Thickening of Oil Sands Composite Tailings

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Abstract

The current oil sands tailings management strategy is to cyclone the tailings stream and combine the cyclone underflow with cyclone overflow which has been allowed to settle for several years in a tailings pond. Gypsum is added to this mixture and a nonsegregating tailings called Composite Tailings (CT) is produced with a solids content of about 60% and a fines content of 20%. The CT is pumped to a disposal area where it is allowed to consolidate under self weight. This paper reports on trials to further increase the solids content of CT using a thickener. A research thickener, 1 m diameter with a 1 m depth, was used to investigate thickening the CT to a solids content sufficient to support reclamation methods. The thickener is equipped with pore pressure transducers down the side of the thickener and pore pressure and total stress transducers in the base of the thickener to fully evaluate the geotechnical processes occurring in the thickener. The pressure and stress transducers in conjunction with sampling allow total stress and effective stress profiles to be determined at any time during the thickening test procedure.

1. Introduction

Current oil sands tailings management strategy is to combine dense fine tailings with regular tailings and gypsum to make a non-segregating mixture called Composite Tailings (CT). Over time CT consolidates to form a "solid" material. In support of the new oil sand mine developments, the oil sands industry is evaluating paste (thickened) tailings technology as an alternative to CT. Without the need for a settling basin and storage of fluid fine tailings, the vision of "solid' tailings can be explored.

Over the past three decades, new types of thickeners have been introduced. High capacity types using improved feed dilution systems (which maximize the efficiency of flocculants) have become the mineral industry workhorses. But because of their size and their rapid response time, the deep thickeners or high capacity type thickeners are much more sensitive than conventional thickeners and as such, require more elaborate control processes and a clear understanding of the material's behavior within the thickener.

The rheology of a paste is controlled by a number of different variables: particle size distribution, particle surface chemistry, liquid viscosity, flocculant quantity and characteristics, concentration of particles and the amount of energy put into the mixture. Rate of paste formation is a primary control parameter. The required solids residence time in the thickener is a function of paste formation rate and is the secondary control parameter.

The challenge in control is to identify a change in the settling rate and adjust the flocculant dose to keep the settling rate constant. Field and bench trials established flocculant dosage are critically affected by feed dilution. Control of the solids residence time and the rate of paste formation must be adequately responsive to avoid exceeding rheological properties that will not discharge from the thickener. Clearly, a level of understanding of the internal physics and operation of the thickeners is paramount to the reliable and economic introduction of this technology to the oil sands industry.

2. Objective

The objective of this research was to develop a fundamental understanding of the behavior of the oil sands tailings slurries within a thickener. Operationally, this research objective is linked to creating a pumpable, lower water content slurry that will form a sloped deposit and releases less water into the disposal area.

The factors that control the efficiency of the sedimentation/consolidation process will be identified within the framework of optimizing the thickener design for production of thickened tailings (paste) from oil sands mining operations. A second objective of the research proposal was the assessment of appropriate monitoring technologies for assessing the consolidation process within thickeners and process control.

3. DESCRIPTION OF 1M DIAMETER RESEARCH THICKENER

3.1 Thickener Operating System

The laboratory thickener model operating system comprises the thickener, rake, mixer, pumps (feed and underflow), and motors (for the rake and mixing tank). A pressure transducer, data logger, and data acquisition computer are also installed to monitor the pressure variation. The schematic diagram shown in Figure 1 depicts the operating system. Photographs of some of these components are shown in Figure 2 through Figure 5. The thickener components are described in the accompanying Figures 6 and 7.

At the bottom of the thickener, there are four total pressure transducers and four pore pressure transducers placed diametrically, as shown in Figure 7. In addition, four pore pressure transducers are mounted at different depths on the inside wall of the thickener. The data obtained from the transducers are logged into a datalogger and stored on a computer for further data processing. The data are recorded in volts that are converted into pressure units via calibration charts.

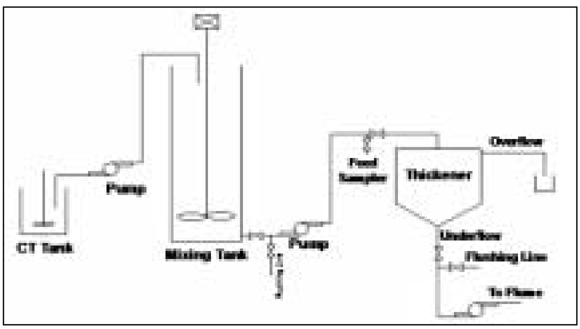

Figure 1: Schematic of thickener operating system.

Figure 2: Mixing tank for thickener feed.

Figure 3: Stirrer in mixing tank.

Figure 4: Thickener setup.

Figure 5: Rake in thickener.

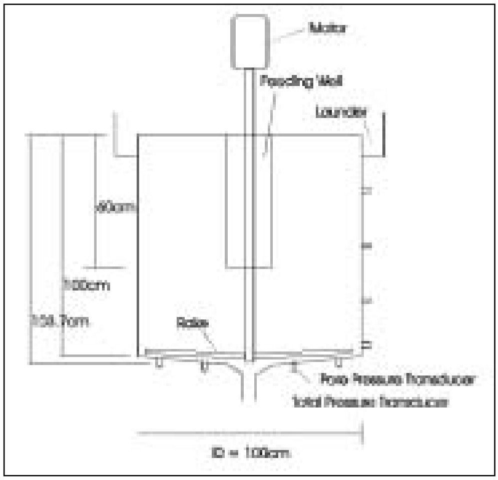

Figure 6: Cross-section of thickener.

