ELECTRO-OSMOSIS IN DEWATERING OF PULP AND PAPER WASTE SLUDGE

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Abstract **– The paper preliminary discusses the alternative of using electro-osmosis in dewatering pulp and paper residual sludge and then analyzes the efficiency of the electro-osmotic treatment for a particular raw sludge.**

Keywords: *electro-osmosis, pulp and paper sludge, dewatering.*

1. INTRODUCTION

Nowadays the environmental problems are seriously taken into consideration all over the world. In the case of the pulp and paper industry, one of the environmental problems to be solved is to manage the wastes that result from the production process.

Pulp and paper mill residual sludge and many other types of bio-solids are considered a source of renewable energy. But the conversion of the raw sludge into thermal or electrical energy is not simple. In order to burn, the sludge must have an enough high level of dryness.

Conventionally screw press, rotary press, filter press or centrifuge systems are commonly used to achieve between 25 and 50% solids depending on sludge type and blending of primary, secondary and de-inking sludge. Recycled wastepaper accounts for more than 50% of the total raw materials used in the production of pulp for papermaking.

But in most cases, conventional dewatering systems are not effective in achieving low enough moisture content, in order to allow its combustion without blending with other fuels. Electro-osmosis seems to offer one potential cost-effective solution. Its use in the treatment of different kind of soils and wastewaters has given promising results [1]..[7].

The paper purpose is to verify if the use of electro-osmosis in dewatering of a particular pulp and paper sludge is effective and presents the results of some laboratory tests.

2. ELECTRO-OSMOSIS

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Electrokinetic phenomena can be categorized into four types. Both electro-osmosis and electrophoresis use an applied electric field to induce motion, whereas both the streaming potential and the sedimentation potential have the opposite electrokinetic coupling in that they use motion to produce an electric field.

A Russian physicist Reuss first observed the electro-osmosis phenomenon in 1808. According to the classical electrokinetic theory, at the interface between a solid and a polar liquid solvent (such as water), the specific adsorption process of some ionic species or electric charging of the liquid by the solid induces a solid double layer. Figure 1 shows the case of an electronegative particle immersed in a polar solvent, when the particle is charged negatively and the positive ions come to neutralize the surface charge and form a compact or Stern layer with typically 4 – 10 A° thick. A more mobile diffuse layer surrounds this and when an electric field is applied, the liquid ions in the diffuse layer move to the opposite electrodes. Each ion will carry a number of water molecules with, determining a water flow to one of the electrodes. The net amount of liquid water depends on the relative mobility of the ions of opposite sign. This process that is called electro-osmosis finds wide applications in biochemical analysis, civil engineering, etc.

The complete mathematical description involves

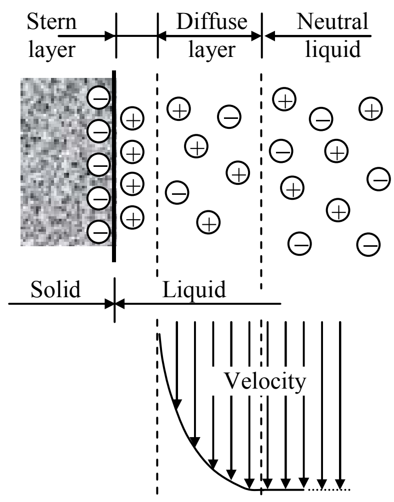

Figure 1: Electrical double layer and electro-osmotic flow caused by a DC electric field

coupled electrical and mechanical equations, since the electric field moves the liquid, and this motion produces a charge density current that must be included in the electrical equations. The electrical problem can be solved independently and its solution inserted in the mechanical problem. In the neutral liquid the Ohm's law is satisfied. In the diffuse layer the ions can be moved by the electric field and drive the liquid in turn, but the compact layer can be described as a linear capacitor. The thickness of the diffuse layer, which is similar to the Debye length, depends on the liquid characteristics

$$\delta_0 = \sqrt{\frac{\varepsilon \cdot D_0}{\sigma}} \tag{1}$$

where σ is the electric conductivity, ε the permittivity of the liquid, and D_0 is the mean ion diffusion coefficient. Although, the models are not valid than in some particular conditions so, usual, an approximation of the double layer is preferred.

Another approach is that using the thermodynamics of irreversible processes, which allows analyzing flows in terms of constituents (i.e. cations, anions, and water molecules). So, considering a simultaneous action of pressure difference, ΔP, and electrical potential difference, ΔU, the volumetric flux, q_v, and the flow of electric current, I, can be expressed as:

$$\begin{cases} q_v = L_{11}\dfrac{\Delta P}{T} + L_{12}\dfrac{\Delta U}{T} \\ I = L_{21}\dfrac{\Delta P}{T} + L_{22}\dfrac{\Delta U}{T} \end{cases} \tag{2}$$

where T is the absolute temperature and the factors L_{ij} are called phenomenological coefficients that do not have explicit values or expressions but must be determined experimentally for individual systems.

