Environmental Assistance for Tailings Disposal

Boswell, J.E.S. & Sobkowicz, J.C.
Thurber Engineering, Calgary, AB, Canada

ABSTRACT
Traditional dewatering methods for Oil Sands tailings such as thickening, flocculation and centrifugation employed to reduce water content and improve consolidation fall short of final requirements for tailings reclamation, especially in the treatment of tailings fines. Some environmental assistance is needed to achieve the additional dewatering required, and to reach target solids contents and shear strengths for the tailings deposit. The paper outlines some key environmental methods and offers a perspective on their use.

RÉSUMÉ
Les méthodes traditionnelles d'assèchement des stériles provenant des opérations minières des sables bitumineux incluent la densification, la floculation et la centrifugation. Ces méthodes sont axées sur la réduction de la teneur en eau et l'amélioration de l'état de consolidation des stériles, et ne sont pas suffisants pour rencontrer les critères finals de réclamation des stériles, particulièrement en ce qui concerne le traitement des stériles à particules fines. Un support environnemental est nécessaire pour atteindre le niveau d'assèchement requis, ainsi que la concentration des solides et la résistance au cisaillement des dépôts des stériles désirées. Cet article souligne quelques méthodes environnementales clés et présente une perspective sur leur application.

1 INTRODUCTION

Development in tailings management over the past twenty years has demonstrated the pivotal importance of increasing solids content and reducing water content prior to deposition. This development has been accelerated in recent times by the imperative of sustainability, manifested in the demand for early reclamation of tailings deposits, the focus on reduction of water footprint and the drive to reduce land take.

Traditional dewatering methods such as thickening, flocculation and centrifugation employed to reduce water content and improve consolidation behaviour, have at times fallen somewhat short of final requirements, especially in the treatment of tailings fines.

Instead, an extended role has been found necessary, for the continued and optimal use of environmental methods especially in improving dewatering of tailings deposits. The significant point is that some environmental assistance is needed to achieve the additional dewatering required, and to reach target solids contents and shear strengths for the tailings deposit.

Environmental methods in this context are understood to include solar evaporation (sun-drying), evaporative desiccation (in a low relative humidity context, often in the absence of sunlight), freeze-thaw, biological treatment and other methods unique to certain tailings.

In this paper the authors describe salient environmental techniques and explore the benefits which they may offer for the management of tailings. They also attempt to quantify the improvement required in target solids contents and shear strengths for certain Oil Sands tailings materials.

2 ENVIRONMENTAL METHODS OF DEWATERING OIL SANDS TAILINGS

2.1 Solar Evaporation

Arid or semi-arid climates are clearly better suited to solar evaporation. Fort McMurray, Alberta has a climatic water deficit, but not as much as the typically South African, Australian, south-western USA or Chilean climates. For most mining areas in South Africa and Australia, annual evaporation exceeds annual precipitation at least threefold. In the typical Canadian winter there is not much potential for sun-drying, for extended periods.

Evaporative drying, freeze-thaw or other desiccative processes are also a function of many environmental factors including:

- Atmospheric humidity
- Wind
- Salt concentration in the pore fluid
- Capillary barrier effects

These factors have a strong influence on tailings desiccation processes.

The benefits of deposition onto a well drained drainage layer should not be overlooked. This has the effect of accelerating the consolidation up to four times, compared to a saturated or completely non-draining foundation. In addition, in cold climates, the drainage could potentially continue throughout the year, and not be hindered by the vagaries of ground freezing and reduced sun-drying.

In his latest book, Blight (2010) provides good background in understanding, estimating and measuring evaporation and evapotranspiration from tailings and waste facilities. He also shows from actual measurements the depth to which evaporation may vary seasonally (up to 16m), and compares evaporation from a wet or dry tailings beach.

Simms et al. (2010) report on the results of simulations which shows the influences of layer thickness, moisture content of underlying layers, capillary breaks and salt crusting on the gravimetric water content over time.

Boswell (1990) found evidence in gold tailings of beneficial desiccation resulting from deposition over free draining dolomitic geology even once the depth of deposit was over 40 metres.

The benefits of drainage are often overlooked in favour of solar evaporation. This is a recurring theme in tailings management; Wilson (2010).

