Effect of Electrical Conditions on the Efficiency of Electrokinetic Drainage Geocomposites for Tailings Dewatering

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ABSTRACT

Mining generates large quantities of water-containing tailings. They may raise large issues if their high stability and low hydraulic conductivity limit their timely consolidation. This is the case for example with oil sands tailings which reach a limit concentration of about 30 wt% solids after a few years, when they are called mature fine tailings (MFT). They experience almost no further consolidation afterwards and have to be kept in dedicated areas for extended periods of time. Electrokinetic drainage geocomposites have been developed to accelerate the dewatering of such tailings by forcing water displacement by electro-osmosis and efficiently draining the expulsed water.

These electrically conductive drain-tube planar geocomposites (eGCP) combine a nonwoven geotextile which provides filtration and drainage, perforated pipes regularly positioned within the geotextile, and a conductive component acting as an electrode. Their efficiency with MFT was demonstrated with a laboratory device simulating tailings dewatering taking place as a result of self-weight consolidation, electro-osmosis and drainage. An increase in solids content from 44% to 70% was obtained with the application of 6.6 kWh per m^3 of treated MFT, leading to an improvement in shear strength from 0 to a mean value of 25 kPa in 43 days.

This paper reports the results of an analysis of the effect of the electro-osmosis treatment conditions on the MFT dewatering efficiency. A higher applied voltage was observed to increase the water extraction and shear strength. In addition, no minimum voltage threshold was detected. In terms of current, a positive effect on dewatering efficiency was also obtained. However, the current-controlled mode led to an increase in dewatering duration and a reduction in extracted water compared to the voltage-controlled mode. The effect of electrode position and dynamic powering was also investigated. These results can be used to guide the design of eGCP treatments for accelerated tailings dewatering.

Keywords: Drainage geocomposite, Oil sands tailings, Dewatering, Electro-osmosis

INTRODUCTION

Mining generates large quantities of water-containing tailings, which can be defined as crushed rock particles that are deposited in a slurry form. This includes coal, tar sand, lead, zinc, gold, silver, copper, molybdenum, nickel, taconite (iron), phosphate, bauxite (aluminum oxide), uranium, trona (soda ash), and potash (Sarsby, 2013). In the case of oil sands mining, there are currently about 180 km^2 occupied by tailings (Fair, 2014). Open-pit mining, which represents a large portion of Canada's production because of the lower cost of the process and low depth of the deposit, generates about 16 tons of tailings for each ton of synthetic crude oil produced (Allen, 2008). The production of crude bitumen, which reached 1.94 million barrels per day in 2013, is expected to double by 2020 (Alberta Government, 2014).

Some of these tailings display a high stability and low hydraulic conductivity. This raises large issues as it limits their timely consolidation. For example, oil sands tailings contain about 70-80 wt% water, 20-30 wt% sand, silt and clay, and 1-3 wt% residual bitumen (Allen, 2008). According to current mining procedures, they are pumped in settling ponds where sand separates rapidly from silt and clay fine particles and forms perimeter beaches around what is called fluid fine tailings (FFT). On the other hand, the fine particles constituting FFT are held in suspension by electrostatic interactions. FFT reach a limit concentration of about 30 wt% solids after a few years, when they are called mature fine tailings (MFT) (Mikula et al., 1996). They experience almost no further consolidation afterwards and have to be kept in dedicated areas and monitored for extended periods of time. In addition to the problem of land use, issues associated with these tailings include the immobilization of water which is not available for reuse by the mining companies, the very low bearing capacity of MFT which represents a drowning hazard for wildlife and workers, and the risk of leaks of contaminants to surface and ground water.

Various solutions have been investigated over the last 20 years for dewatering oil sands tailings, with somewhat limited success. They include recombination strategies leading to consolidated/composite (CT) and non-segregated (NST) tailings, as well as the separate management of coarse and fine tailings using thin lift fines drying, thickening, centrifugation, CO_2 coagulation, water capping, etc. (Fair, 2014). More recently, electrokinetic drainage geocomposites have been developed as a solution to accelerate the dewatering of MFT and processed tailings (Dolez et al., 2014). These electrically conductive drain-tube planar geocomposites (eGCP) combine a drain-tube planar geocomposite (Figure 1) made of a nonwoven geotextile which provides filtration and drainage, and perforated pipes regularly positioned within the geotextile, with a conductive component acting as an electrode. They work by forcing water displacement by electro-osmosis and efficiently draining the expulsed water. Voltage applied between two electrodes causes water and positively charged compounds to move towards the cathode while anions are directed towards the anode (Figure 2).

