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Economic models for the use of electrokinetic geosynthetics

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ABSTRACT: Electrically conductive geosynthetics (EKG) combine electrokinetic phenomena with conventional geosynthetic functions. This produces a range of geosynthetic materials which are able to effect physical and chemical changes to the properties of the soil, sludges, slurries and other materials in which they are placed, These 'active" geosynthetics can be used in a range of applications including the civil and environmental industries; agriculture; mining and waste reduction; and the handling and the reduction of wastes and sludges. Different forms and specifications of electrokinetic materials are required for the different applications The paper addresses detailed economic models for the potential benefits of the use of EKG materials and electrokinetic techniques as an alternative to conventional wick drains; to enhance the process dewatering of sewage sludge or mine tailings; and to permit in-situ treatment and dewatering of sludge lagoons.

1 INTRODUCTION

Electrically conductive geosynthetics (EKG) combine electrokinetic phenomena with conventional geosynthetic functions. This produces a range of geosynthetic materials which are able to effect physical and chemical changes to the properties of the soil, sludges, slurries and other materials in which they are placed, Jones et al (2005). The use of (EKG) active materials provides economic, technical and ecological benefits. Economic benefits arise when solutions are found for previously intractable problems or where existing procedures can be enhanced to be more efficient. Technical benefits occur when new improvements are made in the condition of soils or waste such as improving shear strength or reducing pathogens in waste. Ecological benefits arise when pollutants are reduced or where the need for chemical treatment is reduced or eliminated.

Areas of application of EKG technology where economic benefits can be quantified include: consolidation of ground or lagoons and dewatering either by process, containment filtration or thickening. The paper considers the specific cases of consolidation of soils or wastes for civil engineering applications, process dewatering of sewage sludge, and the in-situ dewatering and thickening of lagoon waste. Technical and economic benefits are identified and cost models presented.

2 CONSOLIDATION

2.1 *Conventional treatment*

Conventional consolidation of soil uses prefabricated vertical drained (PVD) and surcharge loading. The PVDs reduce the drainage paths and the surcharge loading provides the hydraulic head causing drainage to occur in accordance with D'Arcy's law:

$$Q = K_h \, i_h \, A \tag{1}$$

Where Q is flow rate, k_h is hydraulic conductivity, i_h is hydraulic head and A is the area of application.

Conventional consolidation is influenced by:

- Low permeability of the ground
- Surcharge loading required
- The need for stage loading (with very weak soils)
- Smearing of the PVDs reduces effectiveness
- K_h reduces as consolidation proceeds
- Kinking of the PVDs reduce effectiveness

Major limitations of conventional PVD methods include:

- Consolidation impossible for some materials (sewage sludge, mine tailings, dredgings)
- Consolidation can be uneconomically slow (18-24 months treatment time is common)
- Surcharge loading increases material and transport costs and environmental impact.

2.2 *EKG consolidation*

Electrokinetic dewatering of weak soils is based upon electroosmosis. The quantity of water discharged (Q) is determined by:

$$Q = k_e \, i_e \, A \qquad (2)$$

Where k_e is the coefficient of electroosmotic permeability i_e is the potential gradient (volts) and A is the area (as in Equation 1).

Consolidation using electrokinetic geosynthetics in the form of conductive PVDs (e-PVD) offers a number of technical attributes, which have economic benefits:

- K_e is up to10^4 times greater than k_h
- K_e is constant and efficiency increases with consolidation
- No need for surcharge or stage loading
- Maximum electroosmotic flow occurs immediately
- Kinks in the e-PVD increase efficiency
- Speed of consolidation is increased (e.g. 24 months reduced to 3months)
- Smearing of e-PVD is irrelevant.

2.3 *Comparative costs PVD V e-PVD*

The cost of conventional consolidation (C_{con}) is a function of:

$$C_{con} = f[\text{ PVD + Surcharge + Time}] \qquad (3)$$

Where PVD = provide and install, Surcharge = provide, transport, place, remove and dispose, Time = lost opportunity.

The cost of EKG consolidation (C_{EKG}) is a function of:

$$C_{EKG} = f[\text{e-PVD + Running cost + Time }] \qquad (4)$$

Where e-PVD = provide, install and electrical connections; Running cost = DC current; Time = lost opportunity.

- Note: e-PVDs can be installed using the same equipment as a conventional PVD
- The cost of e-PVDs is greater than a conventional PVD but a second order cost compared to surcharge material costs
- Running costs of e-PVD is similar to the cost of fuel required to transport surcharge material
- Time with e-PVD treatment can be 1/8th that with PVD installations.

3 EKG DEWATERING SEWAGE SLUDGE

The objectives of dewatering wastes and sludge are to:

- Reduce volume and disposal costs
- Recover water (of growing importance)
- Increase dry solids content
- Ease mechanical handling
- Reduce transport costs
- Safe disposal (reduce pathogens)
- Permit further processing and/or reuse
- Reduce environmental impact.

Conventional methods of dewatering include:

- Process dewatering (belt or filter press)
- Centrifuge
- Containment filtration (geobags dewatering)
- Lagoon evaporation (do nothing)

3.1 *Conventional dewatering of sewage sludge*

Conventional treatment of sewage sludge using belt press technology produces a sludge cake with a dry solids content of 16 – 20 per cent, Figure 1.

