

Electrokinetic dewatering and thickening. III. Electrokinetic cells and their application to a range of materials

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The choice of electrokinetic cell for use with materials of differing flow characteristics is reviewed with special reference to products previously evaluated in the author's laboratory. Areas in which electrokinetic methods are at present applied are summarized.

1. Introduction

This is the third paper of a series of three [1, 2] which examines the use of electrokinetics in the area of dewatering and thickening. It is the intention of this paper to unify the series of papers by referring to products which have been studied by the author and his co-workers at the Electricity Council Research Centre, Capenhurst, UK.

2. Cell choice

The choice of cell for electrokinetic treatment of process streams.

(i) The physical characteristics of the feed and the final product, e.g.

<i>Feed</i>		<i>Product</i>
Free flowing slurry (sewage)	→	Fibrous mat
Free flowing slurry (PVC)	→	Hard rigid cake
Semi-solid (coal tailings)	→	Non-wetting semi-rigid
Free flowing slurry (ball clay)	→	Plastic to semi-rigid

(ii) The electrokinetic process occurring in the cell. Is it exclusively electrophoretic deposition, electro-osmotic dewatering or a combination of the two?

(iii) The necessity for pH control within the cell.

3. Types of cell

3.1. Moving filter belt cells

3.1.1. Vertical electrode with moving filter belt. This type of cell is most applicable to the dewatering of free-flowing materials which form a thin cake on a fine mesh under gravity filtration prior to the onset of blinding. Sewage is an example of this category of material. By employing a hollow mesh cathode over which is drawn an endless fine mesh polymer filter belt, sewage is allowed to filter through the belt until the cloth becomes blinded. When a current is applied, water moves electro-osmotically into the hollow cathode and sewage builds up on the filter belt. A solids content of up to 30% can be obtained under optimum conditions. In order to remove the sewage cake the endless

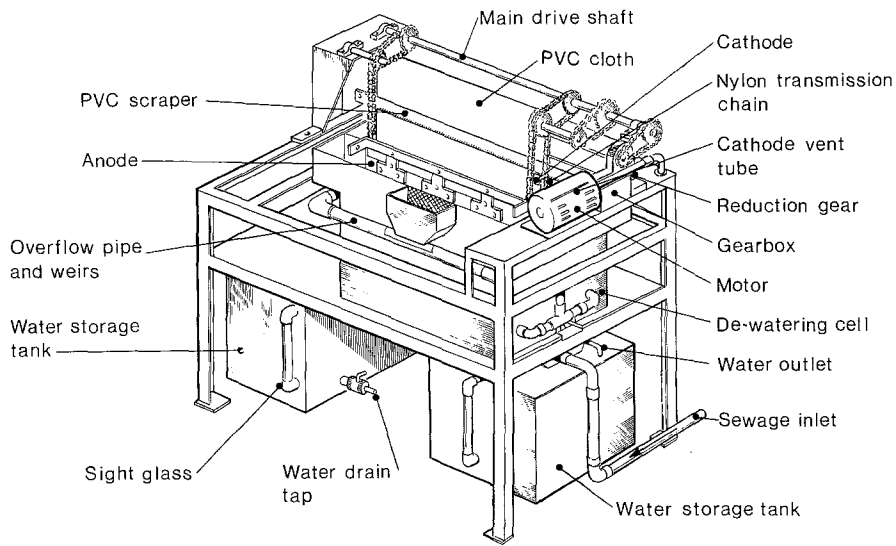


Fig. 1. Schematic diagram of sewage cell.

filter belt is moved slowly over the hollow cathode and solid is scraped off the belt above the cell. This type of cell allows continuous dewatering of sewage. The anodes in the author's studies were lead dioxide on titanium mesh ($0.82 \times 0.6\text{ m}$) and were operated at up to 300 A m^{-2} for many months without failure. A schematic of the sewage cell is shown in Fig. 1, and its performance is summarized in Table 1.

Calculating the power requirement from the data in Table 1, it is found that $96\,000\text{ kWh}$ are required to produce 1 m^3 of water. A removal rate of $1\text{ m}^3\text{ h}^{-1}$ therefore requires $44 \times 10^3\text{ m}^2$ of electrode area. Thus, the electrodes should be vertically orientated to minimize floor area requirement.

