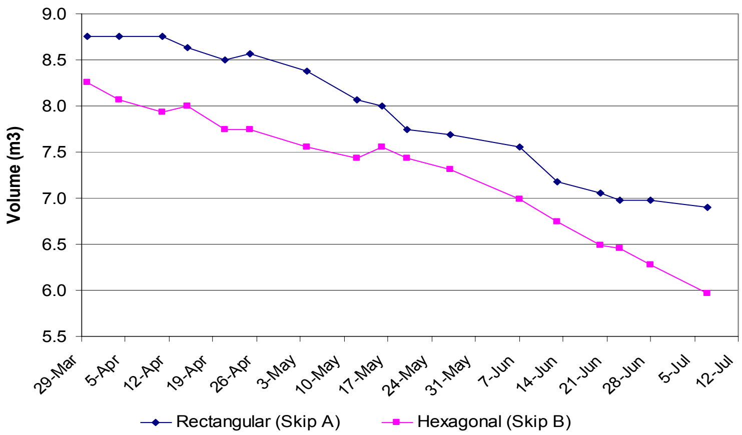

FIGURE 4 CHANGES IN VOLUME OF SLUDGE IN SKIP A AND SKIP B

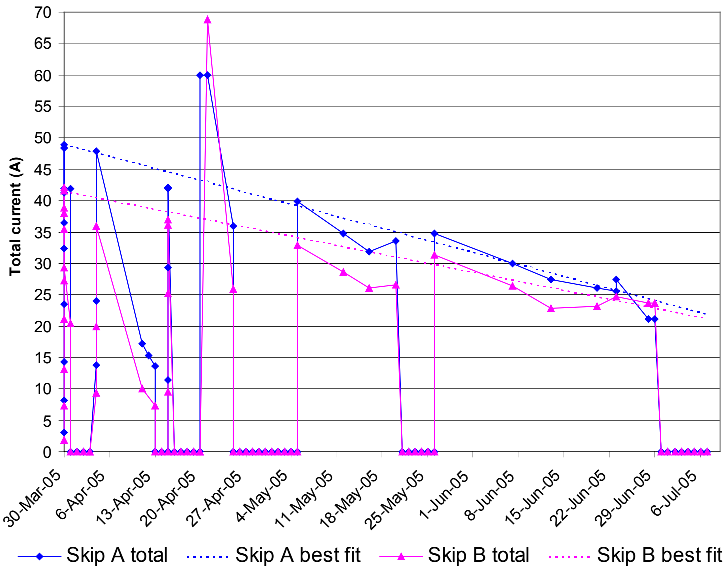

FIGURE 5 CURRENT DRAWN BY THE ELECTRODE ARRAYS DURING THE TRIAL