Figure 1 shows that at a dry solids content of 20% the material is still in liquid form and difficult to transport. Additional treatment is required to permit disposal, which usually includes mixing in straw to provide mechanical stability. If disposal is by incineration then fuel oil has to be added to increase the thermal content of the sludge.

Figure 1 Sewage sludge at 20% dry solids

3.2 *Electrokinetic dewatering of sewage sludge*

The conventional belt press treatment of sewage sludge can be modified to include electrokinetic dewatering in addition to conventional hydraulic dewatering. Using EKG filter belts on a standard belt press produces a sludge cake with dry solids content ≥ 30% and a 50% reduction in volume, Figure 2. Figure 2 shows that at 30% dry solids the sludge is no longer a liquid and can be handled without the addition of bulking material such as straw. In addition, at 30% dry solids many sludge cakes are auto-thermic and hence the addition of fuel oil to aid incineration is not required.

The cost (CE_{-P}) of converting a conventional belt filters press to include electrokinetic dewatering:

$$C_{E\text{-}P} = f[EKG_{belt} - Con_{belt} + Power] \quad (5)$$

Where EKG_{belt} is the cost of the EKG belt; Con_{belt} is the cost of a conventional belt and Power is the cost of DC current required to electrify the EKG_{belt}
(The DC current required is < 30 volts and there are no safety issues associated with high currents.)
The cost savings (C_{saving}) arising from the use electrokinetic dewatering is:

$$C_{saving} = f[BM + F + 0.5(T + D)] \quad (6)$$

Where: BM is the cost of the supply and mixing of bulking material; F is the cost of fuel oil to raise the calorific value of the sludge for incineration; (T and D) is the cost of transport and disposal of the bulked sludge. Disposal cost savings associated with the case in Figures 1 and 2 are shown in Table 1.

Figure 2 Sewage sludge at 30% dry solids and 50% volume reduction

Table 1 Disposal cost comparison relating to Figures 1 and 2

	Conventional Belt press	EKG Belt press
Loading Kg. dry solids/hour	540	540
Operating hours	8000	8000
Cake % dry solids	19	31
Disposal cost £/m^3	15	15
Disposal cost £K/year	340	208
Additional current cost £K/year		6
EKG saving £K/year		**126**
(per machine)		

4 IN-SITU TREATMENT OF LAGOON SLUDGE AND WASTE

The disposal of many industrial wastes and sludges during the last two centuries has resulted in a legacy of sludge lagoons. Many of these materials have a very low hydraulic conductivity and remain in the same liquid condition as when originally disposed of. Handling is difficult as these materials are identified as being "too thick to pump and too thin to shovel". Treatment technologies are expensive and often limited to the addition of solidifying materials such as cement before disposal in a safe landfill. In situ dewatering using PVDs is not possible as the provision of surcharge loading is not practical on sludge, which has no effective shear strength.

The cost of treatment (C) is:

$$C = f[(WC * VC) + M + D] \quad (7)$$

Where WC is the water content of the sludge; VC is the cost of cement, which is a function of the water content; M is the cost of mixing cement and the sludge; D is the cost of transport and disposal of the bulked material (sludge + cement).

4.1 *EKG treatment of lagoon sludge*

In situ treatment of lagoon waste is possible using e-PVDs as electrokinetic dewatering is generated without the need for surcharge loading. The material forming the e-PVD electrodes depends on the nature of the chemical composition of the sludge. Similarly, the current (Amps) required for treatment is a function of the water content and resistivity of the sludge. The rate of dewatering is dependent on the voltage gradient, which in turn is related to the spacing of the electrodes (e-PVDs) and the voltage applied. In some situations treatment time is not critical and the use of low potential gradients is appropriate.

The cost (C) of in situ treatment of lagoon wastes can be expresses as:

$$C = f\,[\text{e-PVD} + P + D] \quad (8)$$

Where: e-PVD is the provision + installation + cabling of the electrokinetic wick drains; P is the power (variable) required for treatment of the particular sludge material; D is the cost of pumping of the cathode electrodes to remove water.

- Note: The need for durable electrodes is related to the inherent nature of the material to be treated, Figure 3. Marine sludge and some industrial wastes require electrodes with enhanced durability.
- Power costs depend on the nature of the sludge and typically vary from (1-10) kWh/m^3 of material treated

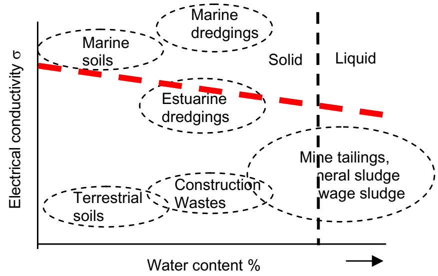

Figure 3. Schematic plot of electrical conductivity vs. water content. The thick dashed line represents an estimated viable treatment limit; the thin vertical dashed line represents the transition from solid (digable) to liquid (pumpable).

5 CONCLUSIONS

Electrokinetic techniques to dewater and treat soils wastes and sludges have been developed which offer significant economic and technical benefits. The paper has described the benefits that can be obtained with regard to the use of e-PVD wick drains; the enhancement of belt press dewatering systems by means of electrically conductive belts and the use of EEKG drains to effect the in-situ dewatering of sludge lagoons. Economic models for these applications are described.

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