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ELECTRO-DEWATERING OF WASTEWATER SLUDGE: FACTORS AFFECTING KINETICS AND ENERGY CONSUMPTION

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ABSTRACT

The treatment of wastewater produces huge quantities of residue (sludge) which contains a large amount of water. A dewatering step is usually carried out prior to further treatment in order to diminish sludge volume and consequently reduce handling and disposal cost. It is commonly conducted thanks to mechanical processes (plate or belt filter presses, centrifuges) which offer a relatively poor efficiency. The water content at the end of the dewatering usually ranges between 65% and 85%. A way to improve the dewatering efficiency is the implementation of an electric field during the mechanical dewatering (electro-dewatering). It has been shown that applying an electric current through the filter cake could reduce significantly the water content of sludge, down to 40%.

A lab-scale device of electro-dewatering has been used to study the phenomena involved in this hybrid process. The experimental set-up consists in a cylindrical chamber where a piston presses the sludge cake on a filter cloth. Two electrodes, one anode and one cathode, are placed at the piston head and under the filter cloth, respectively. Dewatering kinetics and electrical behavior of the sludge cake can be studied with this set-up.

The results of experiments carried out with a constant voltage (or a constant current) show significant correlations between the filtrate flow-rate, the electric current, the electrical resistance of the filter-cake and the water content of sludge. The electric current and the water content of the sludge are found to be key factors that govern electro-dewatering kinetics. Moreover, the electrical resistance through a given cake of sludge is highly correlated to its water content (which decreases during the process). The relationship seems to be valid for a wide range of water content. These results enable a better understanding of how dewatering efficiency and energy consumption are related in the electro-dewatering process.

KEYWORDS

Dewatering, Electroosmosis, Energy Consumption, Activated Sludge, Sewage Sludge

1. INTRODUCTION

Wastewater treatment plants generate a very large amount of sewage sludge. The cost of sludge disposal depends directly on volumes to be treated and thus on their water content. To reduce the volume, the sludge is usually mechanically dewatered (centrifuges, plate filter presses, belt filter presses...) but the performances of these processes are generally poor (Vaxelaire and Cézac, 2004). It has been shown that the implementation of a direct electric current coupled to a mechanical pressing (electro-dewatering) can lead to a considerable reduction of sludge moisture content (Mahmoud et al, 2010, 2013; Tuan et al, 2012). Different experimental procedures were proposed in the literature to study the electro-dewatering of various materials. Two classical operating modes, constant voltage or constant current, were generally used, but only few studies proposed a direct comparison between these two operating conditions. Authors usually show that the dewatering kinetics is enhanced when increasing the current or voltage (Lockhart, 1983; Iwata et al, 2007; Mahmoud et al, 2011) and that the maximal final dryness of the filter-cake is higher with higher voltage. Nothing has been clearly stated concerning this behavior with tests carried out at constant current (they are often stopped before the maximal final dryness was reached). This is generally due to an excessive rise in temperature in the cake (ohmic dissipation). The electrical quantity which naturally makes a link between the voltage and current is the apparent electrical resistance of the system (electrodes + cake). The present work shows the influence of electrical parameters (current, voltage, moment of electric coupling) on dewatering kinetics. It also studies links between the tests carried out with the two operating modes (constant current or voltage). Moreover, the energy consumption is discussed as part of the overall performance analysis of the dewatering process.

2. MATERIALS AND METHODS

2.1 Experimental unit

The experimental set-up used for the study was previously described by Mahmoud et al. (2011). It consists in a filtration/compression cell working with a pressure controlled piston moving in a cylindrical vessel of 70 mm inner diameter. The device presses the material to be dewatered against a filter cloth (SEFAR TETEX MONO SK025, CHOQUENET S.A.S, France). The piston and the vessel were made of non-conducting Teflon™ in order to ensure electrical insulation.

Two perforated disk electrodes were placed at both ends of the compression chamber. They were designed by De Nora (Italia) and supplied by ECS (Electro Chemical Services, Saint-Genis-Pouilly, France). The anode was inserted against the piston head. It was made of titanium coated with mixed metal oxide (MMO) to prevent its oxidation. The cathode lay under the filter cloth. It was made of titanium. Both cathode and filter cloth were held by a perforated grid made of Teflon™ which was maintained by stainless steel external jacket to ensure the mechanical resistance of the unit.

