Dewatering and Consolidation Behavior of Oil Sands Tailings

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Introduction

Canada's oil sands are the third-largest crude oil reserve in the world (Shahandeh, 2018). It is a naturally occurring mixture of sand, water, particular minerals, and bitumen (Elias, 2019). Bitumen can be extracted by either of two methods; 1) In-situ oil sands mining recovers bitumen greater than 75 meters underground, while 2) surface mining recovers bitumen that is relatively close to the surface. The process used depends on how deep the deposits are below the ground. This literature review will focus on the ramifications associated with the latter technique. More specifically, the waste byproduct is known as Fine Fluid Tailings (FFT).

How Surface Mining Creates FFT

FFT's formation is due to the several steps involved in surface mining. Initially, the deposit becomes processed in the ore preparation plant once being extracted out of the mine. A vital function it performs is slurring and aeration; By adding warm water and vigorously mixing the slurry mixture to entrain air bubbles, it accomplishes this task (Beier, 2015). The mixture then travels to the extraction plant, via pipeline, where sodium hydroxide (dispersant) goes into the solution to recover the bitumen. This permits the ore's segregation through a gravity-separation process as the bitumen attaches to liberated air bubbles and accumulates at the surface of the vessel. The residue that remains—coarse sand, fines, process water, dispersant—is a tailings stream (Beier, 2015). Operators divert the tailings into a storage facility known as a tailings pond. After the tailings are pumped into the pond, the coarse sand settles. This action has the potential of capturing 30% or more of the fines within the voids of the coarse tailings stream. The remaining fines are suspended in the tailings ponds and form a sludge-like substance termed FFT.

FFT is a mixture of silt, clay, water, dispersant, and residual bitumen. Given that the fines are less than 45 µm in diameter, the FFT ends up with challenging characteristics (Beier, 2015). It is important to remember, however, that oil sand tailings are not a consistent product. Its properties may vary over a wide spectrum, which is entirely dependent on the variations in ore from the mine and the numerous operations within the Extraction Plant (Sobkowicz and Morgenstern, 2009). Nevertheless, they all share the qualities of having low density and high water content (Beier, 2015). This can ultimately generate several challenges.

Challenges of FFT

There are unique aspects of oil sands tailings that challenge operators in their handling, transport, treatment, and disposal of FFT (Sobkowicz and Morgenstern, 2009). For instance, it contains a residual amount of bitumen, which impacts tailings' characteristics due to being viscous and extremely adhesive. Additionally, another concern is the large volumes of water trapped by the fine solids. This will create the FFT to have high moisture content inevitably and low saturated hydraulic conductivity, which would thereby decrease consolidation rates and strength gain (Morgenstern and Scott, 1995). However, there is one significant issue that trumps all others: Tailings are being produced at huge volumes (as of the end of 2018, there are 1.3 billion cubic meters of fluid fine tailings (AER 2018)). This matter is fortunately recognized and has developed a keen interest in the oil sands industry on how to reclaim tailings into a stable landform. In this way, it can help to restore the land previously used in the mining process. Although in order to attain this objective, there must be an increase in the strength of FFT.

Dewatering Treatments

Due to the extremely slow consolidation and settlement of FFT, the containment of tailings poses a great liability for the oil sands industry. In order to increase the shear strength, density, and decrease the moisture content of the FFT, it is necessary to remove water. Climatic and geological considerations are both important factors that can impact dewatering requirements, but there are several strategies or technologies that may dewater tailings through chemical, mechanical and environmental means.

A tailings centrifuge unit in at Albian's Jackpine Mine.
(https://cosia.ca/initiatives/tailings/projects/tailings-centrifugation)

Since oil sands mining operations started in 1967, 1.3 trillion litres of fluid tailings has accumulated in tailings pond.
(https://www.ctvnews.ca/business/shell-s-jackpine-mine-gets-nod-from-ottawa-despite-environmental-effects-1.1578783)

