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Maureen Donnelly
Western Michigan University

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THE APPLICATION OF ELECTROKINETICS TO IMPROVE SLUDGE DEWATERING

By

Maureen Donnelly

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Advisor: Dr. David Peterson

ABSTRACT

The waste, or sludge, from a mill contains a significant amount of water. It is desirable to remove as much water as possible before the sludge goes to a landfill. In the past electrokinetics have been used to separate solids and liquids in the mining and clay industries. The objective of this thesis project was to determine if the application of electrokinetics can increase the drainage rate of sludge by transmitting an electric current through the sludge. On a larger scope, this application may be used in addition to another process for increased efficiency.

The experiment contained sludge placed between two charged metal screens. The drainage was measured and compared to a control run with no voltage applied to the screens. The results demonstrated that applying an electric field to sludge increased the drainage rate. The increased drainage was due to electro-osmotic forces, which forced the water out of the capillaries, and electrophoretic forces, which caused the positive ions to migrate to the negative electrode carrying water molecules with them. The pH of the filtrate was tested and found to change either acidic or basic, depending on the arrangement of the electrodes, which indicated chemical reactions were occurring.

In conclusion, the application of electrokinetics increases sludge dewatering. I recommend further investigation into the possibilities of applying this concept to another pressing or filtering process which would result in a more efficient process. The drastic change in pH opened other areas for study, as electrokinetics can be used to remove or direct chemical contaminants.

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INTRODUCTION

With increasing public pressure and government regulations, minimizing industrial waste has become a major concern. The pulp and paper industry sends a relatively large amount of waste, or sludge, to landfills. Because of the hydrophilic nature of fiber and waste treatment organisms, the sludge from pulp and paper mills often contains a considerable amount of water. Various mechanisms, including presses and filters, are commonly used to remove water from the sludge prior to disposal in a landfill. Studies have been conducted on the use of electrokinetics to improve dewatering capabilities which could be applied to a pressing or filtering process. The objective of this project was to determine if the application of electrokinetics can increase the drainage rate of sludge. A long-term objective is to use the application of electrokinetics on another process to increase it's efficiency.

BACKGROUND DISCUSSION

Electrokinetics has been used for many years to separate solids and liquids from suspensions in the mining and clay industries. Electrokinetics involves the movement of charged particles or water molecules in an applied electric field. It can be divided into two main areas, electro-osmosis and electrophoresis. Electro-osmosis refers to the movement of a conducting liquid through a porous medium. Electrophoresis refers to the movement of suspended particles through a fluid. The application of electrokinetics to dewater sludge or other water containing solids can be achieved by various systems containing electrodes or cells. Past research and studies conducted found the basic concept in electrokinetic dewatering was the electrical potential causes the positive ions migrate to the negative electrode carrying water molecules with them. Once deposited at the cathode, these ions release their water where they can be collected.

The origins of electrokinetics come from the double layer theory of complimentary charges and distribution of charges at the surfaces (1). One layer of charges is immobile, held tightly together and the other layer is mobile, free to move with the attraction or repulsion of an applied electric field. The electrical potential at the slip plane, which is located between the immobile and mobile layers, is called the zeta potential. Electro-osmosis refers to a liquid moving through a porous medium and is derived in terms of liquid flow through a capillary. When electro-osmotic flow occurs the liquid is moved through the capillary pore network driven by a pressure differential. This pressure is directly proportional to the zeta potential of the capillary walls, the dielectric constant of the liquid, and the electric field strength (2). See Appendix for equation. Electrophoretic movement occurs when the charge on the particle interacts with the applied electric field and the particle migrates towards the electrode of opposite charge. The electrophoretic movement is directly proportional to zeta potential and electric field strength, according to the electrophoretic equation (2). See Appendix for equation.

When an electric current is transmitted through sludge chemical reactions will occur. The chemical aspects of the electrokinetics were discussed in a study involving saturated soil as a medium (3). Electrolysis reactions occur in the pore fluid as a result of the applied electric field. With an electrolyte present, a hydrogen ion (an acid) is produced at a constant rate at the anode and a corresponding hydroxyl ion (a base) is produced at the cathode. Any cations in solution will either precipitate with the hydroxyl ion or deposit on the cathode by receiving electrons from the negatively charged electrode. In the initial stages of the process, the pH decreases to 2.0 at the anode and rises to 12.0 at the cathode. Electrical migration takes place as the positively charged surfaces of particles move toward the cathode carrying surrounding water molecules with them. With this movement the hydrogen ion produced at the anode moves towards the cathode. This acid moving across the soil medium will solubilize salts and displace surface cations on the soil particles into solution. This acid may also react with the hydroxyl ions at the cathode producing water.