2.2 Evaporative Desiccation

A distinction should be made between actual sun-drying and evaporative drying in a low relative humidity environment. While usually more limited in extent, evaporative drying can also take place off a frozen surface in circumstances of low relative humidity.

The key requirement in this case is not solar radiation per se, but the existence of a differential in relative humidity, between the surface of the deposit, and the ambient air environment.

The influence of wind and air movement can be dramatic, in that water molecules are moved quickly away from the desiccating surface, thus allowing more water molecules to escape from the surface and thus advance desiccation more rapidly. This has been observed both at lab scale Mikula (2009), Moore (2010) and in the field Boswell (1987), in the last mentioned case even under circumstances of substantial pore water salinity.

2.3 Freeze Thaw

Beier (2009) in a good summary of research work performed by Dawson, Johnson and others on freeze thaw of Oil Sands tailings and MFT in particular, reported the following:

Freeze-thaw dewatering of MFT is affected by:

a. Initial solid contents

Freeze-thaw is sensitive to the initial solids content as demonstrated by the exponential relationship between initial solids content and the increase in solids content observed by Johnson et al. (1993). Multi-cycle freeze-thaw test performed by Dawson et al. (1999) indicated that freeze-thaw becomes less effective in dewatering as the initial frozen solids content increases (28% increased to 34%, while 43% only to 45%).

b. Layer thickness and temperature boundary conditions

Dawson et al. (1999) indicated for tests on Syncrude MFT that thin layer freezing of MFT resulted in higher thawed solids contents under different boundary conditions. As freezing rates reduced, the thawed settled solids content increased.

2.4 Biological Methods

Sobkowicz (2009) makes reference to the potential for using plants to extract soil moisture from the upper layers of a tailings deposit.

Deeper rooted plants, shrubs and trees hold potential to increase the depth to which the phreatic surface may be depressed. The ability of certain tree and plant species to contribute substantially to soil desiccation is well reported especially in literature in agriculture and irrigation, and is not expanded on in more detail here.

Blight (personal communication) reported the depression of a local water table in a natural soil profile by as much as 40 metres in Vereeniging South Africa, through the desiccation by tree roots from a blue gum plantation over a period of 40 years prior to deforestation in 1980. Subsequent rewetting of the soil profile generated soil heave at the then hitherto unprecedented depths of up to 20 metres in depth.

This environmental method certainly deserves and is likely to enjoy further attention in the years to come in the development of Oil Sands tailings reclamation.

3 GEOTECHNICAL PERSPECTIVE ON DEWATERING TAILINGS

3.1 Introduction

The primary objective in treating the tailings is to remove water and increase solids content, to the point where acceptable geotechnical properties are achieved for efficient capping, reclamation and closure. This implies meeting both strength and long term stiffness targets.

This section addresses two issues (from a geotechnical perspective):

- What are desirable “end-points”, in terms of solids content and strength, for various tailings products.
- What improvements in strength can be obtained by environmental effects during thin-lift deposition.

Typically, oil sand tailings products undergo at least three stages of de-watering to meet reclamation and closure objectives. These are discussed, along with the associated geotechnical science, in the following sub-sections.

3.2 Stage 1 Dewatering (Classification)

Oil sand tailings have in the past been produced in an extraction plant, handled as a “whole” product (i.e., no classification; “WT”), pumped to a tailings pond, and discharged sub-aerially onto a beach (BT). The tailings segregates and the fines portion runs off into a pond, forming first Thin Fine Tailings (TFT), and then with time (and settlement), Mature Fine Tailings (MFT). This may be considered a natural classification process. The characteristics of these materials (WT, BT, TFT, MFT) are shown on Figure 1.

In more recent times, tailings have been purposefully classified in the extraction plant using a hydro-cyclone, and the resulting coarse and fines streams have been handled in various ways to produce Hydrocyclone Underflow Tailings (CUT), Hydrocyclone Overflow Tailings (COT), Composite (or Consolidated) Tailings (CT), Non-Segregating Tailings (NST) and Thickened Tailings (TT). The characteristics of these materials are also shown on Figure 1, (reference should be made to Sobkowicz & Morgenstern (2009), for a detailed discussion of the use of a ternary diagram for showing tailings composition and properties).