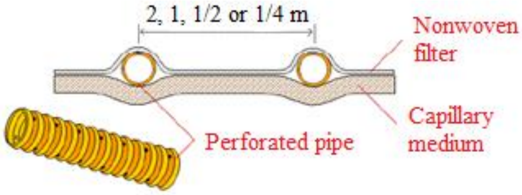

Figure 1 Drain-tube planar geocomposite

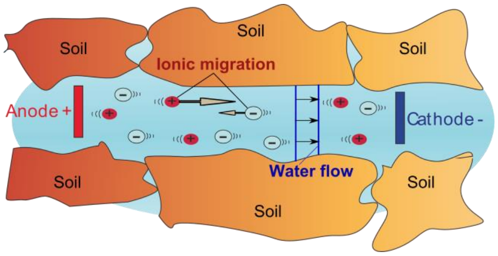

Figure 2 Principle of electrokinetic dewatering

The efficiency of eGCPs at dewatering MFT was demonstrated with a laboratory device simulating the entire path of water taking place as a result of self-weight consolidation, electro-osmosis, and drainage. Results obtained with mature fine tailings (MFT) provided by an oil sands operator and a prototype of eGCP combining a three-layer nonwoven geotextile, a perforated pipe and a tinned copper braid electrode showed an increase in the MFT mean solids content from 44% to 70% as a result of the combined consolidation under self-weight and compressive stress under an equivalent of 1.5 m of fill, followed by an electro-osmosis treatment (Dolez et al., 2014). This led to an improvement in the MFT shear strength from 0 kPa to a mean value of 25 kPa with a reduction in MFT volume of 51% over 43 days. The power consumption associated with this experiment was 130 Wh, corresponding to 6.6 kWh per m^3 of treated MFT.

This paper provides an in-depth analysis of the effect of the electro-osmosis treatment conditions on the MFT dewatering efficiency by eGCPs: voltage, current, power-control mode, electrode position, intermittent activation, and dynamic polarity reversal. The experiments are conducted using the laboratory scale dewatering device as well as a small scale electro-osmosis dewatering cell. They make use of a synthetic MFT formulation developed to limit the effect of the MFT composition variability on the experimental design.

METHODOLOGY

This section describes the eGCP prototype and the synthetic MFT formulation as well as the laboratory scale dewatering device and the small scale electro-osmosis dewatering cell used for the experiments.

Electrically Conductive Drain-Tube Planar Geocomposites

The eGCP prototype used in the experiments with the laboratory scale dewatering device combines a three-layer polyester nonwoven geotextile, with two outer filter layers and a heavier central drainage one, a drainage pipe, and a metal electrode (Figure 3). The thickness of the geotextile is 5.9 mm (ASTM D5199), its mass per unit area is 553 g/m^2 (ASTM D5261), and its filtration opening size is 120 µm (ONGC 148.1-10). The drainage core is made of a 20-mm outer diameter corrugated polypropylene perforated pipe, which provides a high in-plane flow capacity. Finally, a cylindrical tin-plated copper braid (diameter 25 mm, resistivity 1.3 10-3 Ω.m) is positioned along the perforated pipe, which is inserted in a gusset within the geotextile.

The experiments carried out with the small scale electro-osmosis dewatering cell used the same geotextile and metal electrode as the laboratory scale dewatering device. However, in that case, the tin-plated copper braid is positioned outside of the three-layer geotextile.

Mature Fine Tailings

A synthetic MFT formulation has been developed based on geotechnical data found in the literature (Dolez, Chappel & Blond, 2015). A similar dewatering behavior was obtained compared to a MFT sample provided by an oil sands operator. The composition of the synthetic MFT formulation used in the experiments described in this paper includes 57 wt% water, 40.4 wt% kaolinite, 0.4 wt% bentonite, 2.15 wt% bitumen, and 0.015 wt% sodium chloride.

