Development of Accelerated Dewatering Technology for Managing Oil Sands Fine Fluid Tailings

Rick Lahaie
Syncrude Canada Ltd., Fort McMurray, Alberta, Canada
Jack T.C. Seto
BGC Engineering Inc., Edmonton, Alberta, Canada
Denise Chapman
O'Kane Consultants Inc., Saskatoon, Saskatchewan, Canada
W. David Carrier, III
Argila Enterprises Inc., Lakeland, Florida, U.S.A.

ABSTRACT
Syncrude Canada Ltd. has been examining several alternative tailings technologies aimed at reducing the accumulation of mature fine tailings (MFT) and creating trafficable surfaces for reclamation. One such method is "accelerated dewatering", where rim ditching and a decant system combine to promote drainage of surface waters and enhance drying and densification of the MFT. In 2009, a test deposit containing approximately 60,000 m^3 of in-line flocculated MFT was constructed and instrumented. The deposit has since been sampled and tested. Ten months after pit filling, the deposit has settled approximately 1.2 m, corresponding to an estimated 19 percent reduction in volume compared to pit filling. The field test is scheduled to run for several more years and will continue to be monitored, sampled, and tested.

RÉSUMÉ
Syncrude Canada Ltd évalue plusieurs technologies de résidus miniers visant à réduire l'accumulation de résidus de fluide et à créer des surfaces réclamables. Un tel méthode s'appelle «l'accélération de déshydratation», où la drainage des eaux de la surface est promue avec les égouts creusés autour le dépôt et un système de décantation. Au cours de 2009, un dépôt d'essai contenant environs 60,000 m^3 de MFT a été construit et instrumenté. Le dépôt a été échantillonné et des essais in situ ont été réalisées. Dix mois après avoir rempli le creux, le dépôt a tassé environ 1.2 m, correspondant à une réduction volumétrique estimée à 19 pour cent. Le dépôt continue d'être surveillé, échantillonné et testé, et cela va durer pendant encore au moins plusieurs années.

1 INTRODUCTION

Syncrude Canada Ltd. (Syncrude) is seeking ways to reduce the required storage volume and improve reclamation of mature fine tailings (MFT), a very slowly consolidating slurry with approximately 30-35 percent solids content. One method that has been used for over twenty years in the Florida phosphate mining industry and for the disposal of dredged material is to pour clay slurries (or dredged material) into large pits and "rim ditch", i.e., dig ditches around the perimeter of the contained slurry, beginning with ditches several centimetres deep, then progressively deeper. Combined with surface drying through evaporation, rim ditching enhances surface cracking, which forms lateral drains for water that can be removed with a surface dewatering system. Experience in the other slow-consolidating materials has shown that the initial volume of the clay slurry can be reduced to less than half over a five to ten year period and the material can be converted from a fluid to a solid suitable for capping and terrestrial reclamation using mining equipment. This approach has never been applied for oil sands fine tails or in a cold climate such as the Athabasca region of northern Alberta; therefore, a large-scale pilot test is being carried out to evaluate if this method can effectively reduce MFT storage volumes and ultimately produce a working surface that is sufficiently strong to support terrestrial reclamation.

2 BACKGROUND

2.1 Consolidation Behaviour of MFT

A 10 m high standpipe test of Syncrude MFT has been monitored at the University of Alberta since 1982, and the solids content profile was reported by Jeeravipoolvarn et al. (2006) to be fairly uniform even after 21 years. Only the bottom metre to metre and a half of the MFT column was found to show an increase in solids content. The effective stresses in the column were found to be zero or near zero, and only the bottom metre of the column showed a small increase in effective stress over time.

2.2 Rim Ditch Concept

Because of the slowly-consolidating nature of MFT, other processes are required to speed up the densification of MFT. In 2007, a tailings technology screening analysis was conducted by Syncrude and a team of external consultants (BGC Engineering Inc., 2008). Thirty tailings technologies were screened, from which six technologies were short-listed for further development. Of these, "accelerated dewatering" was recommended for commercial demonstration. Other technologies such as centrifuge-dewatering and thin-lift drying have been actively tested and evaluated by Syncrude, the results of which have been reported elsewhere.

MFT can dry naturally through a combination of surface evaporation and freeze-thaw dewatering, although the process can be slow and requires significant management inputs for effective densification. With either process, drying of the upper section of the confined MFT will result in a reduction in its moisture content, and hence void ratio (i.e., shrinkage), due to the negative water pressures induced by the drying or freezing. As the free water surface moves downward in elevation, the unit weight acting on the lower material changes from buoyant unit weight to effective unit weight. Therefore, the material below the new water level is subjected to a surcharge load and as the water level drops, the surcharge load progressively increases. Rim ditching is intended to encourage crust development and cracking, as well as lower the water table.