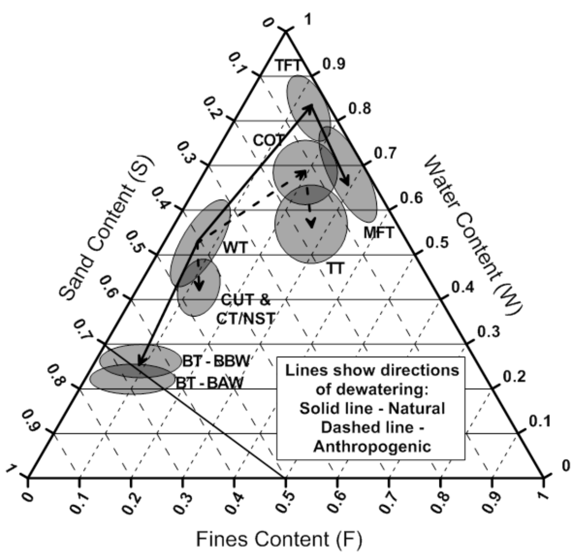

Figure 1 - Stage 1 Dewatering (Classification)

This natural or anthropogenic classification of the tailings imposes a first stage of a dewatering, which will hopefully lead, in the end, to a reclaimable tailings deposit.

3.3 Stage 2 Dewatering (after Tailings Treatment and Deposition)

Various chemical, mechanical and electrical methods are available for treatment of the tailings products shown in Figure 1, for further removal of water (for a detailed discussion of this topic, see Sobkowicz & Morgenstern, 2009). These treatment methods have different dewatering efficiencies, and thus will vary in their ability to meet this objective in a cost-effective manner. Generally speaking, they:

- Increase solids content and reduce water content to near, but still wet of, the liquid limit.
- Increase the yield strength of the tailings to a few hundred Pascals.

This second stage of dewatering is illustrated on Figure 2. The locations shown are not absolute, but will vary with the geotechnical properties of each specific tailings material, depending on ore source, tailings treatment method, and discharge/deposit method. Tailings products whose fines have a higher liquid limit will generally plot higher on the ternary diagram, after the second stage of dewatering, than those that have a lower liquid limit.

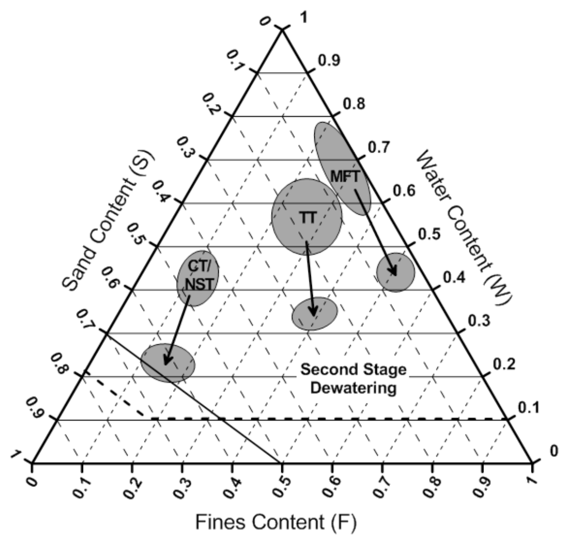

Figure 2 - End of Second Stage Dewatering

The compositions shown on Figure 2 at the end of Stage 2 dewatering apply after a) tailings treatment, and b) deposition, but before environmental or time-related effects have come into play significantly.

3.4 Stage 3 Dewatering – Environmental Effects

Stage 3 dewatering is generally lumped under the term “environmental effects”, as discussed in Section 2 of this paper, but also includes time-related densification caused by settlement/consolidation. These apply as shown on Figure 3 and discussed below.

- CT and NST are granular deposits that will experience some densification with time due to loading and vibration during placement of capping material for reclamation.
- If placed in a thick lift, TT will consolidate with time. Current modeling suggests it could reach an average solids content of 70% after a year or two, and 75% or more after many years. Alternatively, TT could be placed as a thin-lift deposit

(assuming potential segregation issues can be resolved) and with normal environmental effects could achieve solids contents near 80% within a few weeks.

- MFT, flocculated in-line and placed in thin lifts and subject to good environmental conditions, could reach solids contents around 70+% within a few weeks.