A DC power supply EV202 CONSORT (maximum 300 V and 2 A), operating under constant voltage or constant current, was connected to the anode and cathode electrodes. The pressure applied to the piston was controlled by a pressurized air system.

The mass of filtrate was collected in a beaker and measured against time with a weighing scale connected to a computer. Two digital multimeters (ISO-TECH IDM 73) were used to control voltage and current fluctuations in the electro-dewatering cell.

2.2 Sludge

The electro-dewatering tests were carried out with two different types of sludge whose characteristics are listed in Table 1. Activated and primary sludge were collected in two wastewater treatment plants, from aeration tank and primary settling tank, respectively. After transportation to the laboratory, the initial dryness of the sludge was determined by drying at 105°C during 24h. The sludge was stored at 4 °C and used over a period of less than one week in order to limit the variations which may be caused by biological mechanisms. Before each dewatering test, the sludge was conditioned with a cationic polymer and thickened. The polymer was supplied by SNF Floerger. The use of two different types of sludge enables to widen the interest of the results presented in this paper.

Table 1. Sludge characteristics

	Primary sludge	Activated sludge
Origin	Saint-Thibault-des-Vignes, France (77)	Lescar-Pau, France (64)
Initial dryness (%)	1.9	0.5
Mass per sample (g)	500	2000
Type of flocculant	EM 540 L	EM 640 TBD
Dosage of flocculant (g/kg of dry matter)	8	8

2.3 Operating procedure

Before each test, the sludge sample was left about two hours at room temperature to reach this temperature. The cationic polymer was added to the sludge, under stirring at 300 rpm for 20 s with a JAR TEST device. Then, the flocculated sludge was thickened by gravity drainage on a lab-scale device (Ginisty et al, 2012). The dryness reached after thickening was approximately 6.9% for primary sludge and 5.2% for activated sludge.

For standard dewatering test, the thickened sludge sample was introduced in the filtration/compression cell. A mechanical pressure of 5 bar was applied to the piston without electric current (single mechanical compression) for 2 hours. Then the electric current was applied, either by setting the desired voltage or the desired current intensity for a maximum time of two hours. The pressure was maintained to 5 bar during this step. At the end of the first step the cake dryness reached approximately 20% for the primary sludge and 12% for the activated sludge.

During tests carried out under constant current intensity, significant heating was generally observed as process progressed. Experiments were stopped when the temperature at the head of the piston (anode side) reached 80 °C. The dryness of the sludge at the end of the test was measured after a drying at 105 °C for 24 h. The dryness evolution was calculated from the evolution over time of the mass of filtrate.

$$dryness(t) = \frac{m_{DS}}{m_{DS} + m_L(t)}$$

With m_{DS} the mass of dry solids and m_L the mass of water in the sludge cake (which is a function of time).

3. RESULTS AND DISCUSSIONS

3.1 Two electro-dewatering phases

A first series of experiments was carried out with the primary sludge for different voltages (30 V, 40 V and 50 V) and different current intensities (100 mA, 200 mA and 300 mA), respectively. The evolution of the cake dryness over time and the electrical behavior of the system (variations of electric current and voltage respectively) are presented on Figure 1.

