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COMBINED ACTION OF ELECTRO-OSMOTIC DRAINAGE AND MECHANICAL COMPRESSION ON SLUDGE DEWATERING

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ABSTRACT

The efficiency of the implemented industrial means of sludge dewatering, at the present time, is not sufficient. Therefore, research of new techniques of advanced dewatering is necessary. Electro-osmotic drainage, notably used to consolidate soils, has recently been used to dewater sludges. In this work, a laboratory cell has been constructed. It permits one to superimpose a mechanical pressure adjustable to 7 kg/cm^2 to the electro-osmotic drainage. The application of an electrical field decreases the specific resistance of sludges to filtration with variable factor, which can result from both the electrical conductivity and the charge of the particles. However, in thickening, it enables organic sludges to reach very high solids concentration when compared to their dewatering by filtration under high mechanical pressure. The energy consumption does not seem to be an important constraint in sludge dewatering with this technique.

KEYWORDS

Dewatering; electro-osmosis; sludge.

INTRODUCTION

The solid phase in a sludge is extremely dispersed. It has a large specific surface. In such a suspension, the surface forces have a determining role in the liquid–solid separation phenomena.

The solid surface of a suspension in water acquires an electrical charge. Thus, an electrical double layer between the two phases is formed. It is constituted of a fixed layer and a mobile layer. Consequently, the application of an electrical field moves the particles with their mobile layer. Such phenomena, known as electro-kinetic effects, have numerous applications using different techniques, e.g. electro-coagulation, electro-filtration, electro-thickening...

Fundamental laws governing electro-kinetic effects

* Electrophoresis

Electrophoresis is the movement of charged particles within a solvent under the influence of an electrical field. Their speed is given by the Helmholtz–Smolushowski formula:

$$u = (\xi.\varepsilon).(K.\eta)^{-1}.f(\rho,\rho_l).E$$

where

ξ : zeta potential of the particles (mv);
ε : dielectric constant of the interstitial liquid;
η : viscosity of the suspension at ambient temperature;
K : particle shape factor;
$f(\rho,\rho_l)$: function of liquid and particle's electrical resistivity (in practice, it ranges between 0.75 and 1.5);
E : potential drop between the electrodes.

* Electro-osmosis

The application of an electrical field to an electrolyte, placed between two electrodes, generally causes the movement of the solvent, which is electrically neutral, in the direction anode cathode (Depraetere and Damien, 1990). The volume of the liquid extracted from a layer of porous material, constituted of immobile solid particles, is calculated by the Yukawa (1976) formula:

$$q = K.\xi.\varepsilon.p.i.(\rho.\eta)^{-1}$$

where

p : porosity of the medium;
i : electrical current applied to maintain the electrical field at the desired value.

Application to sludge dewatering

Sludge can be dewatered by electro-osmosis. It is placed between two electrodes, which permit to apply an electrical field. Generally, we apply a weak pressure just to maintain the sludge in contact with the electrodes, because, in this case, the volume of the sludge decreases during the operation.

By analogy with the Darcy law, it was possible to introduce the concept of electro-osmotic permeability (Ke) calculated by the Casagrande formula:

$$Q = Ke.S.E/L$$

where

Q : electro-osmotic flow;
S : surface area of the ectrodes;
L : distance between the electrodes.

Electro-osmosis can be used to treat large volumes of sludge *in-situ*. This method is notably employed for consolidation of clay ground (Caron 1969, 1971; Morris *et al.*, 1985; Canbrera-Guzman *et al.*, 1990; Mitchell, 1991; Mitchell and Wade, 1992). Electro-osmosis can be also used to dewater sludges at thin (Door-Oliver Inc) or thick (Deshydrec-Elmerthem) layers.

TABLE 1. Energy Consumption Given by Different Authors (for Different Materials) (Deleuil, 1982)

Author	Material	Energy consumption (kwh/kg of extracted water)
Yukawa	clays (bentonite and	0.05 - 0.1
Von Schwerin	kaolin)	0.045
US Bureau of	Peat	0.021
Mines	calcium phosphate	0.56
Deleuil	clay (kaolinite)	0.02 - 0.1
Elmetherm	slaughterhouse sludge	

For comparison, 1 kg of water needs approximately 1.2 kWh to be evaporated.

The energy comsumption given by different authors is variable. These differences are attributed to the nature of the material, to its initial concentration and especially to its final concentration.

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EXPERIMENTAL APPARATUS: CONCEPTION OF A LABORATORY ELECTRO-OSMOSIS CELL

A laboratory cell has been constructed to study the dewatering of sludges. The novelty of this cell is that we can superimpose a mechanical pressure, adjustable up to 7 kg/cm^2, to the electro-osmotic drainage. This idea was accomplished by modification of a classical pressure cell filtration (AFNOR T97-001, 1979):

- the body material (stainless steel) was changed to a non-conductive material (P.V.C),
- the piston is used as the anode and the filter support as the cathode.