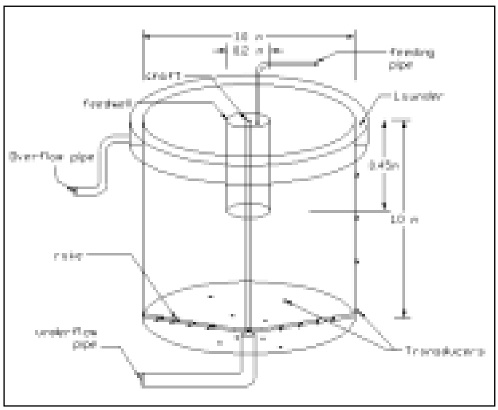

Figure 7: General layout of thickener.

3.2. Thickener

3.2.1. Design of thickener

As a design basis for the 1m diameter thickener, the following operational parameters were chosen:

- Tailings stream: Syncrude's tailings from the flotation stream in the extraction plant.
- Feed solids content of 20 wt%.
- Specific gravity of solids, $G_s = 2.65$.
- Flocculant dosage = 5 g/m^3.
- Initial settling rate, 2.5 m/hr $< \sigma_I <$ 21 m/hr.
- Discharge solids content of 60%.

Based on the design method provided by Concha and Barrientos (1993), for a flocculated suspension at steady state, the unit area UA_o is calculated using the following formula:

$$UA_0 = \frac{A}{\phi} \geq \max\left[\frac{1}{\rho_s \sigma_I}\left(\frac{1}{\phi} - \frac{1}{\phi_D}\right)\right] \quad [1]$$

where A is the cross-section area of the thickener, ϕ is the solid mass flow rate, ρ_s it the solids density, and σ_I is the initial settling rate from bench-scale tests.

To get maximum value of right side of Equation [1], we assume that $\phi = \phi_F$ and σ_I =2.5 m/h, then:

$$UA = \frac{A}{\phi} \geq \left[\frac{1}{2.65 \times 2.5}\left(\frac{1}{0.0862} - \frac{1}{0.3615}\right)\right] \approx 1.34 \quad [2]$$

where the units of UA are m^2/Mg/hr.

If we assume a solids feed rate of ϕ = 0.13 Mg/hr (approximately a mass flow rate of 9.5 L/minute which corresponds to roughly 1/10 of field thickener trial rates) then the area of the thickener is computed as:

$$A \geq \phi \times UA = 0.13 * 1.34 = 0.1742$$

since $A = \pi R^2 = \frac{\pi D^2}{4}$ and so,

$$D \geq \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4 * 0.1742}{\pi}} \approx 0.5 \text{ (m)}.$$

This calculation shows that the diameter of the thickener must be larger than 0.5 m in order to achieve our design objectives. A diameter of 1 m was chosen simply because it was 1/10 the size of a 10 m conventional thickener used in paste field trials. Note that this ratio is 1/100 based on area!

3.2.2. Height of the thickener

The sidewall of the thickener consists of three parts. The middle part is a disassemble part which allows extension of the sidewall.

The height of the thickener can be calculated as follows (Concha and Barrientos 1993):

$$H = c + l + z_c \quad [3]$$

where c is depth of the clarified zone as shown in Figure 8 , l is the height of the fluidised zone, and z_c is the height of the compression/consolidation zone. The height of the compression/consolidation zone can be calculated as follows:

$$z_c = \int_{\phi_D}^{\phi_c} \frac{1 + I_c}{(\rho_s - \rho_f)(0.05 + I_c)\phi g} \frac{d\sigma'}{d\phi} d\phi \quad [4]$$

where I_c is the fraction of increase in capacity needed, g is the gravity acceleration, σ' is the effective stress, and ϕ is the concentration as volume fraction of the solid component. This calculation resulted in the selection of a sidewall height of 1.0 m.

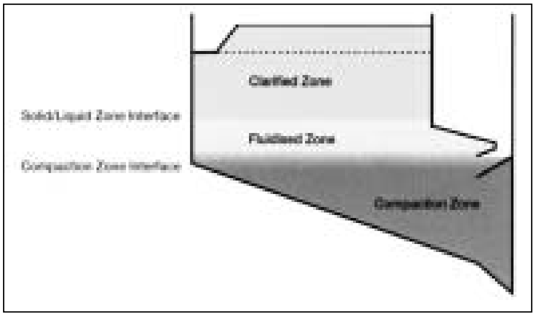

Figure 8: Zones in thickener.

3.2.3. Bottom of the thickener

The bottom of the thickener is a cone with an internal angle of 120 degrees (30 degrees from horizontal) with 4 metal support radial beams and a discharge outlet. The outlet has an I.D. of 2 inches. The bottom can be unbolted and steeper cones can be installed easily.

3.2.4. Instrumentation

The thickener is instrumented for the measurement of mud level, solids content profile, pore pressure, and rheological characterization. Plexiglass panels in the wall allow for viewing the internal thickener performance, as shown in Figure 9.

3.2.5. Pressure transducers

The pressure transducers are calibrated before each test is performed. The silicon pressure transducers (MPX5050 Series) to measure pore pressure are manufactured by Motorola and those used to measure the total pressure are manufactured by Omega. The transducers are connected to a datalogger where data are recorded at specified time intervals and stored temporarily. The output from the datalogger is in volts and is transformed into pressure units via calibration relationships.