A field study involving electrokinetics was conducted at one paper mill (4). Two sites with landfills averaging about 10% solids did not possess the mechanical stability needed to cover. Electrodes were installed in the landfill approximately four feet apart. The cathodes were slotted and fitted with polyester filters to allow water to pass through. A tube inside the cathodes was connected to a vacuum system which pumped out the water. The anodes had a positive charge causing the positive ions in the pore water to move toward the cathodes carrying hydrated water molecules to the cathode. Over a forty day operating period the level of solids was increased from 9% to 27% at one site and 6% to 25% at the other site, measured at a depth of three feet.

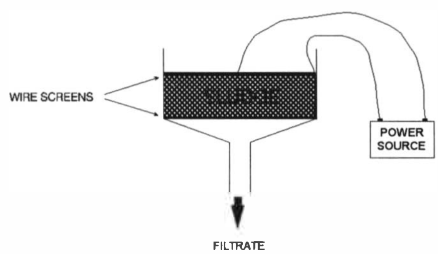
Other types of electrokinetic cells have been designed for dewatering and thickening various materials (5). A vertical electrode with a moving filter belt was found to be effective in dewatering free-flowing materials such as sewage. Initially the sewage filters by gravity through a mesh polymer filter belt drawn over a hollow mesh cathode. Once the cloth becomes blinded a current is applied at the anode, causing the water to move by electro-osmosis into the hollow cathode. Sewage builds up on the filter belt where it is scraped off after the cathode. Results obtained from a sewage dewatering cell showed solids content were increased from 2.63% to 24.2%.

METHODOLOGY

The experiment consisted of a drainage system with two wire screens oppositely charged, one being the cathode and the other the anode. Sludge is placed between the two screens while the water drains by gravity. The drainage rate is measured to determine if the applied electric field increases the drainage rate.

The drainage system was constructed using a buchner funnel supported on a ring stand. See Figure 1. A fine mesh screen was placed on the bottom of the funnel where the water filtered through. A 10 mesh screen was used for the top screen. Wires were soldered to both screens which hooked up to the power supply. A voltmeter was connected to the circuit to measure voltage.

Figure 1. EXPERIMENTAL DESIGN SETUP



Preliminary experimentation indicated the drainage rate would increase when a voltage was applied no matter which screen served as the cathode or the anode. This was not supported in the field studies conducted but warranted investigation therefore one of the experimental variables was the position of the cathode and anode. Two different voltages were used to determine if increasing voltage increases the drainage. The experimental design consisted of five runs: 1) 14 volts with the bottom screen as the cathode 2) 14 volts with the bottom screen as the anode 3) 20 volts with the bottom screen as the cathode 4) 20 volts with the bottom screen as the anode 5) Control with no voltage applied.

The sludge was obtained from the James River Kalamazoo Board Mill, which is a 100% recycle paperboard mill. The procedure for each run used 500 grams of sludge at 2.5% consistency. The sludge was poured on the fine mesh screen in the buchner funnel. The 10 mesh screen was placed on top of the sludge, ensuring good contact. A beaker was under the funnel to collect the filtrate. Once 200 ml of filtrate had drained the voltage was applied. The filtrate was then measured at 15 second intervals for one minute, 30 second intervals for the next two minutes, 60 second intervals for the next five minutes, and one five minute interval for a total drainage time of 13 minutes. The voltage was recorded periodically throughout each run. The pH was measured on the initial 200 ml filtrate, the one minute interval filtrate, and the four minute interval filtrate.

RESULTS

Table I. Drainage Data

Drainage Time (seconds)	Experimental Runs 1 14 +/-	 2 none	 3 20 -/+	 4 20 +/-	 5 14 -/+
15	14.54	8.62	10.21	12.89	7.63
30	26.05	13.81	15.76	20.54	23.76
45	31.72	17.42	22.23	26.77	28.96
60	37.67	20.34	26.45	32.33	35.53
90	45.58	24.54	33.62	39.86	41.25
120	52.53	27.34	39.72	50.91	45.7
150	59.03	29.33	44.57	58.98	49.14
180	64.71	31.04	48.29	61.44	51.94
240	74.12	33.38	53.55	61.96	55.56
300	81.19	35.04	57.52	64.23	58.16
360	84.4	36.35	58.91	65.12	60.86
420	84.73	37.39	59.77	66.39	62.36
480	85.05	38.1	60.19	70.16	63.34
780	85.75	42.31	61.16	72.97	65.5