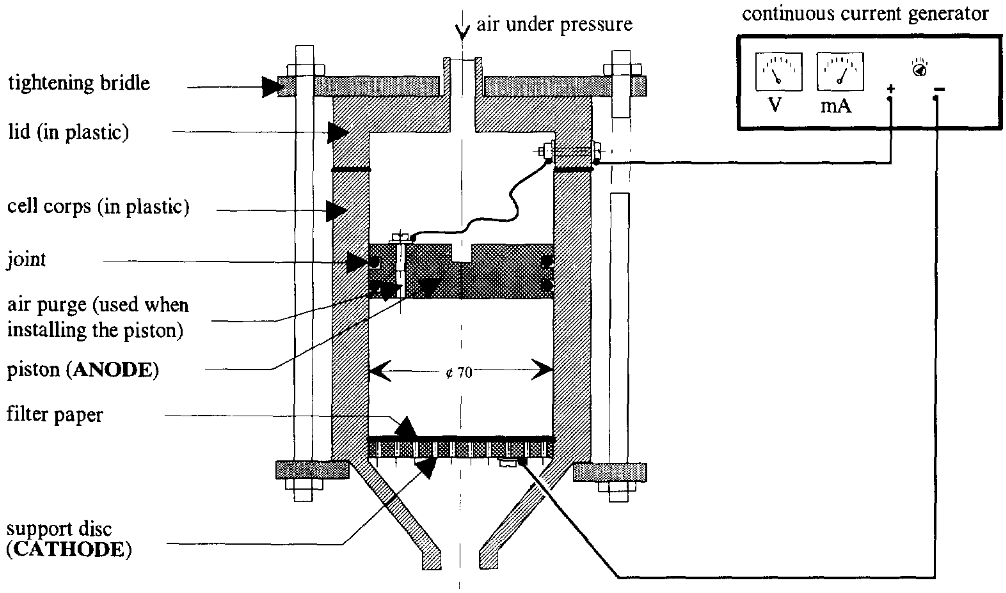

Fig. 1. Laboratory electro-osmosis cell.

RESULTS AND DISCUSSION

* Electro-filtration

When electro-osmosis drainage is combined with a mechanical compression, drainage is accelerated. Table 2 shows the apparent specific resistance to filtration (α) for different combinations of mechanical pressure and electrical field.

The application of an electrical field decreases the specific resistance of the sludges to filtration by a variable factor, which depends on both the electrical conductivity and the superficial charge of the particles.

TABLE 2. Effect of Combined Action of Mechanical Pressure and Electric Field on Sludge Filtration (α is the Apparent Specific Resistance to Filtration)

	Domestic anaerobically digested sludge (ODS=53% ; λ=1500S)(*)				Anaerobically digested sludge from a brewery (ODS=49% ; λ=7000S)(*)	
Pressure (kg/cm2)	1	2	4	6	1	4
Electrical field (V/cm)	α (10^{11} m/kg)	α	α	α	α	α
0	1891	3160	4260	7000	6174	15926
5	1101	2420	2898	4782	6346	16168
10	927	768	556	1434	6447	15950
15	731	202	507	760	6064	16048
20	572	194	180	187	6265	14834

(*) ODS is the organic dry solids content (% of the total dry solids) and λ the electrical conductivity.

* Consolidation by electro-osmotic drainage

In this case, the sludge was flocculated and dewatered by filtration for 2 hours under different mechanical pressures (1, 3 and 6 kg/cm) before subjecting it to an electrical field for 30 min.

Table 3 shows the solids concentration for different combinations of pressure and electrical field, and the fractions of bound and free water (% of dry solids). Indeed, water in a sludge is generally considered to be constituted by two fractions, free water and bound water, depending on the binding energy of water to solid phase (Gazbar *et al.*, 1992). These two factions are quantified by the dilatometric method, based on the theory that bound water does not freeze at temperatures below the freezing point of the pure water. The amount of bound water in the sludge is measured with a dilatometer (Heukelekian and Weisberg, 1956). This technique depends upon the measurement of the expansion, indicated by the change of the level of an indicator fluid (xylene), produced by the freezing of the free water.

We noticed that the free water content decreases considerably with the electrical field, while the bound water content can increase. The application of an electrical field increases the polarity of the particles surfaces.

Thus, water adsorption is favored by electrostatic attraction, due to the dipolar structure of water, which increases the bound water content.

We can conclude that the electro-osmosis drainage acts preferentially by elimination of the free fraction of water. However, a mechanical compression removes both free water and bound water.

* Application to different types of sludges

The experimental procedure consisted of compressing the sludge for 2 hours under 4 kg/cm^2. The cakes are then subjected for 1 hour to a pressure of 40 kg/cm^2 without an electrical field and, to the same pressure (4 kg/cm^2) with an electrical field of 15 V/cm.