Figure 9: Viewing panels in wall of thickener.

The location of the transducers is shown in Figure 10 where the symbol "PP" stands for pore pressure transducer and "TP" stands for total pressure transducer. The difference between the fluid pore pressure and the total pressure is the effective stress or the grain to grain stress in the solids.

In order to carry out the transducer calibrations, the thickener is filled with water up to pre-specified level, for which the hydrostatic pressure is known. The corresponding transducer reading is recorded. The same procedure is followed at different hydrostatic levels and transducer readings.

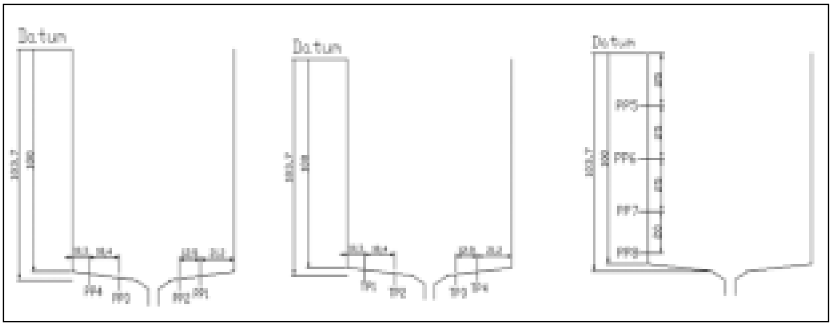

Figure 10: Schematic of thickener showing locations of pressure transducers.

A chart is produced correlating the transducer reading in volts and the hydrostatic pressure in kPa. The calibration tests were carried out while filling and emptying the thickener.

3.2.6. Sampling device

A sampling device which could be lowered into the thickener and opened to simultaneously capture seven samples at different depths was developed (Figure 11). A sliding gate opened the sampling ports allowing the slurry to flow into the receptacles (Figure 12). The samples were analyzed to obtain the solids distribution with depth and calculate the total vertical stress in the slurry within the thickener. Samples were obtained at set times during thickener operation.

4. Composite Tailings Materials

4.1. Composite Tailings Design

4.1.1. Materials

A slurry composed of sand and mature fine tailings (MFT) provided by Syncrude Canada, Ltd. was used in these tests. To maintain the chemistry of the material, release water from Syncrude coarse tailings was used as the mixing fluid during the entire test program.

Wet sieve and hydrometer analyses were conducted on a per barrel basis for both the sand and the MFT. The results are shown in Figure 13 and Figure 14. It can be seen from Figure 13 that the coarse tailings contained 95% sand. Figure

14 shows that the MFT consists of 48% clay size, 44.5% silt size, and 7.5% sand size, by weight.

Samples of sand and MFT were also taken to analyze the solids and fines contents. The composite tailings (CT) were formed by mixing the sand, MFT, and release water at calculated amounts based on their particle size distribution and solids content. The target design solid and fines content for the CT was 60% and 20% by weight, which constitutes a sand-to-fines ratio of 4:1. This volume fraction of sand is not typical for normal thickener duty. The measured solids and fines contents achieved were 57% and 23% respectively.

4.1.2. Segregation boundary determination

As a base case for thickening CT with no additional flocculent or coagulant, testing was conducted initially to determine the required solids and fines contents that would prevent segregation of the CT in the thickener. A number of standpipe tests with different solids contents and fines contents were performed (Table 2). The variation in solids and fines with depth in the standpipes at the end of the tests was measured and the fines capture was calculated. The fines capture percentages were plotted on a solids-fines plot (Figure 15) and a fines capture of 95% was taken as a non-segregating slurry. The contour of 95% fines capture is drawn in Figure 15 as the segregation boundary. Mixes below the boundary are non-segregating and mixes above are segregating.

Figure 11: Slurry sampler in front of thickener.

4.1.3. Coagulant dosage determination

Standpipe tests were performed with CT with a dosage of 1,200 g/m^3 of gypsum added and compared to the no coagulant standpipe tests. The influence of the gypsum on settlement rate and segregation was determined. In addition, one standpipe test with a spiral rake was performed for comparison. As well, a test on thickener underflow was included in the program. Figures 16 and 17 show the solid content profiles and fines content profiles respectively, at the end of the tests. The uniform profiles indicate that no segregation occurred in any of the tests. The rate of settlement of the interface is shown in Figure 18. The gypsum coagulant slurry had a faster settlement rate than the feed without gypsum. The superior settlement produced with a rake is most noticeable. The settlement of the feed and underflow was similar indicating little change in the material as it went through the thickener.

Two dosages of gypsum, 1,200 g/m^3 and 1,500 g/m^3, were tested on both the feed and underflow (Figure 19).

Figure 12: Close-up view of sampling port within slurry sampler.

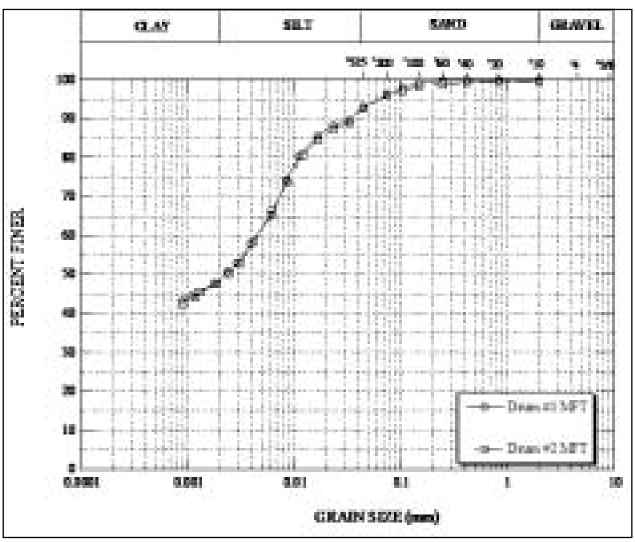

Figure 13: Grain size distribution of sand from coarse tails.