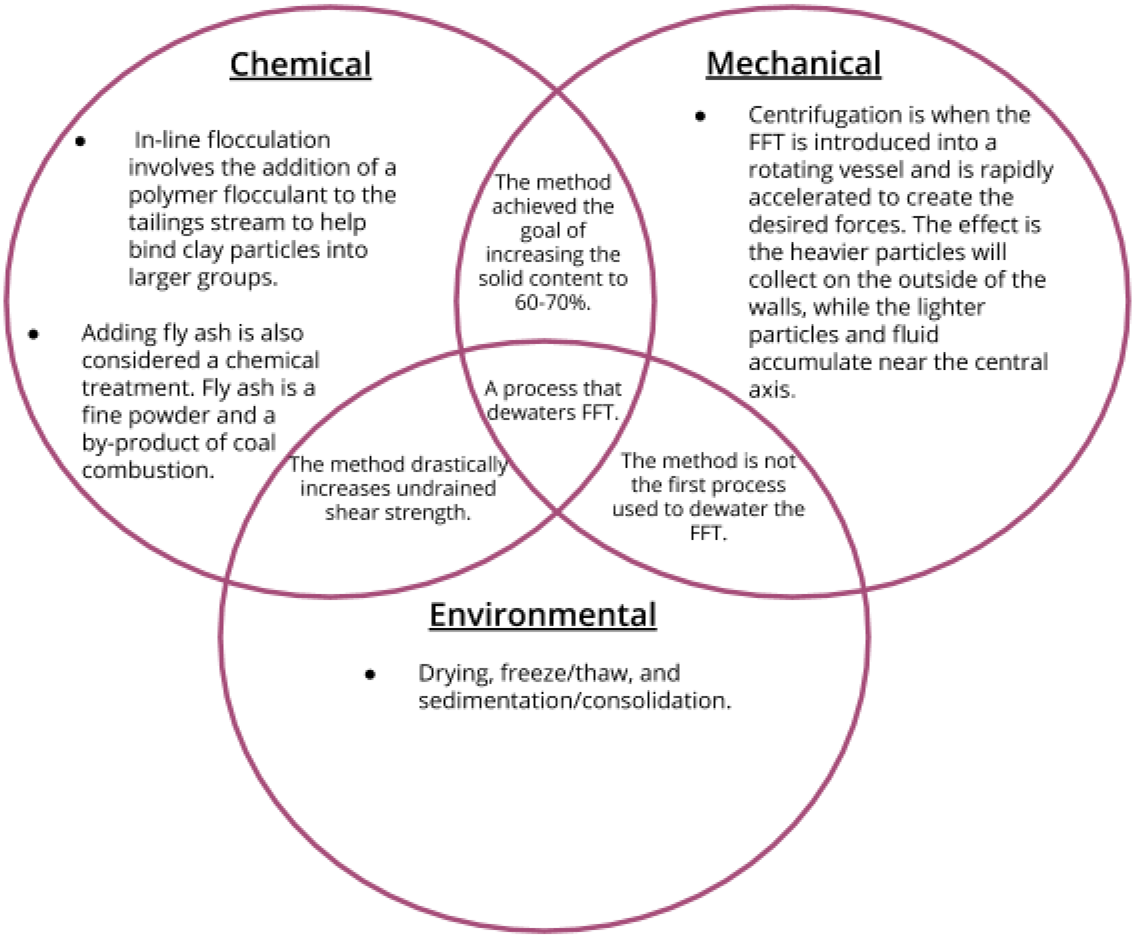

Figure 1 A venn diagram that compares and contrasts different dewatering technologies.

Data Analysis of FFT Consolidation Behavior of FTT

The consolidation behaviour of oil sands tailings can be quantified using large strain consolidation (LSC) experiments. Each of these tests include variable quantities that describe the changes that occur within a sample of FFT as water is being removed. These include 1) undrained shear strength, which is the ability of a material to resist shear forces until failure. 2) effective vertical stress, which is the total weight of the soil up to the surface divided by surface area. 3) total void ratio, which describes the volume of the pores between the solid particles that contain both the volume of water and the volume of gas.

Table 1 summarizes the datasets that were utilized in this study to assess shear strength behaviour in different treated oil sands tailings.

Figure 2 illustrates a positive slope of normalized shear strength as a function of the void ratio. This suggests that the peak strength of all the materials is dominated by non-frictional effects. Figure 3, on the other hand, shows a negative slope of normalized shear strength as a function of the void ratio. This means a dominating frictional effect on soil shear strength. Furthermore, Figure 4 demonstrates the variation in FFT compressibility for the tailings specimens considered in this study.