The climate of the Fort McMurray area is such that mean daily air temperatures range from -19°C in January to 17°C in July and it receives, on average, 455 mm of precipitation each year, of which 70 percent is in the form of rainfall (Environment Canada meteorological station at Fort McMurray, climate normals for 1971-2000). Daily air temperatures are typically subfreezing (i.e., colder than 0°C) from November through March. The average annual potential evaporation is approximately 600 mm, calculated using the Penman method (Penman, 1948) and based on climate data collected from various stations at the Mildred Lake mine site since 2002,

Evaporation is a complex phenomena controlled by such variables as solar radiant heating, air temperature, ground temperature, relative humidity and wind speed. The degree of evaporation is a function of the material and available water near the surface. It can be greatly influenced by the presence of salts and/or bitumen near the surface.

The effectiveness of freeze-thaw dewatering will depend upon its initial solid content, thickness, and the winter climate (i.e., air temperature and snow cover), which ultimately governs the maximum seasonal depth of frost penetration. Proskin (1998) and Dawson et al. (1999) described how oil sands fine tails dewatered after one freeze-thaw cycle. The thawed fine tailings were found to behave like an overconsolidated soil and exhibit enhanced permeability compared to never frozen tailings at the same void ratio.

3 DEWATERING PIT LAYOUT AND INSTRUMENTATION

3.1 Pit Layout

A dewatering pit sized to initially store approximately 60,000 m^3 of MFT, up to 10 m in depth, was constructed on the East Toe Berm, located on the east side of Mildred Lake Settling Basin at Syncrude's Mildred Lake mine site. Initially, the MFT covered an area of approximately 0.9 ha. The dewatering pit was constructed largely as a cut and fill with a ring berm being constructed of re-compacted excavated materials (beach tailings sand, a silty fine sand). The floor of the pit and the lower 3 m of the pit inside slopes were lined with an approximately 0.3 m thick layer of compacted clay fill which was intended to serve as a low-permeability liner to better-define moisture transfer.

The dewatering pit was constructed between April and June 2009. Figure 1 shows a view of the dewatering pit prior to pit filling.

Figure 1. View of containment pit prior to filling.

A decant system was installed comprising of a spillbox and a decant pipe. A fixed steel walkway was installed between the containment berm and the spillbox.

3.2 Test Instrumentation

The dewatering pit was instrumented to monitor transient pore water pressure changes in the deposit and to measure water and energy balance parameters.

Three nests of 7 to 8 vibrating wire piezometers attached to wooden power poles were installed to measure pore water pressures within the stored MFT. An additional vibrating wire piezometer was installed within the foundation sand at each power pole location. Survey rods were fastened to the sides of each pole to provide a visual reference for monitoring changes in the MFT surface elevations over time. Each power pole was anchored with a concrete-filled 777 haul truck tire at its base, as shown in Figure 1. Each piezometer was wrapped in a sand-filled filter sock and fastened to the wooden power pole at the specified heights. All piezometer cables were buried in shallow trenches and connected to a datalogger located at the spillbox.

After the pit was filled, the following near-surface sensors were installed at two locations adjacent to the instrumented power pole locations:

- Time-domain reflectometry (TDR) probes to monitor in situ volumetric water content and electrical conductivity (EC)
- Matric suction (i.e., negative pore water pressure), and
- Heat dissipation or thermal conductivity.

Because of the initial fluid state of the MFT (i.e., untrafficable to foot traffic), plastic modular docks were assembled together to form a walkway and working platform off which instrumentation could be installed, and for sampling and in situ testing of the deposit. Figure 2 shows a view of the floating walkway.

Figure 2. View of floating walkway and instrumentation power poles (August 28, 2009, one week after pit filling).

At the two station locations, sensors were attached to the PVC pipe at 7 to 8 points to a depth below MFT surface between 0.15 m and 2.0 m. The PVC pipe was then attached to the floating walkway. This system allows the instruments to continue monitoring even as the MFT surface settls. All measurement sensors are attached to data loggers.

The meteorological station is located near the spillbox and includes the following instruments:

- Wind speed and director sensor;
- Net radiometer;
- Temperature and relative humidity sensor;
- Tipping bucket rain gauge;
- Albedometer; and
- Infrared surface temperature sensor.