The higher gypsum dosage had a significantly faster settlement rate. No significant difference in feed and underflow performance was noticeable for both gypsum dosages.

Test #	Design S%	Design f%	Actual S%	Final S%	Spiral Rake Speed (rpm)	Fines Capture	Test Duration (days)
TSB1	58	20	58.3	66.4	0.10	98	3
TSB2	60	20	60.6	68.1	0.10	98	2
TSB3	58	20	59.2	71.3	0.25	95	1
TSB4	60	20	59.6	72.4	0.25	96	1
TSB5	63	20	62.8	74.5	0.25	97	3
TSB6-1	55	25	55.7	67.9	0.25	93	1
TSB6-2	56	25	56.1	66.2	0.25	95	1
TSB7	58	25	58.2	67.9	0.25	95	1
TSB8	60	25	59.6	71.1	0.25	96	2
TSB9	63	25	63.4	68.5	0.25	95	2
TSB10	43	25	42.5	60.6	0.25	67	1
TSB11	50	25	49.4	64.7	0.25	82	1
TSB12	41	20	41.0	58.3	0.25	59	1
TSB13	48	20	47.8	65.6	0.25	73	1
TSB14	57	20	56.8	70.4	0.25	91	1

Table 2: Summary table of CT segregation boundary tests for thickener.

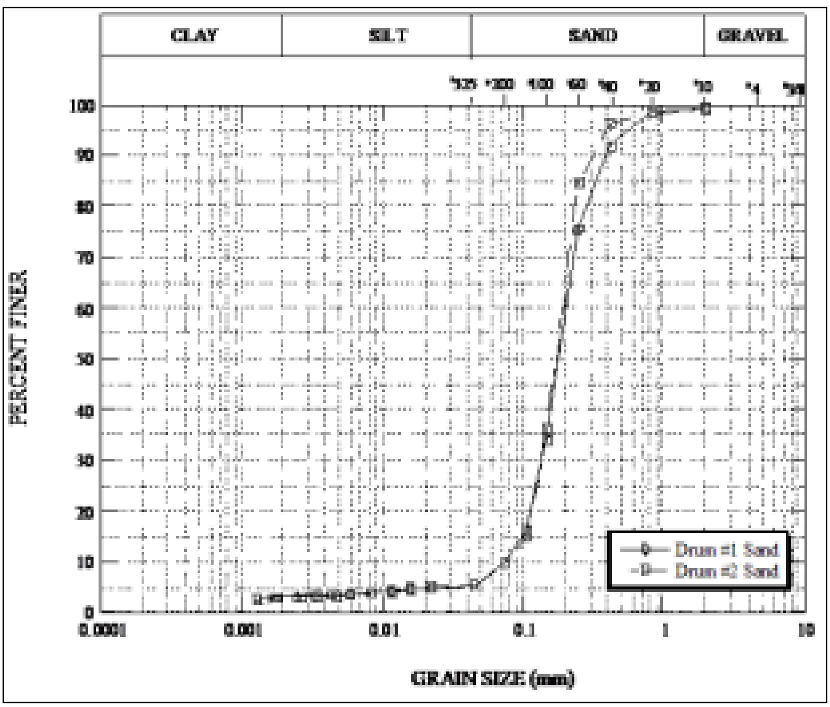

Figure 14: Grain size distribution of MFT.

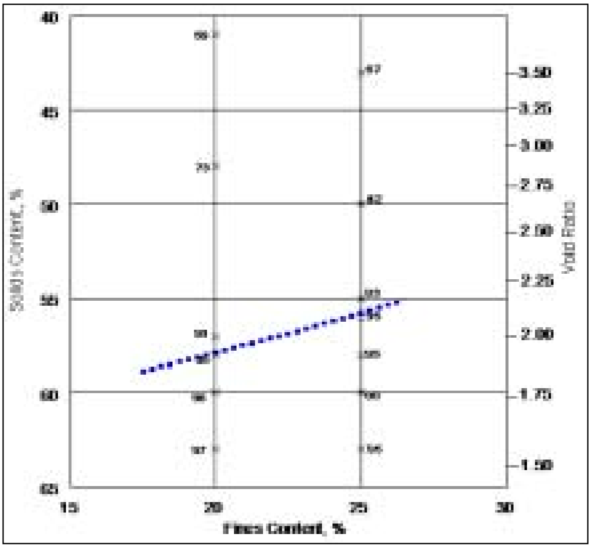

Figure 15: Segregation boundary of Syncrude CT made with 1,200 g/m³ gypsum.