Table II. Voltage Data

Drainage Time (seconds)	Experimental Runs 1 14 +/-	 3 20 -/+	 4 20 +/-	 5 14 -/+
15				12.82
30			15.66	
45				12.9
60	13.25	16.4	16.02	
90		16.7		13.17
120	13.7	17.1		
150	14	17.7		
180	14.3		16.35	13.3
240	14.5	18.3	16.5	13.5
300	14.85	18.5	17.3	13.45
360	15.18	18.75	18.3	13.6
420	15.48		19	
480		20	19.5	14.4
780		21.2	20	

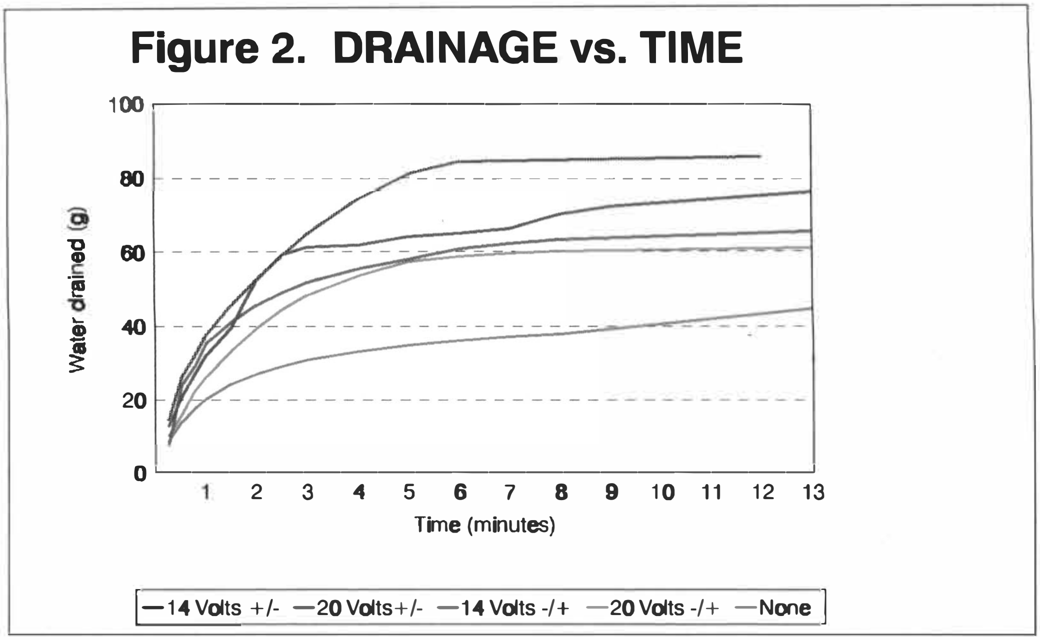


Figure 2. DRAINAGE vs. TIME
100
80
60
40
20
0
Water drained (g)
1 2 3 4 5 6 7 8 9 10 11 12 13
Time (minutes)
14 Volts +/-
20 Volts+/-
14 Volts -/+
20 Volts -/+
None