Manual snow surveys were conducted over winter 2009/2010 for determination of snow water equivalent (SWE) input to the system. Finally, a tipping bucket flow gauge was installed at the decant pipe outlet to measure water flows conveyed by the decant system. Two weatherproof cameras were set up at the edge of the pit to monitor temporal changes to the MFT surface, particularly for crack development. The cameras were programmed to automatically record at least one photograph per day.

4 PIT FILLING

The pit was filled from July 15 to August 22, 2009. MFT treated with a polymer flocculant was pumped into the pit via a 406 mm diameter pipeline. The discharge point was moved around to several locations during filling. All through pit filling, treated samples from the mid-point and end-point (discharge) of the pipeline were collected. The feed MFT gravimetric solids content was measured hourly and averaged 32.6 percent (CanmetEnergy, 2010). More than 80,000 m^3 of material, comprised of 74,100 m^3 of MFT and 6,700 m^3 of polymer solution, was deposited into the pit. The MFT released water as it was being deposited into the pit. Water release was initially very rapid and began to slow down about 15 days after the pit was filled. Water collected at the far end of the deposit due to a slight slope created by the deposited material. The release water was pumped out only when the solids content was determined to be less than 1 percent by weight. Approximately 37,300 m^3 of water had been recovered up to October 2009.

Based on markings on the spill box and along the pit perimeter, it is estimated that the maximum pond elevation was approximately 331.1 m. Given that the pit floor elevation was approximately 321.2 m to 321.3 m, the pit was filled up to a maximum depth of approximately 9.9 m.

Figure 3 shows an aerial view of the test deposit shortly after the pit was filled.

Figure 3. Aerial view of dewatering pit shortly after pit filled.

5 POST-FILLING OBSERVATIONS

At the completion of pit filling, the pond was observed to be covered by a layer of fluid, as shown in Figure 2. By September 11th, about three weeks after the pit was filled, a noticeable crust with some cracking had begun to develop around the perimeter of the deposit as shown in Figure 4.

Figure 4. View of MFT deposit surface on September 11, 2009 (three weeks after pit filling).

Snow first fell on the deposit on October 8, 2009, but did not persist until November 21st.

Figures 5 and 6 present the measured pore pressure histories and profile from one of the instrumented power pole locations, PP-1. The plots clearly show that there is a gradual decline in pore water pressures in these piezometers in response to the lowering of the MFT surface from drainage of the surface ponds.

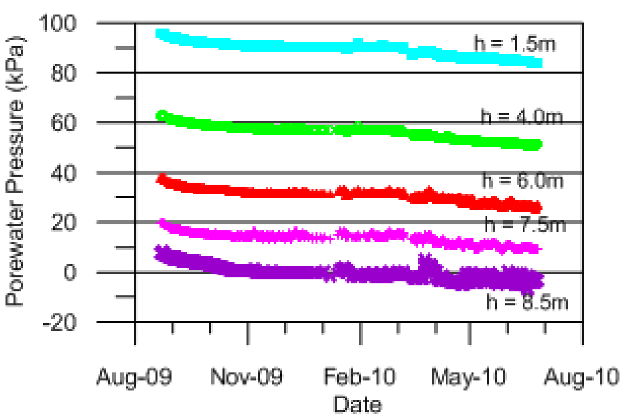

Figure 5. Pore water pressure histories at Station PP-1.

In late-September, 2009, in situ samples were collected from three locations, two alongside the floating walkway and another next to the spill box. Continuous samples over the full depth of the MFT deposit were collected at approximately 50 cm depth intervals using a piston tube sampler. Figure 7 shows a typical sample.

For all collected samples, oven-dried solids contents were determined and laboratory viscometer tests were carried out. The sample yield stress was determined first from the "undisturbed" sample, and then the sample sheared at a rate of 100 rpm for 60 seconds to determine the remoulded yield stress "after one shear", before it was sheared again at a rate of 100 rpm for 60 seconds prior to determine the remoulded yield stress "after second shear".