5. Thickener Tests

5.1. Test Program

Three thickener tests were conducted using Composite Tailings samples with the same solid and fine contents but differing amounts of the coagulant (gypsum). Table 3 provides the details for each of the three tests; CT1, CT2 and CT3. The effect of increasing gypsum dosage on the water release rate was also evaluated during the test program. Comparison between the tests was made for the total pressure, pore pressure, solid content and fines content in the underflow. Rods were employed on test CT2 and CT3 to examine their influence on CT dewatering rates. Flume tests were carried out to check the deposition characteristics of the underflow with different gypsum dosages. Standpipe tests were conducted to enable a comparative evaluation of the performance of the slurry in the thickener.

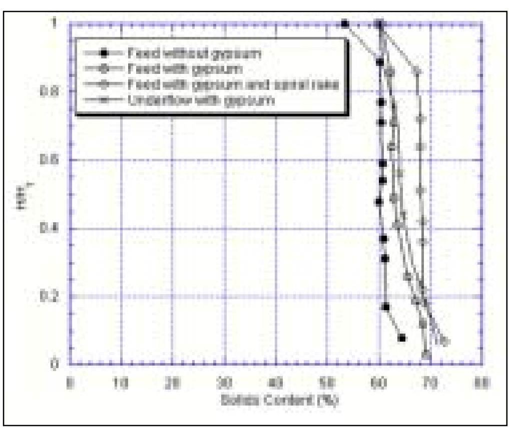

Figure 16: Normalized solid content profile for CT with and without addition of gypsum.

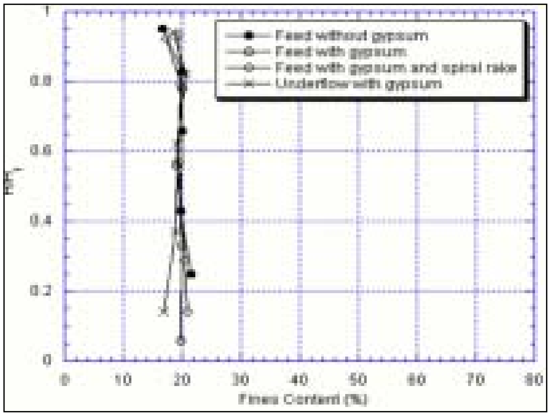

Figure 17: Normalized fines content profile for CT with and without addition of gypsum.

5.2. Composite Tailings Test CT1

Test CT1 was conducted with a design solid content of 60% and fines content of 20%, and no gypsum coagulant added to the slurry. Samples of the feed slurry, overflow and underflow during the thickener test were taken. Figure 20 illustrates the variation in fines content with depth in the thickener at the time the feed pump was stopped. It should be emphasized that the samples were taken using the large syringe at specified depth of the thickener. To avoid diluting the syringe samples with water, valves at the front were closed until the sampling depth was reached, and then samples were taken at specified depth, immediately after opening the valve. Fines content with depth is reasonably constant with a slight decrease near the base where the solids content increases.

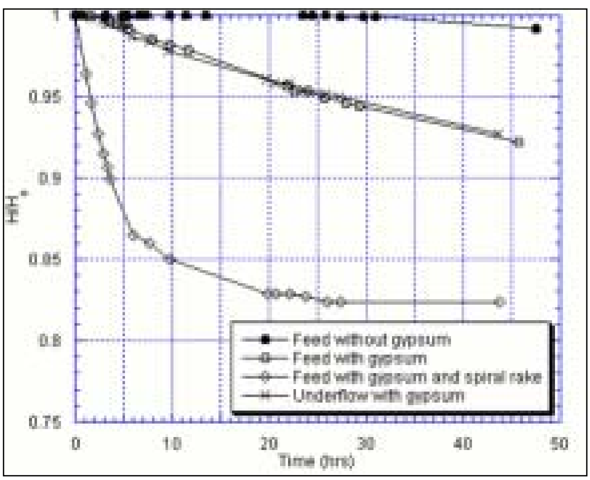

Figure 18: Normalized interface development with and without addition of gypsum.

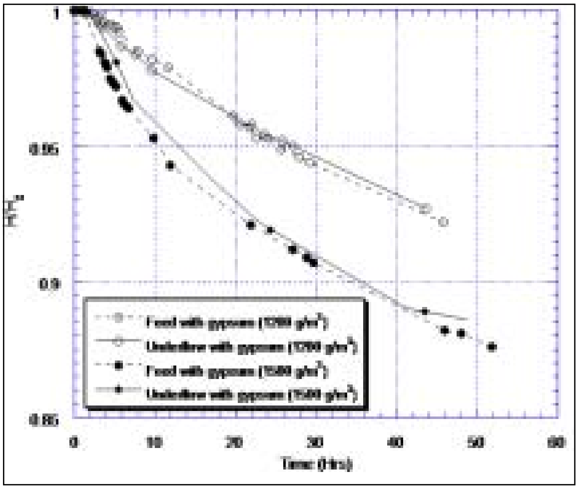

Figure 19: Comparison of gypsum dosage.

As reflected in Figure 20, the settling interface was approximately steady at depth of 0.21 m. The solids contents between a depth of 0.22 m and 0.95 m were nearly uniformly 50%. The only area in which the solids content exceeded that of feed slurry was below a depth of 0.95 m where the fines content decreased to 15%. This demonstrates that most of the slurry in the thickener was initially diluted as it entered the thickener. This also indicates that segregation has occurred below a depth of 0.85 m.