Table 1 Summary of datasets analyzed in the current study (data from Wilson et al. 2018)

Material	**Treatment Description**	**Peak strength dominated by**
Treated FFT	Polymer amended (flocculated FFT)	Frictional effects
TT1	Aged FFT thickened and treated with 2% fly ash	
TT4	Flocculated and thickened tailings	
Untreated FFT	FFT that has no treatment	Non-frictional effects
TT2	Flocculated and thickened; tailings with freeze-thaw effects.	
TT3	Twice flocculated, thickened and freeze-thaw effects.	
TT5	Aged FFT with freeze-thaw effects	
TT6	TT5 treated with 3% fly ash	
TT7	TT6 with freeze-thaw effects	

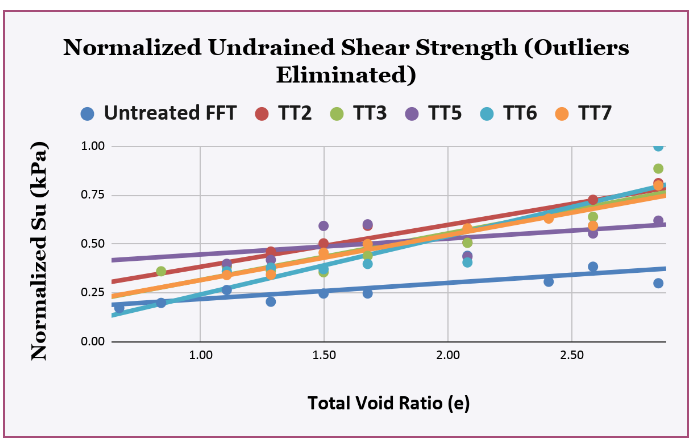

Figure 2 Undrained shear strength versus void ratio for non-friction dominated strength.

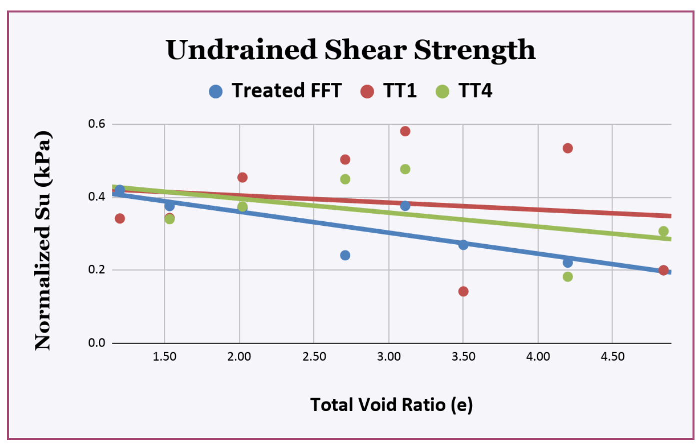

Figure 3 Undrained shear strength versus void ratio for friction dominated strength.

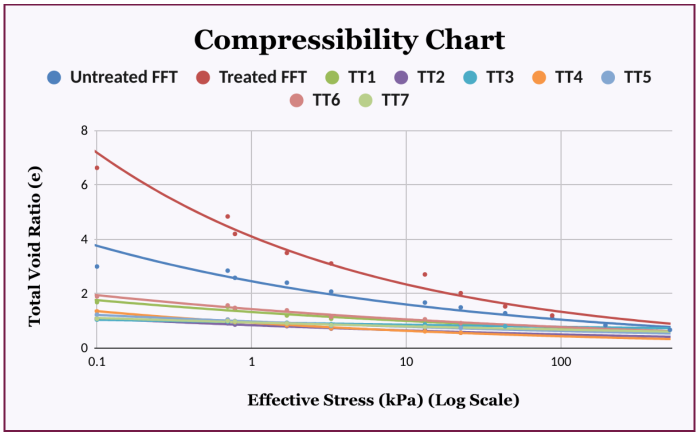

Figure 4 Void ratio versus effective stress for compressibility.

Conclusions

Surface mining produces valuable resources necessary for everyday life. However, it can have a detrimental impact on the environment if the waste is not properly managed. In this study, an assessment of various dewatering methods for the management of oil sands tailings is presented. The aim of dewatering is to lower the moisture content of the FFT and increase strength in order to reclaim the waste into a trafficable landscape. This study also analyzed nine FFT consolidation dataset to understand the dominating effects on the undrained shear strength. Two types of effects were observed namely, frictional and non-frictional effects. Understanding this allows us to determine which treatment is more suitable for a given reclamation scenario.

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