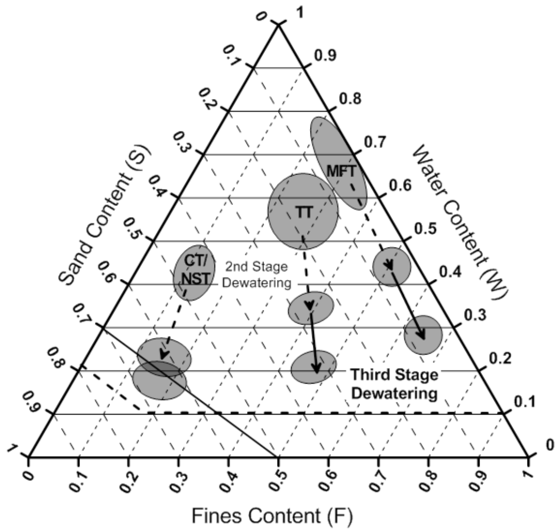

Figure 3 - End of Third Stage Dewatering

The end targets for Stage 3 dewatering shown in Figure 3 are based on one set (of many possible) geotechnical properties. In this case, the assumed liquid limit of the tailings fines is around 50% and that the fines are 50% clay / 50% silt. This results in a predicted strength profile as shown in Figure 4, and tailings end targets based on an acquired strength of about 10 kPa.

The significant point is that some environmental effects will be needed to achieve the Stage 3 dewatering and to reach target solids contents and strengths, as described above. This would include:

- Evaporative drying in the summer and shoulder months. For thin-lift deposition, sufficient drying will be required before another lift can be placed on the deposit, so drying rate at any particular time of the year will determine thin-lift deposition cycle time.
- Freeze/thaw over the winter. The thickness of deposit that can be treated in this manner will be limited by the amount of thawing that can occur in a reasonably short time frame in the spring (prior to adding the next lift for summer treatment).

Clearly, these environmental influences are more effective on thin lift deposits than on thick lift deposits. Boswell (2009) reports on some of the factors influencing the selection of layer thickness.

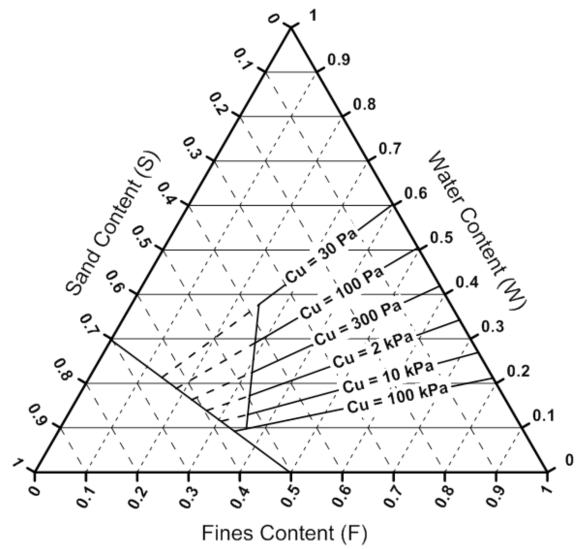

Figure 4 - Possible Undrained Strength Profile

4 ENVIRONMENTAL METHODS IN PERSPECTIVE

The benefits of environmental methods in assisting tailings disposal have been demonstrated. Their merits should not be overstated however, and environmental methods are most effective when considered in their proper context:

4.1 Environmental methods are not a panacea.

They cannot replace solid-liquid separation technology, nor should they. As with biological treatment of contaminants in water, natural processes should be employed as a polishing function, rather than a primary treatment. Environmental methods of dewatering are most effective at or around the air entry value in the consolidation process, in other words, in order to further dewater a tailings material, air must be introduced into the voids to replace water. At this point the consolidation of the solids advances to a point beyond simple settling.

4.2 To achieve sufficient strength, consolidation requires the generation of negative pore water pressures.

A reduction in void ratio is necessary to achieve consolidation. However, in the case of tailings fines, particularly those with high clay content, and with clays exhibiting smectitic behaviour, substantial additional force is required to drive out interstitial water and force the clay particles close enough to generate sufficient shear strength necessary for reclamation. This force is provided by the generation of negative pore water pressures, through desiccation, freeze-thaw or similar effects.