To quantify the liquid flow rate through a porous medium under electric fields, the most known and widely used is the Helmholtz-Smoluchoski theory. Considering the charge layers at the solid-liquid interface as an electric condenser with parallel plates, they found that between the electro-osmotic pressure difference ΔP_{eo} and the applied potential difference ΔU that caused the ΔP_{eo} the following relation can be written

$$\frac{\Delta U}{\Delta P_{eo}} = \frac{Q}{I} = \frac{\varepsilon\zeta}{\mu\sigma} \tag{3}$$

where Q is the electro-osmotic flow, μ the fluid viscosity (Pa.s) and ζ is the zeta potential that can be expressed as

$$\zeta = \frac{4\pi\mu\sigma}{\varepsilon} \cdot \frac{\Delta U}{\Delta P} \tag{4}$$

Knowing that electro-osmosis and the streaming current are two dual phenomena, ΔU is also the measured change in electrical potential that yields when a liquid is passed through a porous material at a certain pressure ΔP.

In the case of de-ionized water, the zeta potential is in the range from 50 to 100 mV [2].

Another form of the Helmholtz-Smoluchoski relation gives the volumetric flow rate Q (m^3/s) of liquid transported by electro-osmosis in a porous medium as

$$Q = \frac{A}{4\pi} \cdot \frac{\varepsilon\zeta E}{\mu} \tag{5}$$

where A is the cross-section of the bed of material (m^2) and E is the applied electric field strength (V/m). The factor 4π is a shape factor for spherical particles or particles having other form but with much greater size than the double layer thickness.

In the last equation could be noticed that the flow of water increases linearly with the applied electric field, when a constant electric field across the material bed is applied. More, since the current is proportional to applied voltage, the flow is also directly proportional to the constant current flowing through the material, in the case of constant electric-current dewatering.

When removing water from a sludge bed, its volume and electric conductivity are decreasing. So, the bed height decreases from the initial value H_0, too. To keep a constant current, the voltage across the bed increases following the increasing of the bed resistance. In this case, an expression for the energy consumed by the bed was proposed [1]:

$$W = \frac{A}{\sigma_1} J^2 \left[\frac{k_w k_{eo}}{2} J \cdot t^2 + H_1 t \right] \tag{6}$$

where $$k_{eo} = \frac{\varepsilon\zeta}{4\pi\mu} \tag{7}$$

and $$k_w = \frac{\nu_{w1}}{\nu_{w1} - \nu_{w2}} \left(\frac{1-\nu_{w1}}{\sigma_2} - \frac{1-\nu_{w2}}{\sigma_1} \right) \tag{8}$$

in that ν_w is the porosity (ratio between the water volume and total volume of the bed), J is the current density (A/m^2) and H_1 is the initial height of the bed. The indexes $_1$ and $_2$ mean before dewatering and after dewatering treatment.

The electro-osmotic coefficient k_{eo} is called also electro-osmotic permeability and is used as an indicator of materials ability to support electro-osmosis. The typical values are included in the range of 10^{-6} ..10^{-4} $cm^2/V.s.$ and compared with the ones of the hydraulic permeability, k_h, which ranges from 10^{-9} to 10^{-5} m/s. The electrokinetik dewatering becomes more efficient as the hydraulic dewatering when the ratio k_{eo}/k_h is high.

One notice analyzing (6) that the expended energy has a quadratic dependence on time. Only in the particular case when the bed resistance does not much alter, the quadratic term is much smaller as the linear one, and expended energy can be expressed as:

$$W = \frac{A}{\sigma_1} J^2 H_1 t \qquad (9)$$

3. SLUDGE DEWATERING AND DRYING TECHNOLOGIES

The first goal of any sludge dewatering process is to reduce the total mass and volume of the solid wastes, but the effectiveness (efficacy) of any sludge dewatering application is almost entirely dependent on the chemical and physical characteristics of the solids and water that comprise a particular sludge. Also in the pulp and paper industry the sludge dewatering technology must be custom-designed, but in this particular case exists the opportunity of energy recovery by using the dried sludge as combustible material.

Pulp and paper wastewater sludge typically contains between 0.5% and 8% dry solids and its consistency must be increased to a minimum of 25% dry solids in order to be land-filled, or to a minimum of 40% to 50% dry solids content in order to be used in an fluidized bed combustion system. However, a typical pulp and paper mill sludge contains high concentrations of ash and water, which limit the effective heating value of the sludge and affect the economic viability of sludge to be converted in energy.

According to [5], water exists in the following physical states:

- Free: water not associated with free particles
- Interstitial, capillary: mechanically bound water which is trapped in the flocs
- Vicinal: physically bound multiple layers, held thghtly to the particle surface by hydrogen bonding
- Chemically bound: water of hydration

If the free water is easier to extract, the bounded or vicinal water becomes difficult to remove. Currently only potential gradients produced by thermal methods are sufficiently high to remove interstitial and vicinal waters, involving high capital and operating costs.

Because the flow of water induced by an electrical potential difference is not limited by pore size, electro-osmosis has the potential to remove interstitial water from the sludge flocs, thus greatly improving dewatering efficiency [5].