Figure 3 eGCP prototype

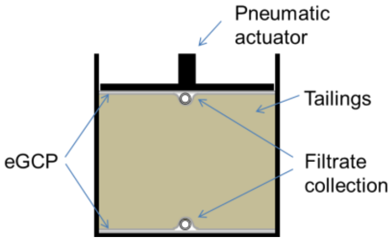

Figure 4 Dewatering device

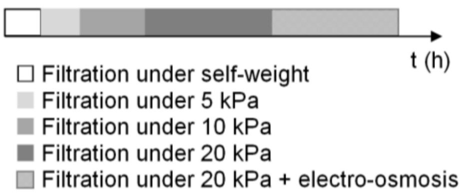

Figure 5 Dewatering timeline with eGCP

Laboratory Scale Dewatering Device

A 20-L laboratory scale dewatering device has been developed to simulate the entire path of water taking place in real FFT disposal, i.e. under self-weight consolidation, electro-osmosis, and drainage (Bourgès-Gastaud et al., 2014). Two eGCPs acting respectively as an anode and a cathode are positioned horizontally on each side of the tailings (Figure 4). The test cell dimensions were selected to allow evaluating a representative area of the eGCP and taking into account the large strain deformation of the tailings: the internal width and depth are 270 x 270 mm and the initial distance between the upper and lower eGCPs is 260 mm. Normal stresses of up to 60 kPa can be applied to the tailings by a system of pneumatic actuator and metal loading plate to simulate self-weight consolidation and consolidation under the weight of the overlying fill. The filtrate is continuously discharged by gravity in the case of the lower eGCP while it is extracted from the upper eGCP using a Venturi vacuum pump. This device allows recording the amount of water expulsed individually by the two eGCPs as well as the height of MFT as a function of time, normal stress and voltage applied between the two eGCPs (Figure 4).

Figure 5 illustrates the sequence of steps conducted to simulate a typical dewatering scenario that would take place in a real FFT disposal area. The first step involves filtration under self-weight exerted by the amount of tailings in the test cell. During that phase, only the lower eGCP is installed and its drainage pipe constitutes the sole outlet for the filtrate. The second phase of the dewatering process involves applying incremental normal stresses of 5, 10, and 20 kPa to the MFT/eGCPs system to simulate the effect of overlaying layers as the pond is progressively filled. The value of 20 kPa corresponds roughly to the stress applied by a 1.5 m-thick layer of MFT. Both eGCPs are active during that phase. In the last step, the normal stress is maintained at 20 kPa and a voltage is applied between the electrically conductive components of the upper and lower eGCPs. Each step is terminated when the filtrate expulsion has reached 60% of its asymptotic value.

Small Scale Electro-Osmosis Dewatering Cell

A small scale, 4.5 L dewatering cell was also developed for investigating solely the electro-osmosis phase of the eGCP dewatering treatment. It consists in a 15 x 17 x 75 cm cell with a perforated base for drainage suspended over a 200 mL graduated cylinder (Figure 6). The geotextile is placed over the perforated base of the cell with a strip of electrode material acting as a cathode positioned on top of it. The anode is floated over the tailings using a polystyrene block loaded with a stainless steel plate, which applies a normal stress of 4.6 kPa on the MFT to ensure that the contact is maintained throughout the experiment. The amount of extracted filtrate and the height of MFT are recorded as a function of time.