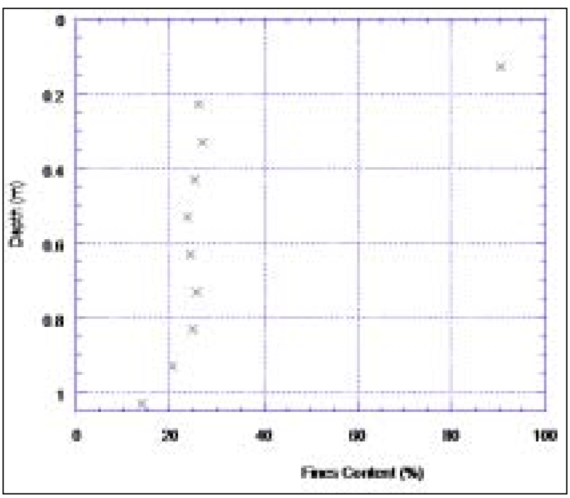

Figure 20: Fines content profile at the end of pumping feed slurry – CT1.

Figure 21 shows the total pressure, pore pressure and hydrostatic pressure at different depths in the thickener for test CT1. The total pressures were determined based on the saturated unit weight of the samples taken at the corresponding depths. The pore pressures were interpolated using the measured pore pressure at depth of 0.75 m, 0.50 m, 0.25 m and 0.0 m. The hydrostatic pressure distributions for the respective water surface levels are also plotted in the figure to serve as a reference.

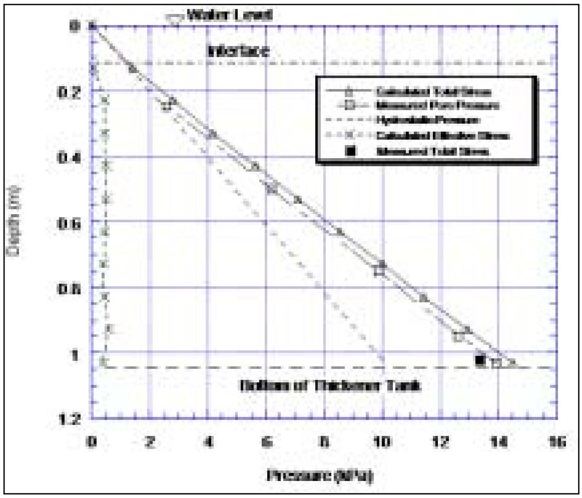

Figure 21: Pressures and stresses at the end of Test CT1.

Figure 21 indicates that the excess pore pressure had not completely dissipated; indicating continued consolidation of the slurry at the bottom of the thickener. Interpolated pore pressure in conjunction with hydrostatic pressure suggests that the process of self-weight consolidation in the thickener is very slow.

5.3. Composite Tailings Test CT2

This test was conducted with a design solid content of 60% and fines content of 20%, with a gypsum coagulant dosage of 1,200 g/m^3 of slurry. The measurement of pH and conductivity were carried out simultaneously.

5.3.1. Total and pore pressure measurements and calculations

The thickener was initially filled with release water to a depth of 53 cm before pumping in the CT material. The gypsum was added in solution form to the main mixing tank. After thorough mixing, feed slurry was pumped into the thickener at a rate of about 3.3 l/min.

The pore water pressure transducer readings are shown in Figure 22. All four transducers show reasonably consistent readings. The total pressure readings are plotted in Figure 23.

Test #	CT1	CT2	CT3
Test Date	**7/11/2002**	**9/17/2002**	**10/22/2002**
Design Solids Content, %	60	60	60
Design Fines Content, %	20	20	20
Gypsum, g/m^3	nil	1200	1500
Rake Geometry	Rakes alone	Rakes + 4 rods	Rakes/4rods /4 plates
Rake Speed, rpm	0.5	0.5	0.25
Test Duration (fill only), hours	2	2	2
Test Duration (fill & U/F), hours	3.5	3	4
Total Feed Vol, L	~1400	~1200	~1400
Feed Rate, L/min	4.3	3.4	3.5
O/F Rate, L/min	1.1	0.05	0.1
U/F Rate, L/min	3.2	3.3	3.6
Initial Water Level in Thickener, cm	35	53	45

Table 3: CT Test Program.

There are some cyclic peaks observed in the total pressure transducer, particularly TP2 and TP3. The rake mainly influences the transducer closest to the underflow exit location. Figure 24 shows the pore pressure transducer readings at the side of the thickener. In both Figures 22 and 23, initial surges of pressure are observed. This phenomenon may be attributed to stopping of feed pump while underflow pump was functioning. The plot of combined pore pressure and total pressure readings are shown in Figure 25. The comparison is shown at the end of filling the thickener (September 17) and then three days later (September 20). The pore pressure shows a dissipating trend in three days of observations. The effective stress plot shows some increase with depth in three days. The hydrostatic pressure distribution is included for comparison.

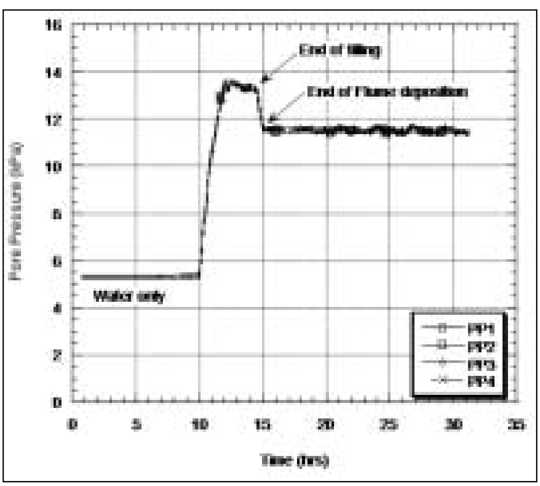

Figure 22: Measured pore pressure for CT2 at the bottom of the thickener.