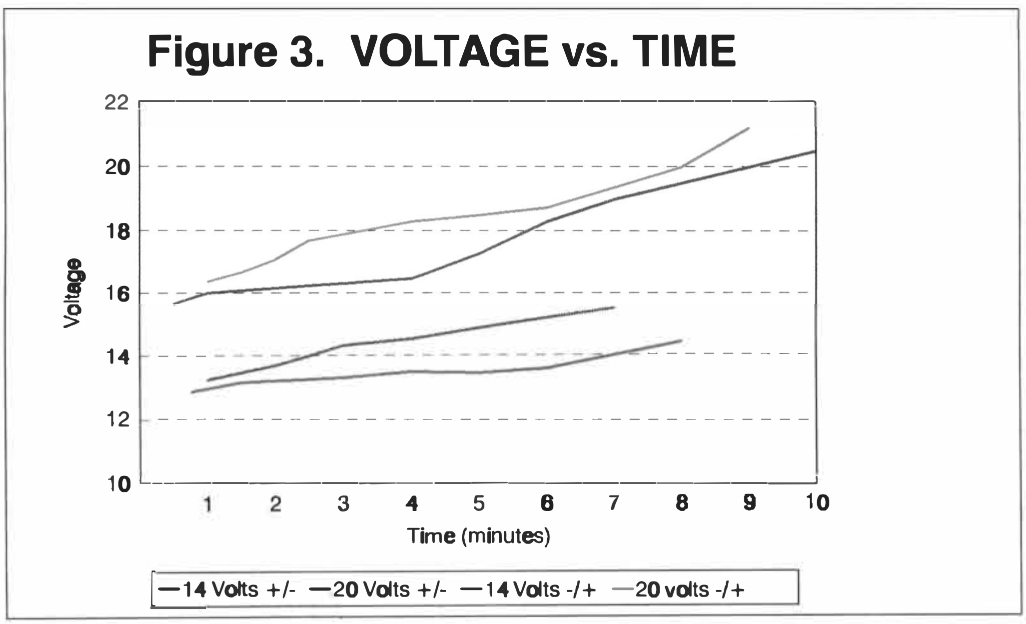


Figure 3. VOLTAGE vs. TIME
22
20
18
16
14
12
10
Voltage
1 2 3 4 5 6 7 8 9 10
Time (minutes)
14 Volts +/-
20 Volts +/-
14 Volts -/+
20 volts -/+

Table 3. FILTRATE pH

Time	12 Volts +/-	20 Volts +/-	12 Volts -/+	20 Volts -/+	No Voltage
Initial	7.23	7.24	7.11	7.05	7.12
1 min	8.8	10.54	6.21	6.53	7.75
4 min	11	11.83	4.53	4.22	8.14

DISCUSSION

The results shown in Figure 2 indicate that the drainage rate was increased by applying an electric field to the sludge. Therefore the results support the fact that electrokinetic movement occurred which caused more water to drain. Because the drainage rate was increased with the electrodes in either, position a significant contribution to increasing the drainage rate was the electro-osmotic force which drives liquid out of the capillaries in the presence of an electric field. The electro-osmotic effect occurs regardless of the direction of the electric field unlike the eletrophoretic effect. The drainage rate appeared to be higher when the bottom screen was negatively charged which demonstrates the electrophoresis occurring. The positively charged ions migrate to the negative electrode carrying water molecules with them.

The results of varying the electric field strength did not show the trend that was expected. The lower voltage had a higher drainage rate when the bottom screen was negatively charged while the lower voltage was only slightly higher in the other electrode position. Electrophoretic and electro-osmotic forces are both directly proportional to field strength and should have increased with increasing voltage. The graph of the 20 +/- showed an uneven trend unlike the others which produced smooth curves. A probable cause may have been the current flow was fluctuating or disturbed due to poor contact of the top screen with the sludge surface. Figure 3 illustrates how the voltage increases with time. A fundamental physics equation is voltage equals the product of electrical current and resistance. Water is the conductor in the sludge thus as it drains the electrical current decreases. The fiber and other solids in the sludge cause resistance, therefore the resistance increases as water drains.

As the water drains the chemical composition changes which is demonstrated in Table 3. The pH became acidic and turned a clear yellow after a short time when positive electrode was on bottom. Correspondingly the pH became very basic when the negative electrode was on bottom and a yellow color appeared on the top surface of the sludge due to the positively charged screen. These results were predicted in literature cited previously which indicates it is very probable that electrolysis reactions occurred. Various chemical reactions could have occurred, the yellow color may be due to some metal ion or a salt of a metal ion.

CONCLUSIONS

Applying an electric field through sludge increased the drainage rate due to electrokinetic principles. The drainage rate was higher when the bottom screen served as the cathode (negatively charged electrode), although both electrode arrangements increased the drainage rate. The filtrate was significantly effected by the electric field as the pH turned acidic and yellow in color when the positively charged electrode was in the bottom position, and when the bottom screen was negatively charged the pH turned basic.

RECOMMENDATIONS

As the research and results from this project indicate that the drainage rate can be increased by applying an electric field to sludge, I recommend further investigation regarding the application of electrokinetic principles to another water removal process. Transmitting an electric current through sludge is not as effective as other mechanical processes by itself, but applying it to another pressing or filtering process may increase the efficiency. The chemical change that occurred in the filtrate could be controlled and used to dissolve or remove contaminants from a material.

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APPENDIX

The pressure developed due to a voltage applied through a capillary, resulting in electro-osmotic flow can be calculated by the following formula:

$$\Delta P = \frac{2\zeta\varepsilon F\ell}{\pi r^2}$$

ζ = zeta potential ε = dielectric constant of bulk phase F = field strength
ℓ = capillary length r = capillary radius

The electrophoretic velocity of a particle can be calculated by the following formula:

$$\mathcal{V} = \frac{\zeta\varepsilon F}{4\pi n}$$

n = viscosity of bulk phase