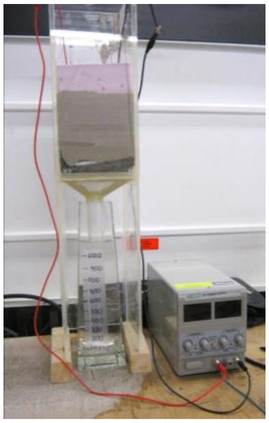

Figure 6 Electro-Osmosis Cell

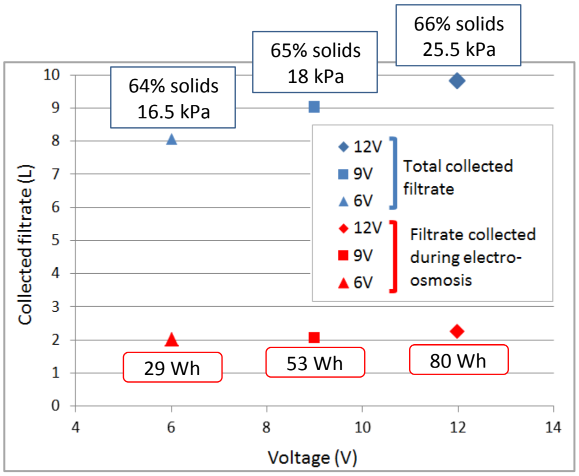

Figure 7 Effect of voltage with laboratory scale dewatering device

RESULTS AND DISCUSSION

Effect of Voltage

Experiments were conducted using the laboratory scale dewatering device with three different voltages selected for the electro-osmosis step: 6, 9 and 12 V. The cathode was situated at the lower eGCP. The total duration of the experiment was similar for the three conditions, around 550 h. As shown in Figure 7, an increase in the total amount of collected filtrate is observed with increasing voltage. When only the electro-osmosis phase is considered, the increase in extracted water is still visible but with a much smaller extent. The larger effect observed with the total filtrate amount is thus attributed to the variability in the initial self-weight and normal stress consolidation steps of the dewatering treatment. The values of solids content, final shear strength of the MFT, and power consumed are also displayed in Figure 7; an increase at higher voltage is obtained as well.

The effect of voltage was also investigated using the small scale electro-osmosis dewatering cell. Five voltages were selected between 2 and 12 V. Both the collected filtrate volume and the consumed power per volume of collected filtrate increase with voltage (Figure 8). However, the collected filtrate appears to reach a maximum above 9 V while the increase in consumed power per volume of collected filtrate seems to be exponential.

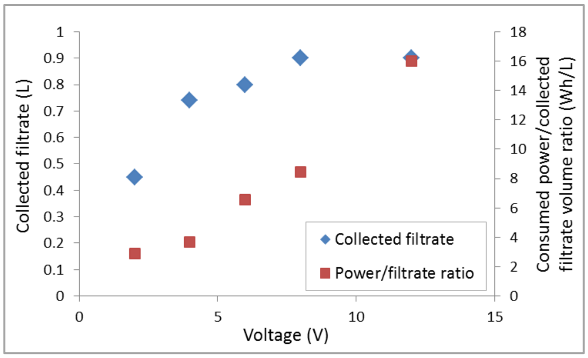

Figure 8 Variation of collected filtrate and consumed power/filtrate volume ratio as a function of voltage (small scale electro-osmosis dewatering cell)

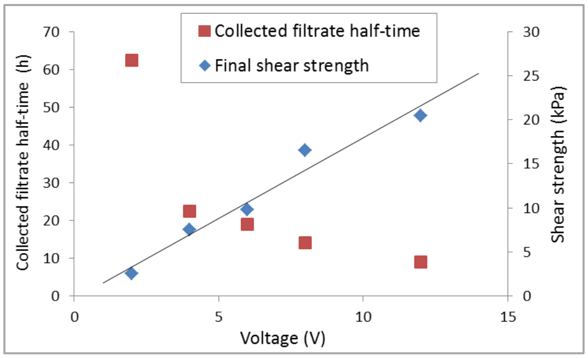

Figure 9 Variation of final MFT shear strength and collected filtrate half-time as a function of voltage (small scale electro-osmosis dewatering cell)

As shown in Figure 9, the collected filtrate half-time, defined at the time to reach half of the maximum value of collected filtrate, decreases when the voltage is increased; the drop is rapid for the lower values of voltage then slows down above 4 V. An optimal choice of voltage can thus be made to maximise the volume of collected filtrate while minimising the treatment time and consumed power per volume of collected filtrate. Finally, the results in terms of final MFT shear strength are also displayed in Figure 9. They show a linear increasing trend with voltage. No sign of a lower voltage threshold for MFT dewatering efficiency with eGCPs is thus recorded at least until 11 V/m.