TABLE 3. Results of the Dewatering of a Domestic Sludge (Anaerobically Digested) by Electro-Osmotic Drainage

Pressure kg/cm^2	Electrical field (v/cm)	Solids concentration (%)	Bound water/MS (%)	Free water/MS (%)	Bound water/ Free water (%)
1	0	20.8	140	240	26.3
3	0	25.0	101	199	33.5
6	0	27.8	87	173	33.7
1	10	24.7	162	150	51.9
3	10	32.0	110	110	51.6
6	10	33.2	107	107	53.2
1	20	29.4	170	70	70.8
3	20	28.9	85	72	55.4
6	20	40.1	77	73	48.1

TABLE 4. Comparison of Dewatering by Electro-Osmotic Drainage to Dewatering under Mechanical Pressure (Domestic Sludges)

sludge	solids concentration (%) under 4 kg/cm^2	solids concentration (%) under 40 kg/cm^2	solids concentration (%) under 4 kg/cm^2 and 15 V/cm	energy consumption in kwh/kg of extracted water
1	35	39	48	0.08
2	16.4	18.2	27.8	0.15
3	14.5	15.7	22.7	0.17
4	32.2	37.2	36.6	0.06
5	42.2	46.3	50.9	0.16
6	22.3	23.2	30	0.15
7	29	36.3	40.8	0.2
8	39.5	42.7	48.6	0.18
9	15.8	21.6	28.4	0.06
10	18.7	21.5	31.7	0.12
11	24.3	29	32.6	0.09

Generally, the increase of the pressure from 4 to 40 kg/cm^2 does not substantial improve considerably the dewatering. However, the application of an electrical field under the same pressure shows a significant increase in sludge solids concentration. Cambefort and Caron (1961) showed that when the hydraulic permeability of a soil is weak, which is the case of dewatered sludges, the electro-osmotic permeability becomes predominant.

The energy consumption for electro-osmotic drainage varies with sludges between 0.05 and 0.2 kWh/kg of water extracted. Thus, energy does not seem to be an important constraint in sludge dewatering by electro-osmosis.

* Influence of the sludge conductivity on electro-osmotic drainage

This factor directly influences on the energetic loss by the Joule effect. It determines the electrical intensity necessary to maintain the electrical field constant.

It was shown that electro-osmosis acts preferentially by elimination of the free fraction of water. Therefore, it was interesting to study the effect of an increase of the salinity of the interstitial aqueous phase of the sludge both in electro-filtration and in consolidation by electro-osmotic drainage.

– Influence on electro-filtration

Table 5 shows the apparent specific resistance to filtration under a pressure of 1 kg/cm , for different doses of $Na_2SO_4,10H_2O$ without application of an electrical field and under an electrical field of 10V/cm.

TABLE 5. Effect of the Increase of Sludge Conductivity on its Electro-Filtration

Dose of Na_2SO_4, 10 H_2O (g/l)	Sludge conductivity (mS)	α (10^{11} m/kg) under P=1 kg/cm^2 and 10 V/cm	α in the same conditions without electrical field
0	1.2	788	1997
1.25	1.7	1394	1830
2.5	2.1	2365	1832
5	3.1	4164	1665

The increase of the salinity, in the absence of an electrical field, decreases slightly the specific resistance to filtration. However, it increases significantly with the application of an electrical field.

The increase of the conductivity reduces the zeta potential at the surface of the solid phase of the sludge. This does not favor the electrokinetic phenomena but has a positive effect on the degree of particles flocculation.

– Influence on electro-osmotic drainage

The sludge (domestic, anaerobically digested) was dewatered under 1 kg/cm^2 for 2 hours. Then we superimposed an electrical field of 10 V/cm for 30 min.

The efficiency of the electro-osmotic drainage is evident from the final solids concentration of the sludge cake.

Table 6 shows that the increase in the salinity of the sludge does not improve the electro-osmotic drainage.

CONCLUSION

In this work, a laboratory cell has been constructed. It permits one to superimpose a mechanical pressure adjustable up to 7 kg/cm^2 to the electro-osmotic drainage.

TABLE 6. Effect of the Increase of Sludge Conductivity on its Electro-Osmotic Drainage

sludge cnditionning	applied electrical field (volts/cm)	solids concentration of the cake (%)
Unconditionned	0	29.1
Unconditionned	10	37.1
Na_2SO_4 10 H_2O (5 g/l)	10	37.0

The application of an electrical field decreases the specific resistance of the sludges to filtration by a variable factor which can result from both the electrical conductivity of the sludge and the superficial electrical charge of the particles.

The electro-osmotic drainage in the thickening phase enables domestic sludges to reach very high solids concentration when compared to that of cakes obtained without applying of an electrical field under the same pressure (4kg/cm^2) and under a pressure of 40 kg/cm^2. The energy consumption for electro-osmotic drainage varies with sludges between 0.05 and 0.2 kWh/kg of water extracted. The evaporation of 1 kg of water requires approximately 1.2 kWh to be evaporated.

It was also shown that electro-osmosis acts preferentially by elimination of the free fraction of water in sludges. However, an increase of the salinity of the interstitial aqueous phase of the sludge does not result in any improvement, either in electro-filtration or in thickening by electro-osmotic drainage.

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