The energy required to produce a tonne of sewage from a 2.63% solids feed is calculated from the experimental data to be 3307 kWh on a dry weight basis. This figure is specific to a slurry feed of 2.63%. However, if pre-thickening using gravity settlement is employed to thicken the sewage sludge to 5.2%, the energy required decreases to 60% of that required for a 2.63% solid feed. The relationship between sewage slurry feed and the reduction in energy, relative to a feed of 2.63%, is shown in Fig. 2. It is obviously advantageous to allow sedimentation and drainage to occur if

Table 1. Typical results obtained from the sewage dewatering cell

Initial solids (%)	2.63
Voltage (V)	30
Water electro-osmotically removed (Wh ml^{-1})	0.096
Volume of water transported ($\text{ml cm}^{-2}\text{ h}^{-1}$)	2.25
Solids recovered (%)	24.2
Chemical oxygen demand (p.p.m.)	
Initial	3450
Final	120
Biological oxygen demand (p.p.m.)	
Initial	2220
Final	100
Suspended solids (p.p.m.)	
Initial	17720
Final	< 5

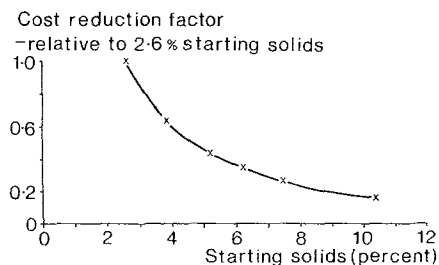


Fig. 2. Relationship between sewage feed concentration and the percentage reduction in energy.

possible, so that the initial solids are as high as possible — electro-osmotic costs are directly related to the water to be removed. Lockhart [3] has drawn similar conclusions.

3.1.2. Horizontal filter belt cell. This type of cell is best suited to the dewatering of materials which can be described as semi-soild. These can be dewatered using a cell with a horizontal polymer belt moving across and between the two electrodes. In this cell the cathode was a stainless steel mesh and the anode was fabricated from silicon iron (18% Si; 82% Fe). The cell layout is shown in Fig. 3. An example of a product examined in this type of cell is coal tailings. This material would appear to be an ideal candidate for electro-osmotic dewatering with a high initial solids feed at 55% and a high final solids continuous discharge of 70%. However, work carried out at Capenhurst [4] on the feasibility of dewatering coal tailings demonstrated that although the volume of water to be removed is small the rate of removal is low, i.e. $1.25 \text{ ml cm}^{-2} \text{ h}^{-1}$. To match the throughput of a continuous vacuum drum filter, it can be calculated from the results that a cathode area larger than the conventional filter area would be necessary.

Another problem that arises with high levels of solids is that of increasing ohmic resistance as dewatering proceeds. This results in heating in addition to the electro-osmotic process. Another complication with naturally occurring materials may be the presence of small amounts of chloride. This was the case with the coal tailings examined in this study, which were found to contain 0.1 M chloride. The added cost of removing anodically generated chlorine would be unacceptable in the case of coal tailings which is regarded as a waste product.

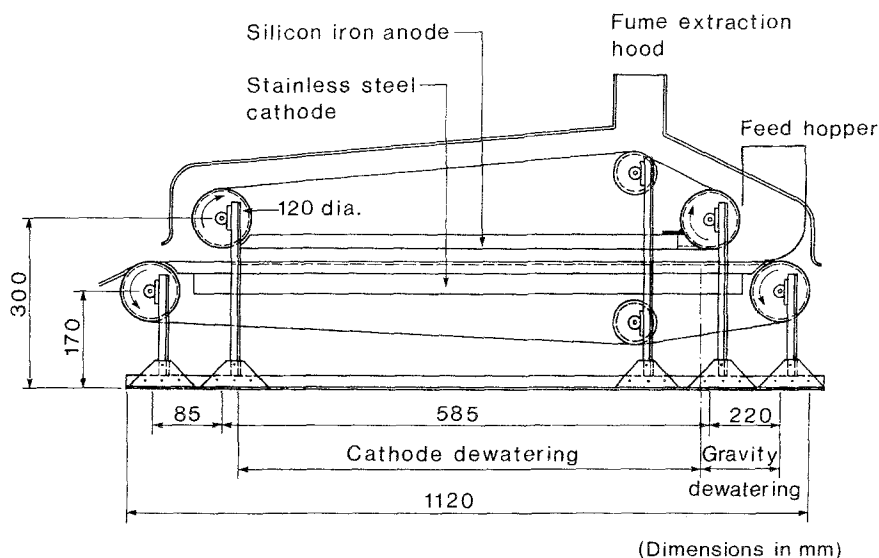


Fig. 3. Schematic diagram of horizontal filter belt cell.