Effect of Current

The same type of experiments was conducted in a current-controlled mode. Three values of current were selected for the laboratory scale dewatering device experiments: 15, 30 and 45 mA. The cathode was situated at the lower eGCP. The total duration of the experiment was similar for 30 and 45 mA, around 550 h. It was much longer at 15 mA, with a total of 840 h. This can be attributed to the electro-osmosis phase duration which increased from 220 h at 30 and 45 mA to 460 h at 15 mA. In terms of collected filtrate, a steady decrease is observed as the current is decreased (Figure 10). It is accompanied with a reduction in solids content in the final MFT, as well as a drop in MFT final shear strength, from a mean value of 41.4 kPa at 45 mA to less than 10 kPa at 15 mA. On the other hand, the reduction in current also led to a very strong decrease in consumed power, from more than 150 Wh at 45 mA to less than 40 Wh at 15 mA. For the MFT and eGCPs used for these experiments, the value of 30 mA thus appears to allow reaching a good degree of dewatering while maintaining the consumed power and treatment duration at a reasonable level.

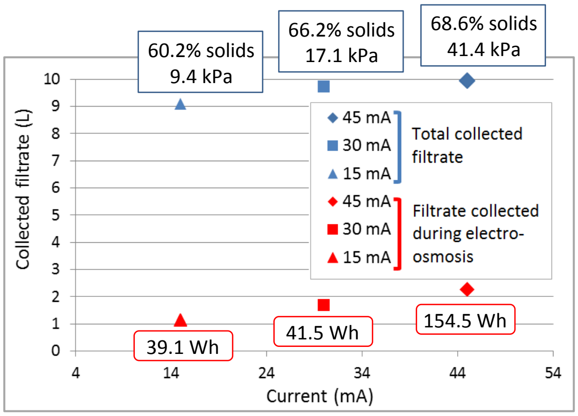

Figure 10 Effect of current with laboratory scale dewatering device

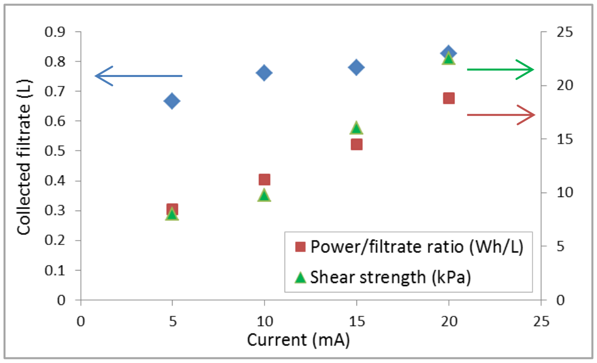

Figure 11 Effect of current with small scale electro-osmosis dewatering cell

Experiments were also carried out using the small scale electro-osmosis dewatering cell. Four values of current were selected between 5 and 20 mA. As illustrated in Figure 11, the volume of collected filtrate increases with the current, as well as the consumed power per volume of collected filtrate and the final MFT shear strength.

Comparison of Voltage- and Current-Controlled Modes

A comparison of the MFT dewatering efficiency was made between the voltage- and current-controlled modes using the small scale electro-osmosis dewatering cell. The voltage-controlled experiments were conducted at 2, 4, 6, 8 and 12 V while the current-controlled ones used 5, 10, 15 and 20 mA. Figure 12 shows the variation of the consumed power as a function of the total collected filtrate for the voltage- and current-controlled experiments. It can be observed that for the same consumed power, a larger amount of filtrate is extracted from the MFT with the voltage-controlled mode than with the current-controlled one. The voltage-controlled mode also leads to a higher filtrate flow rate (Figure 13). This indicates that the MFT dewatering efficiency of voltage-controlled electro-osmosis by eGCPs is higher compared to the current-controlled mode.