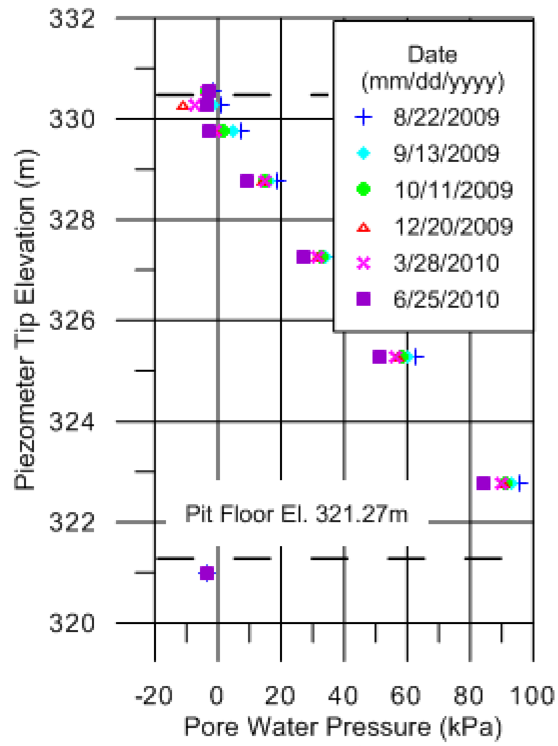

Figure 6. Pore water profiles at Station PP-1.

Figure 7. Typical MFT sample.

Other laboratory index tests, including Coulter particle size analyses, and the Dean Stark test for determining the bitumen-water-solid distribution, are also being carried out, but the results have not yet been available at the time that this paper was prepared.

Within a metre distance from the sample hole locations, field vane tests and ball penetration tests (BPTs) were also conducted. The field vane is a common geotechnical tool used to measure the in situ undrained shear strength of cohesive soils. For this test, an electronic downhole vane system with a 150 mm by 300 mm vane was used. The ball penetration test is a variation of the cone penetration test where the cone-shaped tip is replaced by a spherical attachment. It is an investigation tool that is generally used to measure the undrained shear strength of very soft cohesive soils. The ball tip used in this investigation has a projected area of 100 cm^2 and was pushed by hand at a rate of approximately 2 cm/sec. The remoulded shear strength was determined by inserting and extracting ("cycling") the ball tip a number of times between specific depth intervals. Correlated against the vane test results, an N_{ball} value of 10.5 was used to estimate undrained shear strengths (peak and remoulded).

Figure 8 presents the solids content, peak vane strength and BPT-computed undrained shear strength profile determined in late-September 2009 from one of the three test hole locations, TH SEP09-05. At this location, the solids content ranged from 32 percent at the surface to 48 percent just above the foundation interface, averaging 43 percent. There is a trend of increasing solids content and shear strength with increasing depth. The average undrained strength at this location was approximately 1 kPa and the remoulded strength approximately half of that.

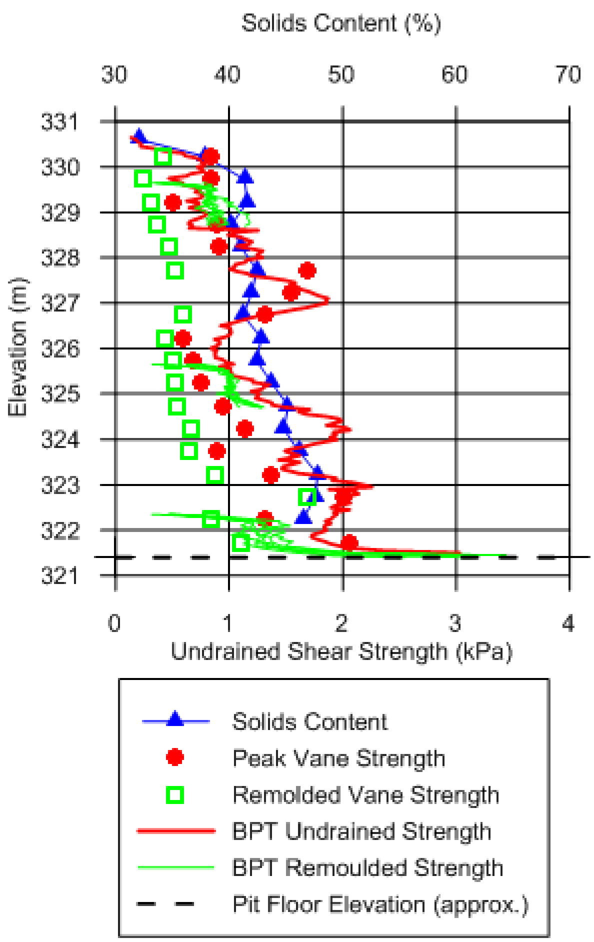

Figure 8. Solids content and Undrained Shear Strength Profiles, Test Hole SEP09-05.