3.2. Concentrator cell

In many industrial processes large volumes of water are used. This water often contains a low concentration of solids (< 1% of the total volume) which must be removed or at least reduced to very low levels. To investigate electrokinetic removal of solids at a low level, ball clay was used as a model material in a concentrator cell.

The cell comprised two vertical, parallel, platinized titanium electrodes (anode and cathode), each contained in a dialysis membrane bag so that they formed separate compartments. Separation of the electrode from the slurry prevented the evolved gas bubbles causing back mixing of the electrophoretically migrating clay particles and also allowed the pH in each compartment to be controlled. A multiplicity of dialysis membranes, 5 mm apart, were located between the two platinized titanium electrodes, providing a total membrane surface area of 3 m² in a cell volume of 30 dm³. On application of an electric field, clay particles migrated towards the anode until they contacted a dialysis membrane; on the cathode side a water-rich phase formed adjacent to a 'cathode' membrane. This accumulation of solid on the one hand and an aqueous phase on the other resulted in solids falling under gravity on the anode side of each membrane; the term electrodecantation was coined by Pauli [5, 6] to describe this phenomenon. The concentration of the clay feed ranged from 0.037 to 0.33% for flow rates between 0.325 and 1.3 dm³ min⁻¹. If four cells each of 3 m² membrane area were operated in series the calculated power requirement for a clarified effluent stream would be 17.6 kW m⁻³.

3.3. Clay cell — parallel plate cell with chain-driven scraper removal system

This cell was discussed in Part II [2] and was used as part of a beneficiation process. The electrokinetic stage was used to reduce the water content from 80 to 30%. Following this concentration, thermal drying was applied to complete the drying process. The economic advantage gained by applying an electrokinetic stage in this overall drying process is best illustrated by comparing the thermal energy requirement with the electrokinetic energy case. These are 667 and 62.5 W h dm⁻³ respectively. The energy savings speak for themselves.

3.4. PVC cell — parallel plate cell with polymer mesh collector removal system

The drying of emulsion PVC has been discussed elsewhere [7] and, as with ball clay electrokinetics, can be used to reduce the overall energy required to produce the dry PVC product. Conventionally, emulsion phase PVC with a particle size in the range 0.1–0.2 μm has had to be spray dried. The feed to the spray dryer is normally in the region of 45% solids and a large volume of water has therefore to be removed. By using an electrokinetic concentration stage prior to a final drying stage the water content can be reduced from an initial 55% to 15% so that the thermal energy necessary to provide a dry product is very much reduced. Typically, the overall drying cost is reduced by a factor of about four.

Unlike the ball clay case, it is necessary to control the pH of the electrophoretic deposit since at a pH less than 2.3 the heat stability of the PVC product is impaired. The pH in the vicinity of the platinized titanium anode is controlled by surrounding the anode with a membrane (ion exchange or semi-permeable) so that the PVC slurry is prevented from contacting the anode. By providing this separate compartment, alkali or acid additions can be made so that the pH can be controlled.

The electrophoretically deposited PVC, which formed as a hard solid on the anode membrane, was allowed to grow through a polypropylene collector mesh placed close to the membrane. After the deposit had grown to a thickness of about 20 mm the mesh collector was withdrawn from the cell with PVC deposit firmly attached to it. The solid PVC was removed from the collector mesh before the collector was returned to the cell. A schematic of a section through the cell is shown in Fig. 4.

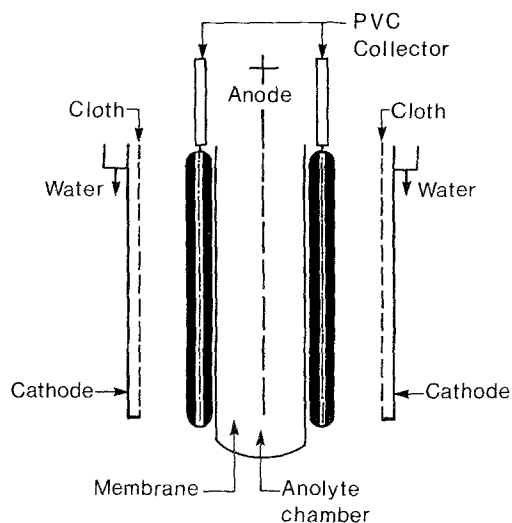


Fig. 4. Schematic section through the PVC cell.