4.3 5 or 10 kPA is not the destination.

Under the right conditions, environmental methods are able to further advance the consolidation process such that tailings deposits can be self supporting, with strengths of hundreds of kPA.

This is a necessary advance, since 5 or 10 kPa is not sufficient to enable a hydraulic fill structure to be self supporting. It is also unlikely to be sufficient to remove the risk of liquefaction of a deposit where this risk exists. An advance to strengths of hundreds of kPa is necessary and possible, for final reclamation of a tailings deposit to be successful.

4.4 The key to environmental benefit is through thin lifts.

Boswell (2009) and many others referenced in that paper point to the substantial benefit of deposition in thin lifts (typically less than 200mm) in mobilizing environmental methods of consolidation, especially through self drainage and desiccation. That paper describes the key factors which would influence the selection of lift thickness in a deposition design or operation, and suggests some typical lift thicknesses under a variety of conditions.

Thicker lifts substantially reduce the effectiveness of drainage and desiccation since the drainage path length is increased. Drainage and desiccation are not linearly dependent on path length. The deleterious effect of increase in lift thickness is exponential in nature.

4.5 Sub-aerial deposition is preferred over sub-aqueous.

As described earlier in this paper, environmental methods are only engaged once the air entry value has been reached for a deposit. Thus it is axiomatic that sub-aqueous deposition (below a free water surface) will necessarily preclude air entry, and thereby most of the associated benefits of environmental methods.

4.6 Environmental methods are generally cheaper than electro-mechanical means, but take longer.

Traditional solid-liquid separation technologies and dewatering methods for Oil Sands tailings such as thickening, flocculation and centrifugation employ substantial resources of energy and human and financial capital.

The utilization of natural processes such as drainage, capillary flow, desiccation and freeze thaw while clearly less expensive, do require the expenditure on significant amounts of human and financial capital in order to fully mobilize their benefit to tailings management.

5. CONCLUSION

In the medium term it may be that electro-mechanical or chemical methods will be found to successfully dewater and consolidate Oil Sands tailings.

It is the authors' view however, that in the longer term, environmental methods will continue to be pursued and employed, in the drive to reduce the cost of tailings placement and reclamation.

REFERENCES

Beier, N., Alostaz M. and Sego D. 2009. Natural Dewatering Strategies for Oil Sands Fine Tailings, *Tailings and Mine Waste 2009, Banff* 845 - 858.

Blight, G.E. 2010. Geotechnical Engineering for Mine Waste Storage Facilities *Balkema.* 405 - 429.

Boswell, J.E.S. 2009. Strategies for dealing with Fine Fluid Tailings and Suspended Fines: Some International Perspectives, *Tailings and Mine Waste 2009, Banff* 171 - 184.

Boswell, J.E.S. 1990. Unpublished tailings surveillance reports to Hartebeestfontein and Buffelsfontein Gold Mines in Stilfontein, South Africa.

Boswell, J.E.S. 1987. Unpublished report to NCP on the water balance for saline evaporation ponds in Chloorkop, Johannesburg, South Africa.

Dawson, R.F., Sego, D.C. and Pollock, G.W. 1999. Freeze-thaw dewatering of oil sands fine tails. Canadian Geotechnical Journal 36 (4), 587-598

Johnson, R.L., Bork, P., Allen E.A.D., James, W.H. and Koverny, L 1993. Oil Sands sludge dewatering by freeze-thaw and evapotranspiration. Alberta Conservation and Reclamation Council Report No. RRTAC 93-8, 247p.

Mikula R. 2009. Personal communication.

Moore, T. 2010. Unpublished laboratory testing of flocculated MFT.

Simms, P., Dunmola, A., Fisseha, B. and Bryan, R. 2010. Generic modeling of desiccation for cyclic deposition of thickened tailings to maximize density and to minimize oxidation, *Paste 2010, Toronto*, 293 - 301.

Sobkowicz, J.C. and Morgenstern, N.R. 2009. A Geotechnical Perspective on Oil Sands Tailings, Keynote Address at *Tailings and Mine Waste 2009, Banff* xvii - xli.

Wilson, W. 2010. Professor at University of Alberta. Personal communication.