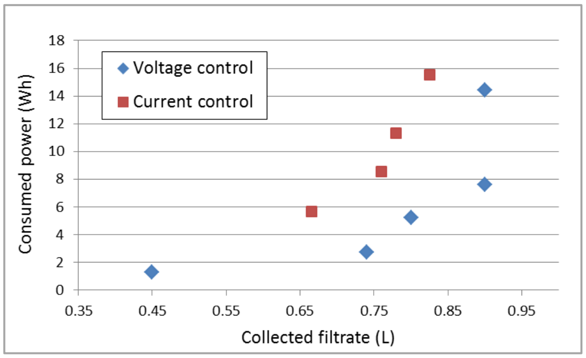

Figure 12 Variation of consumed power as a function of collected filtrate for voltage- and current-controlled modes (small scale electro-osmosis dewatering cell)

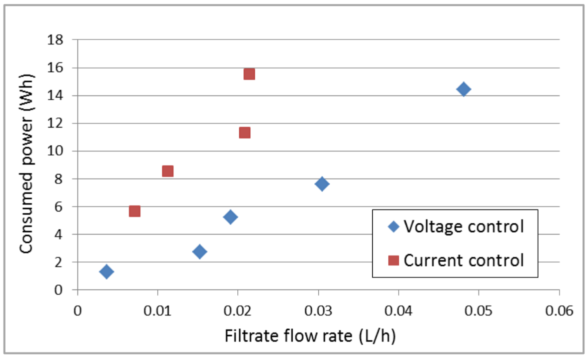

Figure 13 Variation of consumed power with filtrate flow rate for voltage- and current-controlled modes (small scale electro-osmosis dewatering cell)

Effect of Electrode Position

Two experiments have been carried out with the laboratory scale dewatering device by reversing the position of the cathode and the anode. The duration and amount of collected filtrate for the electro-osmosis step are markedly different for the two experiments: 197 h and 2.25 L with the cathode on the bottom, and 146 h and 1.47 L with the cathode on the top. A difference is also recorded for the final MFT solids content and shear strength, with respectively 66% and a mean value of 25.5 kPa with the cathode on the bottom, and 62% and 11.9 kPa with the cathode on the top. The corresponding values for the power consumed are respectively 80 and 45 Wh. However, when the consumed power is divided by the amount of filtrate collected during the electro-osmosis step, similar values are obtained with 35.6 Wh/L for the experiment with the cathode on the bottom, and 30.5 Wh/L with the cathode on the top. This indicates that the position of the electrode influences the amount of water that can be extracted by electro-osmosis with eGCPs but not the power it takes to extract that water.

Effect of Intermittent Powering

The effect of intermittent powering of the electrodes on the MFT dewatering efficiency by eGCPs was studied with the small scale electro-osmosis dewatering cell. The power was turned off during 5 minutes every hour for the first six hours of the experiments (Figure 14). Table 1 provides the results for the two experiments conducted with intermittent powering as well as those for three experiments carried out in the same conditions except for the intermittent powering.

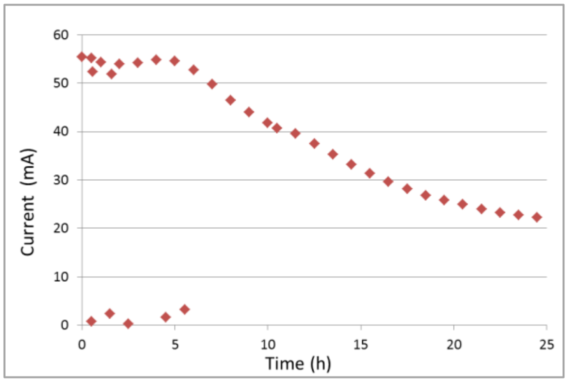

Figure 14 Variation of current as a function of time for an intermittent powering experiment (small scale electro-osmosis dewatering cell)

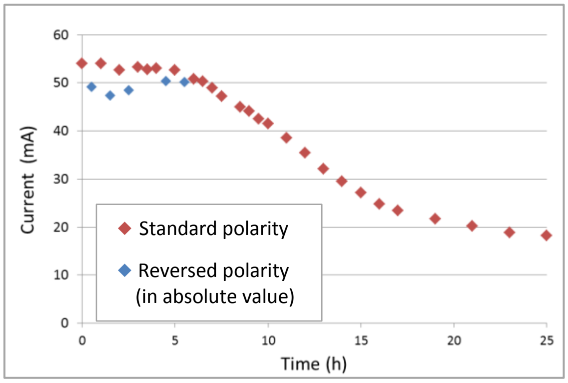

Figure 15 Variation of current as a function of time for a dynamic polarity reversal experiment (small scale electro-osmosis dewatering cell)

The data in Table 1 show that intermittent powering, even if only applied for part of the electro-osmosis treatment, reduced by almost 40% the dewatering time. However, in the experiments that were carried out, there was also a reduction in the final MFT solids content, which translated into a 50% drop in the final MFT shear strength. A reduction in consumed power was noted as well. This preliminary work on intermittent powering shows that this solution may offer an interesting potential for MFT dewatering by eGCPs, but it will need to be further refined to be fully beneficial.