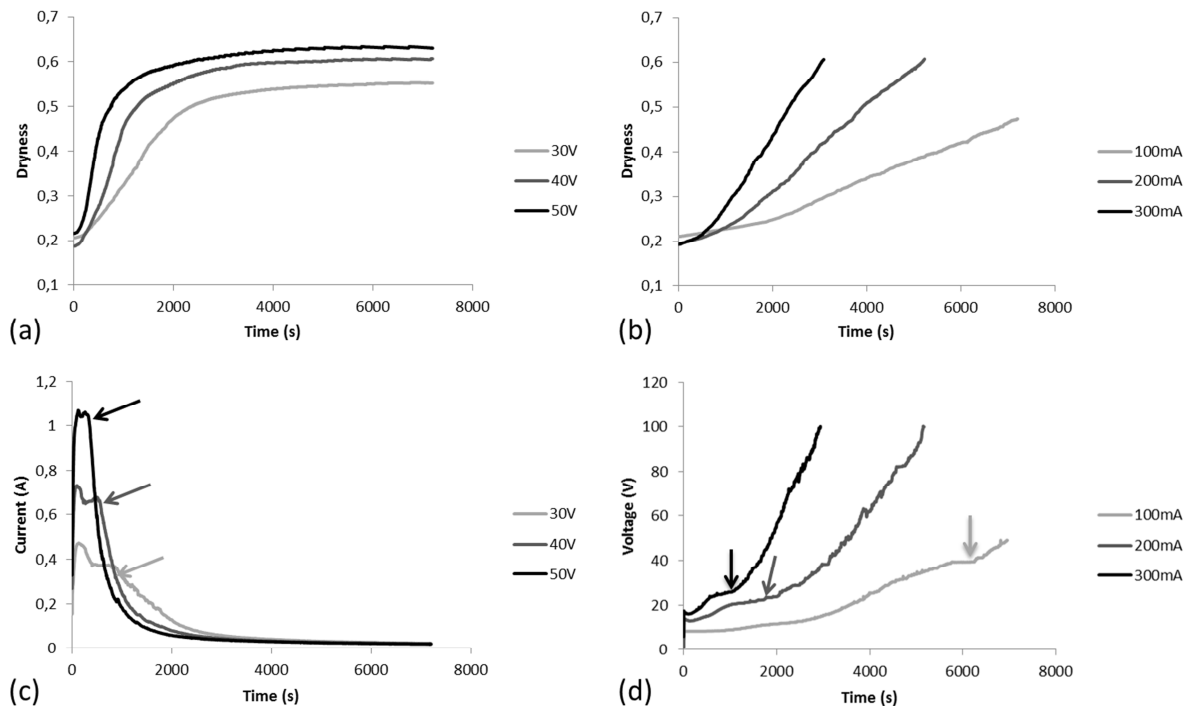


Figure 1. Dryness versus time for tests at constant voltage (a) and constant current (b). Current variations for tests at constant voltage (c) and voltage variations for tests at constant current. Primary sludge.

According to other results presented in the literature (Gingerich et al, 1999; Mahmoud et al, 2011; Citeau et al, 2012) both, the current and voltage play a major role on the dewatering kinetics. Tests carried out at constant voltage shows a rapid dewatering

kinetics at the beginning of the process but this kinetics weakens over time. Tests conducted with a constant current intensity show more steady dewatering rates. When looking at the electric current curves (voltage respectively) it is possible to analyze the electro-dewatering process with two distinct phases. During the first phase (phase 1) the current intensity (respectively the voltage) varies with no obvious trend. Then a second phase (phase 2) can be observed where the temporal variations become monotonous. During phase 2, for tests performed at constant voltage, the current intensity decreases over time (Figure 1c) while the voltage increases continuously for tests conducted at constant current (Figure 1d). The transition between the two phases is shown by arrows on Figures 1c and 1d. The analysis of the process with different phases was already proposed by Mahmoud et al. (2011) but only from tests carried out at constant voltage.

Very similar results were also observed with activated sludge as shown on Figure 2. The dewatering kinetics followed the same trend with respect to the intensity of the electric current: higher currents (or voltages) led to a faster dewatering. Transitions between phase 1 and phase 2 were even more marked (arrows on Figures 2c and 2d).