There are some factors affecting the electrokinetic potential of cellulosic fibers [3]:

- Chemical composition is perhaps the most important. Solid residues from pulp production and paper-milling operations contains usually a majority fraction of moisture, some organic content in the form of wood or recycled paper fibers, significant amounts of ash and trace quantities of heavy metals, chlorinated organic compounds and pathogens.
- Mechanical processing must be also taken into account because involving changes in the observable charged nature of pulp fibers
- The repeated drying of fibers can favour the fiber pores to remain closed and so these ones will have a reduced ability to absorb water
- The effects of solution PH on fiber charge and electrokinetik potential are complex.
- Some electrolytes have been found to affect the charged nature of cellulosic fibers to a much greater degree than others. Polyelectrolytes offen display high-affinity adsorption behavior on cellulosic fibers, leading to dramatic changes in electrokinetic behavior.
- Multivalent cations tends to have a much more dominant effect of fiber surface charges, compared to low-valence ions

However, for each unique application the various options that are commercially available for sludge dewatering should be evaluated independently. Investigation of the benefits that may be realized from the use of chemical additives and/or innovative control strategies should also be considered.

3. LABORATORY TESTS ON SLUDGE WASTES FROM VRANCART S.A.

The main characteristic of Vrancart S.A. pulp and paper mill is that uses a raw material with a high content of recycled (secondary) fiber as opposed to virgin wood materials. The moisture content of sludge at the end of production process is about 90%. During years, the cellulosic waste residuals were transported in an open land-field deposit, operation that now is forbidden by the environmental regulations. More, this deposit must be removed or integrated in the natural surroundings. In order to reduce its volume, the necessity of sludge dewatering becomes obvious. If enough low moisture content will be achieved (lower than 45%), the opportunity to use the dried sludge as combustible material will increase the efficiency of the whole process.

A two steps mechanical dewatering was used. First a filter press lowered the moisture content from 91% to about 72% and then a screw press improves the lowered moisture content to about 55%. After trying to burn the dried sludge in a fluidized bed boiler the conclusion was that the sludge fires too late, at the boiler exit, because of the still high moisture content. Other attempts to dewater mechanically were without success so the electro-dewatering was taken into consideration.

3.1. Experimental method

A simple laboratory test bench was realized from a PVC cylinder with 190 mm inner diameter, two aluminium electrodes of 2 mm thickness and a rectified and filtered DC source. Both electrodes were perforated and had 4 mm diameter holes, ranged at 6 mm distance one from other. Supplementary textile gauze covered the electrode's surfaces to improve the wet sludge detainment. The cylinder has a vertically axis and allow a gravitational dewatering trough the lower electrode. An autotransformer allows varying the applied electric field strength.
Each sludge sample has an initial weight of 1100 g and moisture content of about 91% (about 100g dry solid and the rest water). A weighing machine was used to permanently measure the probe weight as well of the removed water.
During the tests a constant compression of 0.22 N/cm^2 was applied and an electric voltage ranging between 30 and 70 V over the bed with initial 3.5 mm thickness.

3.2. Results and discussion

Five kinds of two hours tests were several times performed; the obtained averaged values have been inserted in Table 1. The first one was the witness test, in that dewatering was the result only of gravitation forces. Then the tests 2 and 3 were performed at a constant current of 1A, and the tests 4 and 5 at a constant current of 3A. The difference between the tests of the same electric current was the addition of half-hour water removing by gravitation before applying the two hours electro-osmosis treatment in the case of the tests 3 and 5.
In the Table 1 the notation are: I – constant electric current, m_0 – initial mass of the sample, u_0 – initial moisture content of sample, m_l – liquid water removed in test, m_v – removed water by vaporization, m_w – total mass of the removed water, m_f – final mass of the sample and u_f – final moisture content of the sample.

	1	2	3	4	5
I [A]	0	1	1	3	3
m_0 [g]	1100	1100	1100	1100	1100
u_0 [%]	91	91	91	91	91
m_l [g]	454	695	728	707	712
m_v [g]	-	137	119	164	166
m_w [g]	454	832	847	871	878
m_f [g]	646	268	253	229	222
u_f [%]	84.5	62.7	60.5	56.3	55

Table 1: Experimental results.

One notice that:

- the moisture content get by electro-osmosis is close to the one obtained by two step mechanical drying;
- even if the electro-dewatering takes more time than the mechanical one, at the end, the sample is warm and an important quantity of free water is close to the anode (the upper electrode); keeping the sample in the dry laboratory environment, the sample weight lowers to about 180 g and the moisture content to about 44% after 24 hours;
- with the electric current value the dewatering increase, but also the quantity of water removed by vaporization and that affects the process efficiency;
- between 60% and 80% of water is removed in the first half hour after applying electro-osmosis.

4. CONCLUSIONS

The experimental results prove that electro-osmosis could help in the dewatering process of the pulp and paper sludge from Vrancart S.A., but the economic viability of the whole process depends on a lot of factors and needs a detailed analysis.
Further research must take into account the optimization between the electro-osmosis time, electro-osmosis current and compression strength, as well as the use of chemical flocculants.

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