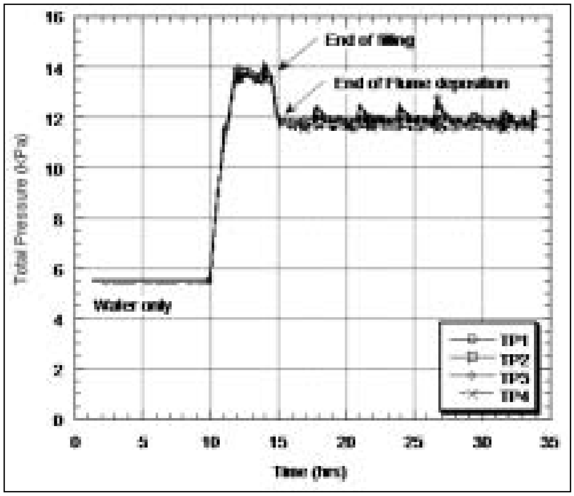

Figure 23: Measured total pressure for CT2 at the bottom of the thickener.

5.4. Composite Tailings Test CT3

The objective of this test was to assess the influence of vertical and horizontal water release bars attached to the rake, as shown in Figure 26. As well, increased gypsum dosage on the water release rate was also tested. A slurry with a solids content of 60% and a fines content of 20% was tested. The gypsum dosage was 1,500 g/m^3. The segregation boundary tests show that this mixture was not prone to segregation.

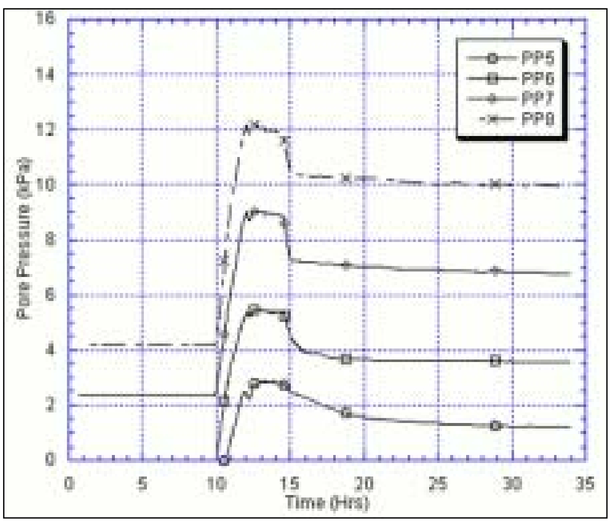

Figure 24: Pore pressures measured along side of thickener – Test CT2.

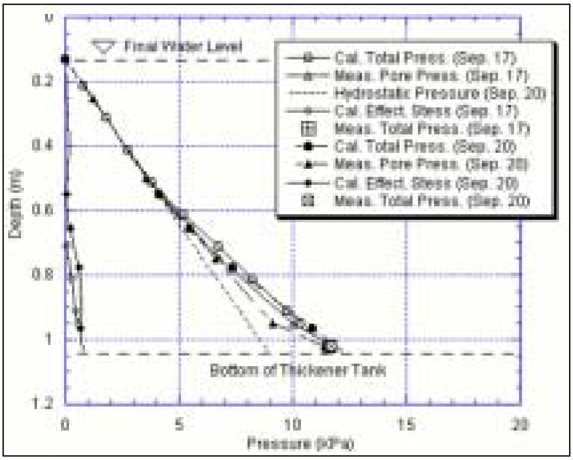

Figure 25: Pressures and Stresses at the End of Test CT2.

5.4.1. Total pressure and pore pressure measurements and calculations

Initially the thickener was filled with 45 cm of release water. Then the slurry with gypsum added (at 1,500 g/m^3 of slurry) was pumped into the thickener at the rate of 3.4 L/m. An increase in pore pressure was measured at the bottom and on the side, as well as an increase in the total pressure at the bottom (as shown in Figures 27, 28 and 29). Pore pressures and total pressures drop rapidly after the thickener was completely filled with slurry. Then pore pressures at the bottom and on the side dissipate more slowly.

Figure 26: Geometry of vertical and horizontal bars attached to rake.

5.4.2. Total pressure and pore pressure measurements and calculations

The total pressure change reflects the settling of the solid particles. Dissipation of pore water pressure can be observed in this plot, while the effective stress remains almost the same. This results from decreased total pressure at the corresponding level. Theoretically the total pressure above a certain depth should decrease and below that depth it will increase. At the bottom of the thickener, the total pressure should be the same all the time. The discrepancy between the calculated total pressure from measured solid contents and the theoretical values may be due to the introduction of a new sampling device and lack of experience in using it.

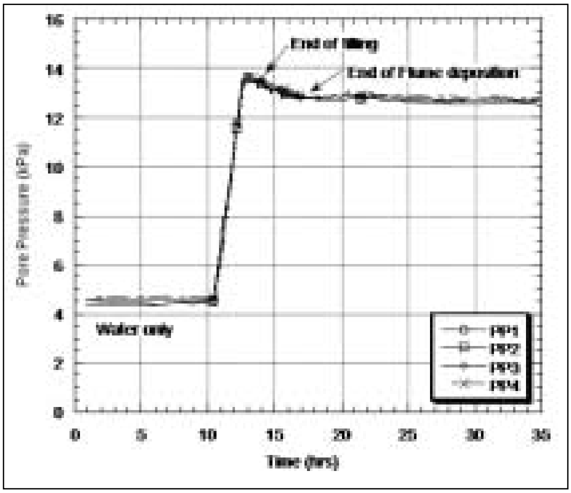

Figure 27: Measured pore pressure for CT3 at the bottom of the thickener.