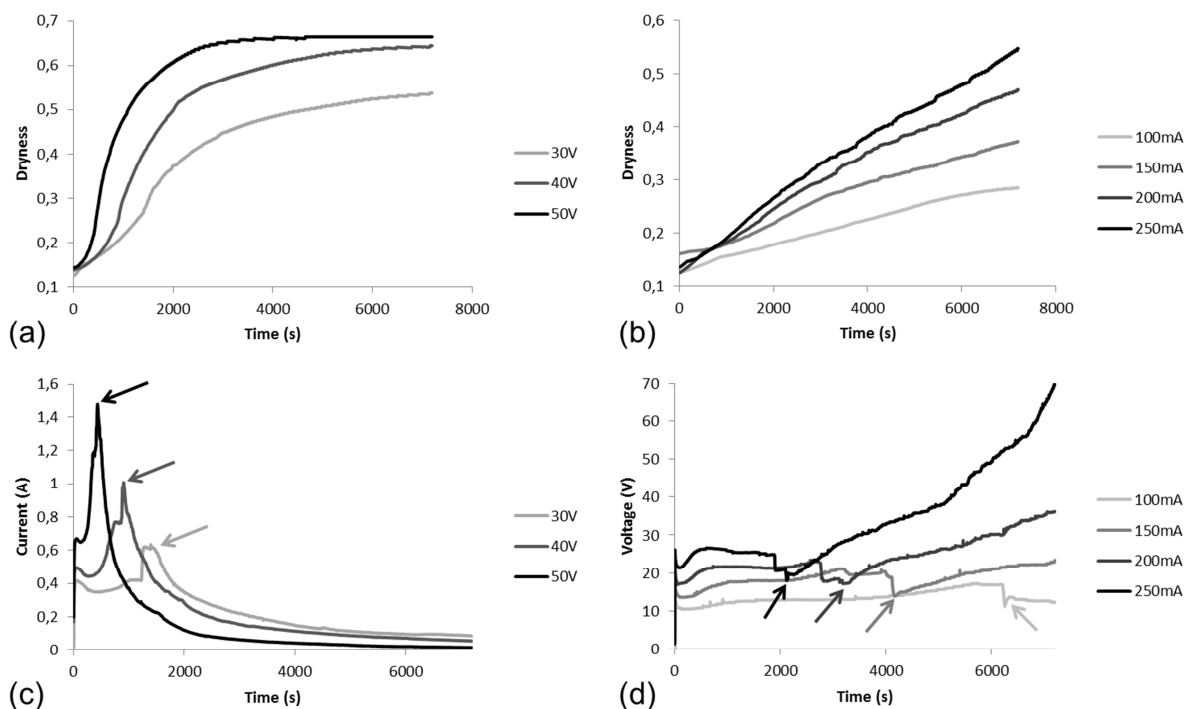


Figure 2. Dryness versus time for tests at constant voltage (a) and constant current (b). Current variations for tests at constant voltage (c) and voltage variations for tests at constant current. Activated sludge.

From Figure 1 and 2, it seems that the duration of phase 1 depends on the current intensity (or voltage respectively). This phase was shorter when the applied current intensity (or voltage) was higher. When the electric current is switched on, many phenomena may take place such as the starting of electrode reactions and migration of charged species (ions and other charged particles) from one electrode to the other through the sludge cake. The first phase appears as a transient stage of the process

before a more steady state (phase 2). Finding the same behavior with the two types of sludge tends to show that the presented results are typical characteristics of the electro-dewatering process itself.

3.2 Electric current and filtrate flow-rate

As it was mentioned previously, it seems that a higher current intensity leads to a faster dewatering, even for tests conducted with a constant voltage (in this case the dewatering rate decreases with the current). To complete this result the filtrate flow rate was plotted as a function of the electric current for tests carried out at different constant voltages (Figure 3). The transition between the first and the second phase is represented by an arrow. As it can be seen on Figure 3a no obvious relationship between filtrate flow rate and electric current appeared during the first phase of the electro-dewatering process.

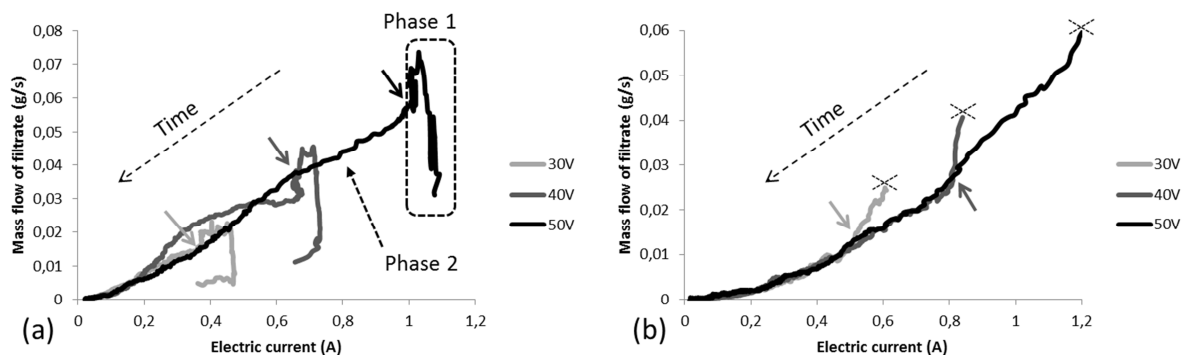


Figure 3. Mass flow of filtrate plotted against electric current for tests at constant voltage with: (a) primary sludge, (b) activated sludge (phase 1 is partially cut for a better reading of the graph)