The automated cameras have worked well. Figure 9 shows how the surface at northern edge of the deposit changed over a four-week period between October 27 and July 1, 2010 (two to ten months after pit filling).

Figure 9. Surface changes along northern edge of deposit between late-October 2009 and early-July 2010.

Over the winter of 2009/2010, the elevation of the top weir board at the spillbox was at 330.6 m. There was little to no water flow measured at the decant pipe outlet until March 2010. By the end of winter (March), frost penetrated to various depths into the MFT deposit, ranging from none near the spillbox to approximately 0.5 m. Temperature measurements from the VW piezometer sensors indicated that temperatures in the bottom half of the MFT deposit did not change much during the winter, remaining greater than 20^{o}C.

In mid-March, 2010, frozen MFT core samples were collected at ten locations, two each in the vicinity of instrumented power pole locations, and three each near the perimeter pit of each the north slope and the west slope. The frozen crust was sampled using a 2-man portable auger with a CRREL core barrel attachment. The CRREL core barrel is a tool used in geotechnical engineering for coring frozen, fine-grained soils. The CRREL core barrel provided 103 mm diameter cores over the full depth of frost. The core samples were quickly wrapped in a thick plastic bag, temporarily packed in coolers with dry ice and then stored in a freezer. Some frozen samples were set aside for bulk density and thaw strain measurements and the remaining samples were placed in sealed plastic containers and allowed to thaw. Frozen bulk densities ranged from approximately 1030 kg/m^3 to 1150 kg/m^3. The initial solids content of three frozen specimens ranging from 30 to 33 percent increased to between 33 and 39 percent after thawing. The measured thaw strains ranged from 26 to 32 percent, averaging 32 percent, and are lower than the 45 to 50 percent thaw strains reported for fine tails with similar initial solids content reported by the OSLO New Ventures Group (Dawson et al., 1999).

Table 1 summarizes the geotechnical index properties of the MFT in the test deposit. The Atterberg limits were determined from samples collected from the deposit in September 2009.

Table 1. Geotechnical Properties of MFT Deposit

Index Property	Range	Average
Initial Solids content (%)	18 – 39	33
Initial Water content (%)	155 – 455	207
Solids content (Sep. 25) (%)	32 – 48	42
Water content (Sep. 25) (%)	108 – 212	138
Fines content (% < 44 μm)	73-95	90
Liquid limit (%)	52 – 76	63
Plastic limit (%)	21 – 31	24
Plasticity index (%)	28 – 53	39
Undisturbed Yield Stress (Pa)	260 – 2730	1090
Remoulded Yield Stress (Pa)	80 – 2620	330
Thaw Strain (%)	26 – 32	32

Potential (or theoretical maximum) rates of evaporation of the MFT surface were calculated using the Penman (1948) method for the meteorological data collected. Between July and November 2009, the measured rainfall was approximately 115 mm and the potential evaporation calculated to be 274 mm. Between March and June 2009, the measured precipitation (rainfall and snow-water equivalent) was 139 mm and the potential evaporation calculated to be 362 mm. This suggests that this is a drying environment where the potential evaporation exceeds the incoming rainfall and the MFT is able to supply sufficient water to meet atmospheric demands.

Initial albedo measurements indicated that the MFT surface had albedo ranging from 0.15 to 0.20, meaning that it reflects as much shortwave radiation from sunlight as bare soil.

By April 20, 2010, over 4200 m^3 of water was conveyed by the decant system, corresponding to approximately 470 mm of water, of which 290 mm of the outflow was attributed to snow melt and 180 mm attributed to water from the deposit (based on comparisons of electrical conductivity measurements from shallow depths within the deposit and from water collected at the outlet of the decant pipe). Since early-May 2010, there has been negligible measured outflow, even after precipitation events.

The near-surface moisture transfer measurements from the TDR and suction sensors have only shown measurable results since the MFT surface thawed in April 2010. They sensors have remained in a near-saturated condition and further testing is planned to improve the calibration of the TDR measurements.

In April 2010, a fairly large, shallow pond was present at the deposit surface (see Figure 10). By mid-June 2010, the pond disappeared. Figure 11 shows a view of the surface in July 2010. Figure 12 shows a closer view of crack formation around instrumented pole PP-3 in July 2010.

The average surface elevation of the deposit is estimated to have dropped from initially 331.1 m to 330.7 m after one month, 330.4 m after seven months, and 330.0 m after ten months. This corresponds to a change in material volume contained in the pit from initially 59,700 m^3 to 48,800 m^3, or an 18.3 percent reduction in volume.

