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Dewatering of oil sands tailings with an electrokinetic geocomposite

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ABSTRACT

The oil sands industry generates large quantities of mineral waste, such as fluid fine tailings (FFT), whose disposal is often challenging. The use of planar electrokinetic geocomposites (eGCPs) in FFT disposal areas could improve in-situ dewatering by allowing water to drain after it is expulsed during consolidation and by permitting the use of electro-osmosis (EO) to displace a significant portion of the remaining water. Four dewatering experiments involving mature fine tailings (MFT) are presented here: in three of them increasing normal stresses are applied on the MFT followed by EO; in the fourth test, EO is applied before the normal stress is increased. The results show that eGCPs adequately filter MFT; the particles did not clog or blind the filter. MFT were significantly dewatered under an applied normal stress followed by EO. EO was very efficient at extracting the more tightly bound water that remained after mechanical dewatering. In one configuration, a significant improvement of the shear strength from nearly 0 kPa to a mean value of 25 kPa was obtained, which is significantly higher than the 10 kPa required by Alberta regulations. The final solids content in that case was about 70%, starting from an initial solids content of 45%. The energy required for that test was 10.6 kW h per dry tonne.

1. Introduction

Alberta, Canada, holds the largest concentration of oil sands in the world. Despite the recent drop in oil price, production of crude oil from oil sands is expected to increase from about 2.3 million barrels per day in 2014 to 3.5–4 million barrels per day in 2025 (Alberta Oil Sands Industry, 2015). To limit the environmental impact of oil sands mining, the Energy Resources Conservation Board (ERCB) of Alberta issued Directive 074 on tailings management in 2009, requiring mining companies to reduce fluid tailings by capturing fine tailings (ERCB, 2009). These fine tailings must also be processed so that materials deposited the previous year reach a minimum undrained shear strength of 5 kPa the year of deposition and 10 kPa within five years after active deposition has stopped. It is to be noted that this Directive was suspended on March 13, 2015, in part because available technologies did not allow mining companies to reach the requirements (Beier et al., 2012). However, it still appears relevant as a target for the development of oil sands tailings dewatering strategies.

The production of 1 tonne of synthetic crude oil with the Clark hot water extraction process requires mining 12.3 tons of oil sands and uses 9.7 tons of water (Allen, 2008). The waste from this process is 15.6 tons of tailings with an average composition of 70–80% water, 20–30% sand, silt, and clay, and 1–3% residual bitumen. These tailings are typically stored in tailings ponds retained by perimeter dykes constructed from the relatively coarser fraction of tailings. After deposition, the coarser particles such as sand segregate from the finer particles to form beaches. The finer particles (clay and silt) flow toward the center of tailings ponds to form "fluid fine tailings" (FFT) (Masala, 1998). Further consolidation of the FFT takes place under self-weight and under the weight of the overlying fill. However, the fine particles are held in suspension by electrostatic interactions; they have very low consolidation rates and reach a maximum solids content of about 30 wt% solid after several years, at which point they are called "mature fine tailings" (MFT) (Jeeravipoolvarn, 2010; Mikula et al., 1996).

FFT/MFT are problematic because their high clay content and water content result in a low shear strength, which limits pond rehabilitation (Mamer, 2010). Their very long drying time also leads to very high fresh-water consumption, because water stored in the ponds cannot be reused in the mining process (Junqueira et al., 2011). Although 85% of the water used in the oil sands mining, extraction, and upgrading operations is recycled, 1.7 tons of water remain bound in FFT for every tonne of synthetic crude oil produced. The tailings ponds in which FFT and MFT are stored also represent a significant environmental risk due to the potential for leaks, failure, and the migration of contaminants (Frank et al., 2014).

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Dewatering FFT is therefore essential to rehabilitating tailings ponds, limiting the risk of failure, as well as reducing tailings ponds footprint and fresh water consumption (Farkish and Fall, 2013). It is currently the object of large efforts from oil companies, for example with the Canada's Oil Sands Innovation Alliance (COSIA) initiative, as well as from a number of research groups throughout the world, so that next-generation strategies are developed for practical, economical, and environmentally responsible disposal of tailings (Fair, 2014).

Two approaches are currently envisioned to dewater FFT: predeposit treatment with a continuous dewatering system able to dewater huge volumes of tailings or postdeposit dewatering using physical processes after deposition.

Predeposit dewatering techniques include recombination strategies leading to consolidated and non-segregating tailings (Simieritsch et al., 2009) as well as the separate management of coarse and fine tailings using thickening (Chalaturnyk et al., 2002), centrifuging (Houlihan, 2009), filtering (BGC Engineering, 2010), and super absorbent polymers (Farkish and Fall, 2013) for instance. Such processes generally require large modifications of the bitumen recovery operations. For example, tailings centrifuging or blending with dry clay are favored solutions because of the high solids content obtained directly out of the separation plant (Devenny, 2009). However, this solids content is too high to allow hydraulic transport of the tailings and requires stacking conveyors or trucking, which increases the cost of filling tailings ponds compared to the conventional mining method (Devenny, 2010). In addition, these pretreatments involve the use of chemicals (flocculants, coagulants) or dewatering units (filter belt, filter press, centrifuge, etc.), which adds to the cost.