With some PVC slurries it was noted that an increase in cell voltage accompanied the mixing of the catholyte (pH 11) with the anolyte. This suggests that one of the PVC additives is cationic and migrates in the applied field to the cathode where it is withdrawn with the electro-osmotically pumped water. This reprotonates on mixing with the anolyte, lowering the conductivity. If the mixing is discontinued and 1 M alkali used to control the pH, the voltage falls to its initial value. In order to limit the 'poisoning' effect of the additive, which caused the voltage to increase, an ion exchange membrane was used to provide a barrier between the cathode and the cathode filter cloth. The solution containing hydroxyl ions generated at the cathode was then withdrawn and mixed with the anolyte to partially neutralise the hydrogen ions. This reduced the amount of 'top up' alkali required to maintain the anolyte pH at a predetermined value.

The cell throughput is impressive, as a cell of 10 m^2 of electrode area is capable of producing 1.5 tonne of PVC product per hour at 82–86% from a slurry feed of 42% solids.

Utilizing a cell in which membranes are used as described above the pH within the cell can be controlled so that materials sensitive to pH changes can be successfully thickened.

3.5. Rotating drum electrode

The application of rotating drum electrodes has also been examined by the author both for sewage (electro-osmotic dewatering) and for the electrophoretic deposition of titanium dioxide. The application of a drum electrode has obvious advantages with respect to the handling of solids. Solids can either be removed by using a fixed doctor blade or by string discharge techniques. As already pointed out in the case of sewage, large volumes of water have to be removed, so that the use of a drum which occupies a large volume per unit area of electrode is inappropriate.

In the case of titanium dioxide (particle size $0.2\text{--}0.5\ \mu\text{m}$) a drum anode surrounded by a membrane was used with a semi-cylindrical cathode concentric with the anode. The cathode was similar to that used in the clay cell with a fine filter cloth separating the catholyte compartment from the slurry. A membrane was provided around the anode because the pH affected the dryness of the deposit. At a pH of 8.5 and a current density of $400\ \text{A m}^{-2}$, solids at 58% could be obtained. The energy required to produce this level of solids was between 200 and 300 kWh per dry tonne and 0.15 Wh per ml of water removed by electro-osmosis.

Although drum electrodes do have advantages for facilitating the handling of solids, constructional difficulties can arise. It must be remembered that electrolysis accompanies the electrokinetic

processes and, therefore, gases form at the electrodes. These must be removed, and in the case of a drum electrode surrounded by a membrane or a cloth this is not a simple operation, especially in view of the fact that the drum is also rotating. It is better to use vertical electrodes which allow gas bubbles to rise naturally and to devise a suitable method for the removal of the deposited solids rather than to use drum electrodes. Fabrication and maintenance costs will also be lower.

4. Overview

Electrokinetic processes can be extremely effective as demonstrated by their application to the 'drying' of clay and PVC. These processes can also be applied to *in situ* dewatering of, e.g. soils, phosphate slimes and to high-cost, low-volume throughput materials, e.g. separation of blood serums. Thickening of products may be effected in some drying processes, levels of solids being increased from 20% to higher levels before final drying is carried out, so reducing the overall drying cost. In some cases, where salt concentrations are unacceptably high for electrokinetics to be effective, the salts can be removed by washing with water so that the conductivity is reduced to a value that allows electrokinetics to operate effectively. Dyestuffs are an example of this approach.

In the case of biological systems and food products, where salt concentrations are acceptably low and, therefore, electrokinetics can be applied, pH control becomes important, so that denaturing or hydrolysis of the products does not occur. This is relatively easy to apply on the laboratory scale (or where throughputs are low) using ion exchange membranes and buffers in the anolyte and catholyte compartments, but is problematical on the industrial scale where large volumes of broth may be involved. Additionally, removal of the thickened product is required. Several alternative removal techniques have been examined in these laboratories, some of which have been presented above and others given in [7]. In attempting to introduce any new technology it is important to ensure that the product meets commercial specifications and also that the electrokinetic device produces the product in the required form so that it can be interfaced simply with any existing plant.

5. Conclusions

If a product slurry or emulsion which is difficult to dewater by conventional means has a low conductivity (10^{-2} – 10^{-1} S m⁻¹) and a zeta potential in the range ± 100 mV then electrokinetics should be considered as a possible alternative technique to conventional dewatering methods or to remove some of the water prior to final drying.

The technology is available to enable electrokinetic techniques to be implemented and is at present employed across a wide range of materials, e.g. PVC thickening, 'low tech' consolidation of soils etc. [8, 9], electrophoretic deposition of paint, β -alumina tube production, blood serum separation and the electrofiltration of clays.

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