At the opposite, during the second phase, a rather strong correlation between the decrease of the electric current and the decrease of the filtrate flow rate was observed. For a given current intensity, the filtrate flow changed in a rather limited range of values. The correlation was found to be valid for the two types of sludge studied in the present work. This result tends to show that this behavior is a process characteristic which does not depend on the sludge origin. Consequently, during the second phase the control of the dewatering kinetics seems to be achieved by the electric current. This behavior can be explained by the fact that the electro-osmotic phenomena are related to the displacement of ions (mainly cations in the case of sewage sludge), which move as the electric charges are released from the electrodes. As the electric current controls the amount of charges released, it is therefore not surprising that electric current play such an important role in dewatering kinetics. However, this result admits some limits. Indeed, the tests carried out at a constant current intensity do not lead to a constant dewatering rate. The filtrate flow rate decreases during the process and cannot depend only on the current intensity. The influence of other parameters such as the cake dryness and the history of the dewatering process needs to be investigated, as it is proposed in the next section.

3.3 Filtrate flux and dryness

The electric current intensity has been shown to be a key factor which impacts significantly the dewatering. However, other parameters such as cake dryness may influence the electro-dewatering. In that way, a series of experiments was carried out with a constant current intensity (300 mA) to study the influence of the dryness of the sludge cake on the filtrate flow rate. The electric was applied to the mechanical process at different times (i.e. at different cake dryness).

Figure 4 shows the variation of the filtrate flow-rate against the filter-cake dryness. Electric current was switched on at different moments, after 2 hours (standard), 30 minutes, 10 minutes of mechanical pressing and also from the beginning of the dewatering process.

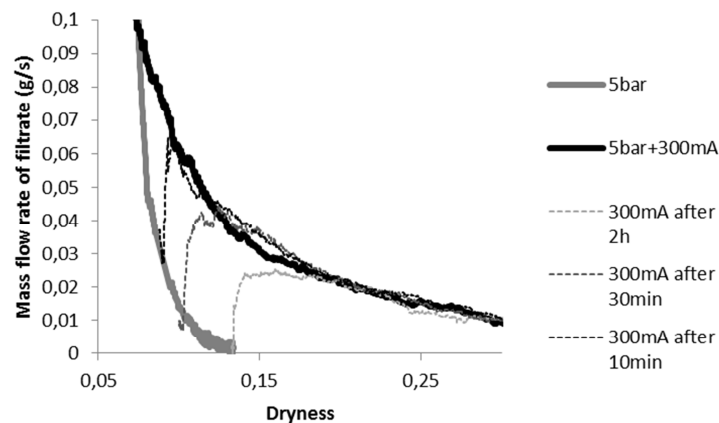


Figure 4. Mass flow rate of filtrate versus sludge cake dryness. With and without electric current. Electric current is added at different times. Activated sludge.

This series of experiments showed that the filtrate flow rate increased when an electric field was applied. The electric current enables to generate higher flow rates in comparison to a single mechanical pressing, and also higher final cake dryness. Finally, two main curves can be analyzed. The one without electric current (single mechanical pressing) and the one corresponding to the electro-dewatering process (pressure + electric current). It is striking to observe that there were only these two curves and that the flow rate of filtrate “jumped” from one to the other for each experiment. For a given current intensity the flow rate depended only on the filter-cake dryness, regardless of the time when the electric current was applied. This result shows that the filter-cake dryness is a key factor affecting the dewatering kinetics as well as the current intensity.

3.4 Electrical resistance and dryness

To compare tests carried out respectively at constant current intensity and constant voltage, it was convenient to find a parameter which could be common to these two operating modes. The apparent electrical resistance of the cell (voltage across the sludge cake divided by the current intensity) seemed to be an interesting parameter for this purpose. Consequently, the evolution of this resistance was studied with experiments carried out with various operating conditions: different voltage or current,

two types of sludge, different times for the applying of the electric current (during the full dewatering process or after 2 hours of single mechanical compression).

3.4.1 Influence of electrical current or voltage

Figure 5 shows the change in electrical resistance against cake dryness for tests carried out with activated sludge, when the electric field was applied after 2 hours of single mechanical pressing. Figure 5a enables to compare experiments conducted with different currents, namely 200 mA, 250 mA and 300 mA. Similarity between the three experimental curves appears excepted at a low dryness where a discontinuity in the resistance curve can be observed. This “jump” of resistance corresponds to the transition between the two phases mentioned in paragraph 3.1. For the three experiments the dewatering kinetics was different but the relationship between electrical resistance and cake dryness remained the same.