By comparison, the postdeposit treatment strategy allows preserving the conventional operations (hydraulic transport, use of tailings sand for dike construction, etc.). For instance, the use of vertical "wick" drains has been tested in the field to dewater and consolidate oil sands fine tailings capped by a coke layer (Wells and Caldwell, 2009). Even though the technique appears as very promising, mixed results were obtained as a result of the test: no significant flow was recorded either from the shallowest or the deepest drain. Only the middle one produced a reasonable amount of liquid, about 6 L/h, over the 500 h of the test. In addition, it is expected that flow rates will gradually decrease as water is drained and the hydraulic conductivity of the tailings around the wick drains lowers.

A new avenue proposed consists in laying electrokinetic geocomposites (eGCPs), which combine a planar drainage geocomposite and a metal electrode, in the FFT disposal area during filling. Tailings are dewatered by the following two mechanisms:

1. Filtration from classical drainage geocomposites and in-plane water transport. This mechanism involves separating water from soil particles with a geotextile filter, and removing water via the drain tubes (Koerner, 1997). Drainage geocomposites have already demonstrated their efficiency for liquid collection in geotechnical engineering and environmental applications such as landfills, roadway embankments, and earth dams (Arab et al., 2009; Bordier and Zimmer, 2000). Constructing FFT disposal ponds with layers of eGCPs creates horizontal drainage paths and allows water to be removed (Faure et al., 1993).
2. Electro-osmosis (EO) induced across the FFT layer by the application of a voltage via conductive elements embedded in the eGCPs. This leads to the migration of water from the anode to the cathode (Fourie and Jones, 2010; Jones et al., 2008). This technique has been used in remediation projects involving the extraction of contaminants like heavy metals, radionuclides, and some organic compounds from soils and slurries in industrial environments (Acar et al., 1995). The application of this concept has also been proposed for geosynthetic structures (Jones et al., 2008; Pugh and Jones, 2006): sewage sludge dewatering, conditioning and composting; material and soil consolidation, strengthening and reinforcement; stabilization of slopes, cuttings and embankments; reduction of soil liquefaction; moisture control in sports turf; and bioremediation of contaminated sites.

The objective of this paper is to evaluate the efficiency of an eGCP prototype for dewatering FFT. For this study, a new laboratory device developed by Bourgès-Gastaud et al. (2015) was used. It combines EO and the application of normal stress to simulate the different consolidation phases during the filling of a FFT disposal area. To explore the relative importance of each phase, four tests were conducted, with each one having a different duration for each phase. The tests were conducted using MFT obtained from Muskeg River, Alberta. They were characterized by thermogravimetric analysis, energy-dispersive X-ray spectroscopy, and X-ray diffraction.

2. Materials and method

2.1. eGCP prototypes

The dewatering experiments were carried out with eGCP prototypes combining filtration and drainage media and an electrode.

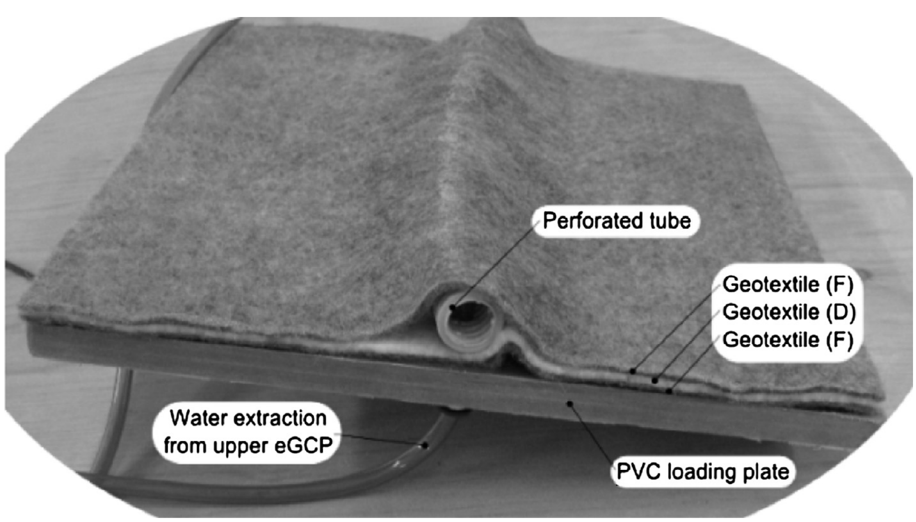

Fig. 1. Photograph of an eGCP on a PVC loading plate. The eGCP is made of three geotextiles that serve as filters (F) and drainage layer (D).