Effect of Dynamic Polarity Reversal

Experiments were also conducted with the small scale electro-osmosis dewatering cell to study the effect of dynamic polarity reversal on the MFT dewatering efficiency by eGCPs. As illustrated in Figure 15, the polarity of the electrodes was reversed during 5 minutes every hour for the first six hours of the experiment. It must be noted that no filtrate was collected from the top of the cell, including when the polarity was reversed and the cathode was positioned at the top of the cell.

The results of the experiment conducted with dynamic polarity reversal can be compared in Table 1 with those provided from standard experiments, i.e. with continuous powering. A reduction in dewatering time is obtained as well as in consumed power. On the other hand, the final MFT solids content and shear strength is also reduced. As for the effect of intermittent powering, this strategy will gain in being further explored.

Table 1 Results for experiments with intermittent activation, dynamic polarity reversal, and standard continuous powering of the electrodes (small scale electro-osmosis dewatering cell)

	Intermittent powering		**Dynamic polarity reversal**	**Standard continuous powering**		
Time to reach 80% of the total collected filtrate (h)	12	10.5	12	18	18	17
Mean final MFT solids content (%)	65.7	65.2	65.7	67.0	66.6	67.1
Mean shear strength (kPa)	14.5	12.0	14.0	28.4	28.7	23.0
Consumed power (Wh)	11.7	7.5	10.5	12.2	12.7	13.1

CONCLUSION

This study has investigated the effect of electrical conditions of the electro-osmosis treatment on the efficiency of MFT dewatering by eGCPs. The eGCPs combine a three-layer polyester nonwoven geotextile, a drainage pipe, and a tin-platted copper braid electrode. They are positioned horizontally on each side of the volume of MFT to dewater. A synthetic MFT formulation was used for the study: it includes water, kaolinite, bentonite, bitumen, and sodium chloride. The experiments were conducted with a laboratory scale dewatering device developed to simulate the entire path of water taking place as a result of self-weight consolidation, electro-osmosis and drainage, as well as with a small scale electro-osmosis dewatering cell.

An increase in collected filtrate volume, final MFT solids content and shear strength, and power consumed is recorded with increased voltage, while the dewatering time is reduced. The collected filtrate appears to reach a maximum at high voltage while the increase in consumed power per volume of collected filtrate appears to be exponential. An optimal choice of voltage can thus be made to maximise the volume of collected filtrate while minimising the treatment time and consumed power per volume of collected filtrate. On the other hand, the final MFT shear strength is proportional to the voltage. No lower voltage threshold thus appears to exist for MFT dewatering with eGCPs.

A similar behavior was obtained in the current-controlled mode, with the collected filtrate volume, final MFT solids content and shear strength, and consumed power per volume of collected filtrate increasing with increased current. However, a comparison of the voltage- and current- controlled modes reveals that, for the same power consumed, a larger amount of collected filtrate and a higher filtrate flow rate are obtained with the voltage-controlled mode. More efficient MFT dewatering by eGCPs thus appears to be obtained with voltage-controlled electro-osmosis.

An analysis of the effect of the electrode position indicates that less water is extracted from MFT by eGCPs when the cathode is situated above the anode, even if the consumed power per volume of collected filtrate is not affected. Finally, preliminary investigations of the effect of intermittent powering and dynamic polarity reversal of the electrodes on the MFT dewatering efficiency by eGCPs show that the reduction in dewatering time and power consumed obtained appears to be accompanied by a decrease in the final MFT solids content and shear strength.

These results obtained with a synthetic MFT formulation provide an initial basis for the design of eGCP treatments for tailings dewatering. The behaviors observed will have to be confirmed/refined with MFT samples collected on mining sites.

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