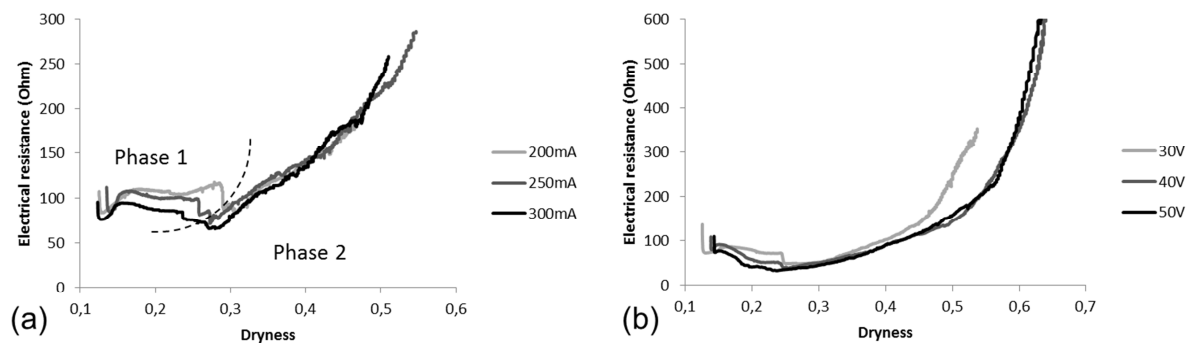


Figure 5. Electrical resistance versus dryness for experiments at constant current (a) and constant voltage (b). Activated sludge.

Figure 5b shows experiments carried out with different constant voltages, namely 30 V, 40 V and 50 V. The data obtained for both, 40 V and 50 V, were very similar showing a good correlation between the electrical resistance and cake dryness. For experiments conducted at constant current, a single correlation between electrical resistance and sludge cake dryness was also observed although the dewatering kinetics were different in the two experiments. The curve resulting from the experiment conducted at 30 V also fitted the two other ones for a cake dryness ranging between 25% and 45%. Then the electrical resistance increased faster than it did with the two other voltages. It can be assumed that this excessive increase in electrical resistance was due to a poor electrical contact at the cathode. This latter was not in direct contact with the sludge cake and might suffer from a gradual drying when the flow rate was too low (due to low current intensity or voltage). While the cathode dried, the electrical contact became poorer. Otherwise, it is also possible to observe on Figure 5b the transition between phase 1 and phase 2, but the transition is less noticeable than on Figure 5a.

3.4.2 Influence of the electro-dewatering mode and of the coupling time

The variation of electrical resistance against cake dryness was plotted on Figure 6, for experiments carried out with different operating conditions (constant voltage, constant current intensity, and different times to apply the electric field).

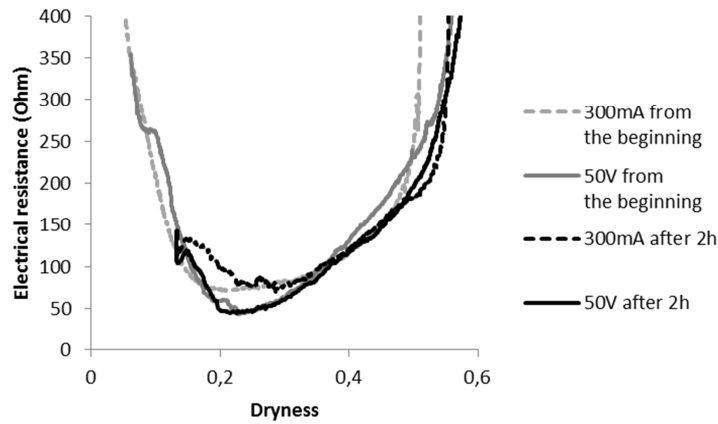


Figure 6. Electrical current versus sludge cake dryness. Comparison between constant current and constant voltage modes. Different times where electric current is switched on. Activated Sludge.

The comparison of the whole data showed that the variations of the electrical resistance with respect to cake dryness were very similar from one test to another. The overall resistance decreased at the beginning of electro-dewatering and then increased until the process stopped. The good agreement between the data seems to confirm that the electrical resistance depends slightly on the selected operating mode (constant current or voltage). Furthermore the history of the process (single mechanical pressing or combination with an electric current) does not influence the variation of the electrical resistance. Finding correlations between, respectively, kinetics parameters such as sludge cake dryness or flow rate of filtrate, and electrical parameters (electrical resistance and current intensity), is crucial to understand the link between the dewatering kinetics and the energy consumption of the process.