Figure 10. View of MFT deposit surface on April 26, 2010 (eight months after pit filling).

Figure 11. View of MFT deposit surface on July 6, 2010 (ten months after pit filling).

Figure 12. View of MFT surface around instrumented pole PP-3, July 6, 2010 (ten months after pit filling).

6 FUTURE ACTIVITIES

The test deposit is intended to be regularly rim-ditched, monitored, sampled and tested for at least another five years. In July 2010, the deposit was again sampled and in situ strength tests were carried out, but the results were not yet available at the time that this paper was prepared. Chemistry testing of water samples collected at the decant outlet and from the decant water from the thaw strain tests will be conducted. Near surface samples of the MFT will be collected over the summer to track concentrations changes of constituents as the surface evolves. Laboratory testing will be conducted to refine the calibration of TDR measurements for MFT. Specialized laboratory tests, including consolidometer testing, hydraulic conductivity testing, and determination of the soil water characteristic curve (SWCC), are under way to characterize the compressibility, permeability, and unsaturated soil properties of the flocculated MFT.

Data obtained from the field test will be used for numerical modelling of desiccation/consolidation modelling and, potentially, full-scale deposition designs.

7 CONCLUSIONS

Over the summer of 2009, a 0.9 ha containment pit was constructed and a decant structure was installed. The test deposit was instrumented to monitor the consolidation and dewatering response of the MFT deposit over time, to collect data on surface energy and water balance parameters, and to document visual changes to its surface with time.

The following observations have been made based on the field observations to date:

- In-line flocculation of the MFT resulted in the release of water from the treated MFT as the pit was being filled.
- The feed MFT had an average initial solids content of 33 percent. In-line thicknening of the MFT with a polymer addition enhanced water release from the MFT such that the average solids content was raised to approximately 42 percent one month after pit filling.
- The MFT surface began to dry and crack shortly after the pit was filled. Crack development began around the edge of the deposit.
- In September 2009, one month after the deposit was filled, peak vane strengths through the MFT deposit ranged from 0 to 2.6 kPa (generally increasing with depth) and averaged 0.7 kPa. Remoulded vane strengths were, on average, approximately 0.5 kPa. Undrained shear strengths determined from the ball penetration test matched very well against the field vane tests.
- Over the winter of 2009/2010, frost penetrated to an average depth of 0.3 m. The bulk densities of the frozen MFT cores ranged from 1030 kg/m^3 to 1150 kg/m^3. Thaw strain tests indicated that thawing of the frozen MFT core specimens resulted in approximately 30 percent volumetric strain.
- By the middle of June 2010 (approximately ten months after pit filling), there was no longer surface water on the deposit.
- The average elevation of the MFT surface is estimated to have dropped from initially 331.1 m to 330.7 m after one month, 330.4 m after seven months, and 330.0 m after ten months. This corresponds to a change in material volume contained in the pit from initially 59,700 m^3 to 48,800 m^3, or an 18.3 percent reduction in volume.

ACKNOWLEDGEMENTS

The authors would like to thank Syncrude Canada Ltd. for permission to publish the information contained in this paper. Thanks also to O'Kane Consultants Inc., BGC Engineering Inc., CanmetEnergy, Geoforte, ConeTec Investigations, and the University of Alberta for providing engineering and technical support to the project.

REFERENCES

BGC Engineering Inc. (2008). 2007 Tailings Technology Assessment Report. Report submitted to Syncrude Canada Ltd., Project No. 0534-005-01, April 28, 2008.

CanmetEnergy, 2010. Rim Ditch Dewatering Test Plot. Report prepared for Syncrude Canada, Division Report Devon 09-80 (CF), November 2009.

Dawson, R.F., Sego, D.C., and Pollock, G.W., 1999. Freeze-thaw dewatering of oil sands fine tails. Canadian Geotechnical Journal (36): pp. 587-598.
Jeeravipoolvarn, S., Scott, J.D., and Chalaturnyk, R.J., 2006. Three Ten Meter High Standpipe Tests on Tailings. Sea to Sky Geotechnique 2006, Proceedings of the 59th Canadian Geotechnical Conference, Vancouver, BC, pp. 1078-1085.
Penman, H.L., 1948. Natural evapotranjspiration from open water, bare soil and grass. Proceedings of the Royal Society of London, Series A, Vol. 193, pp. 120-146.
Proskin, S.A., 1998. A Geotechnical Investigation of Freeze-Thaw Dewatering of Oil Sands Fines. Ph.D. thesis, University of Alberta.