3.5 Overall performance of the process

The electro-dewatering process can be more or less time and energy-consuming. It is possible to determine the overall performance by taking into account these two aspects. Finding a good overall performance is a way to determine what the best operating strategy is to dewater the sludge cake efficiently. By varying the time when the electric current is switched on, the overall time and energy consumption of the process change. The earlier the electrical current is switched on in the compression stage, the faster the kinetics is. However, from an energy point of view, there is no specific need to consume electrical energy while a single mechanical compression allows itself to extract significantly the water. But, if it is assumed that energy expense can reduce operating time, it is thus interesting to define a cost function which is proportional to the process time and to the spent energy (electrical energy mainly).

$$cost = f(time, energy) = time \times energy$$

This cost function can be plotted against the cake dryness for activated sludge (Figure 7). Tests were carried out at constant voltage (50 V) and constant current (300 mA), respectively. For both cases the electric current was switched on at different times of the compression stage. The data obtained show that reaching higher cake dryness leads to higher costs.

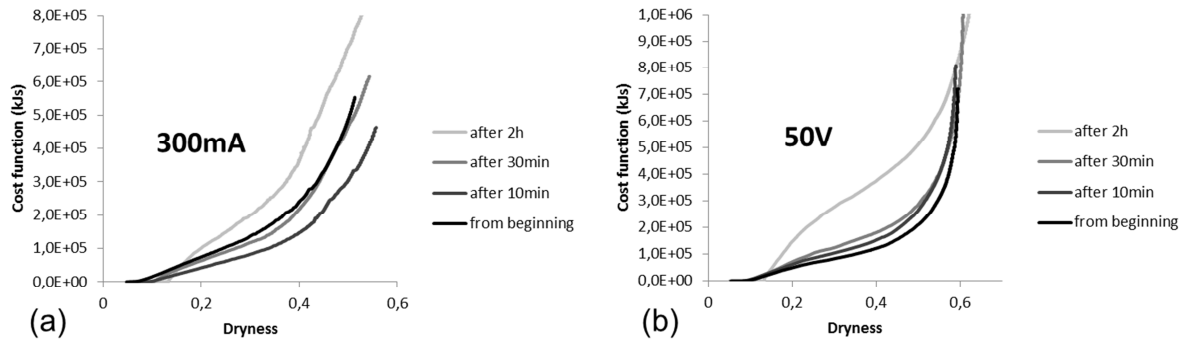


Figure 7. Cost function plotted against sludge cake dryness for tests at constant current (a) and constant voltage (b) with different time when the electric current is switched on. Activated sludge.

For tests conducted at constant current intensity the lowest cost (i.e. the best time / energy ratio) was observed in the case where the electrical current was applied after 10 minutes of single mechanical compression (Figure 7a). This optimum value was found according to the chosen cost function. For tests conducted at constant voltage, the lowest cost was obtained when the electric current was applied during the full process (Figure 7 b). Obviously, this was verified only for dryness higher than 13% (which is the maximal dryness reached by mechanical compression). These results may be explained by the fact that the electrical resistance throughout the system was high at the beginning of compression stage. Consequently, the electric current flow through the filter-cake was energy-consuming, especially when the effect of an electric current addition was slight on the dewatering rate. For tests carried out at constant voltage the process was self-balanced. The electric current intensity was low when the electrical resistance was high. As the sludge cake thickness decreased the current increased due to a drop in electrical resistance. At this time the benefit of the electric current was more significant and the process less energy-consuming.

CONCLUSION

The presented work shows with two types of sludge (primary sludge and activated sludge) how electro-dewatering process operates. The tests carried out were used to study the electrical behavior of the sludge over process time. The presence of two distinct phases was pointed out. The large impact of the current intensity through the sludge cake on the dewatering kinetics was demonstrated and a correlation with the filtrate flow rate was highlighted. Furthermore, a comparison between the tests conducted at constant voltage and at constant current was possible thanks to the analysis of the electrical resistance of the system. A strong correlation between the electrical resistance and the filter-cake dryness was established. These data on

electrical resistances and filtrate flow rate allowed to point out links between dewatering kinetics and energy consumption of the process. Besides, the overall performance analysis of the process has enabled to find a balance between a fast dewatering and a too high energy consumption.

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