Nearly uniform solid content and fines content of the slurry below the solid-water interface can be observed from Figure 30. When compared with the solids content and fines content of the feed slurry, the curve demonstrates that there is no substantial water released from the slurry. Non-segregation of the slurry also can be deduced from the curves. Figure 31 shows a decrease in fines content and increase in solid content below the interface three days later. The non-uniform variation in fines content and solids content with depth indicates segregation of the slurry. Figure 32 demonstrates the ability of the thickener instrumentation to capture the development of effective stresses within the slurry.

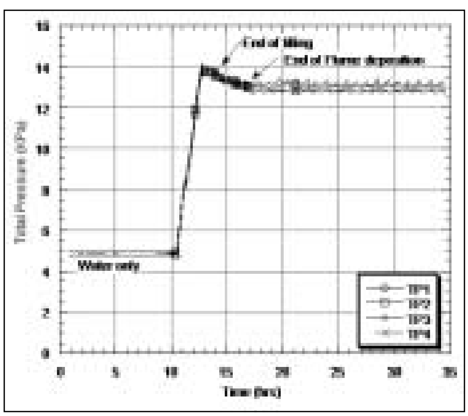

Figure 28: Measured total pressure for CT3 at the bottom of the thickener.

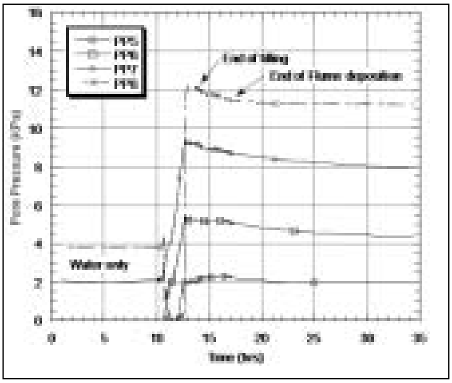

Figure 29: Measured pore pressure for CT3 at the side of the thickener.

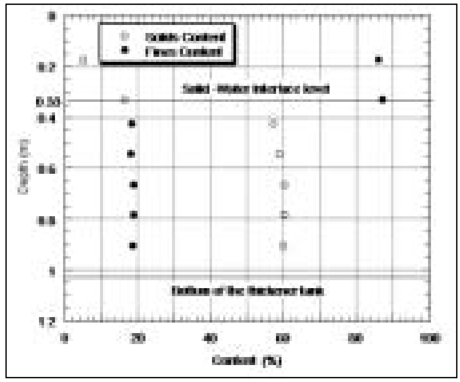

Figure 30: Solids and fines content profiles for CT3 at the end of deposition.

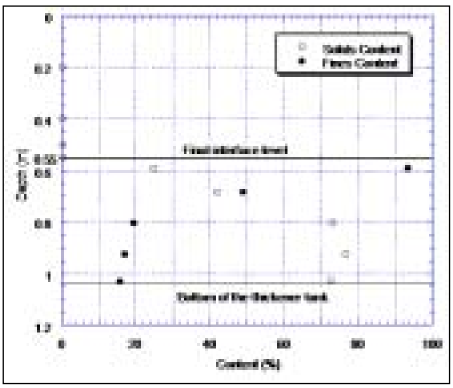

Figure 31: Solids and fines content profiles for CT3 after 3 days of consolidation in thickener.

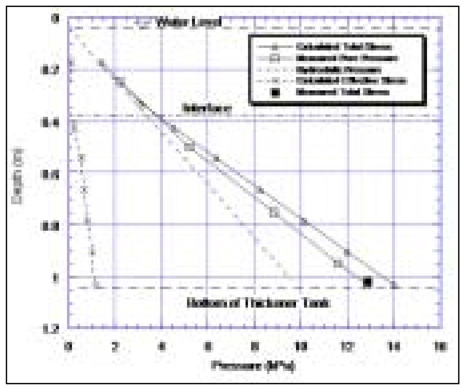

Figure 32: Pressures and stresses at the end of CT3.

6. Flume Tests – CT3

Flume tests were conducted for the underflow slurry to analyze the beach effect of the underflow material. The underflow was pumped using a 3-stage positive displacement pump into the flume and the time for the flow front to reach a specified point was recorded. When the flume was full, the pumping of the slurry was stopped. Then the depths of the slurry at different positions were measured to calculate the slope of the beach. The slurry was left in the flume for 15 days and the beach height was recorded at different times. The process during the filling of the flume was recorded by video camera.

The velocity of the flow is presented in Figure 32. The travel velocity decreased with an increase in travel distance. The low velocity at later time is due to dissipation of energy as it traverses the flume length.

The beach depth at different positions is presented in Figure 33. The decrease of depth with time suggested consolidation had occurred within the deposit. The solids content and fines content profiles were obtained by sampling at the middle layer. The results are shown in Figure 34. The average solid content decreased with distance. The fines content shows an increasing trend, especially at the flume end, where it shows a considerable increase. At the end of the flume, there is an indication of segregation, whereas along the rest of the flume length the readings do not indicate the occurrence of segregation.

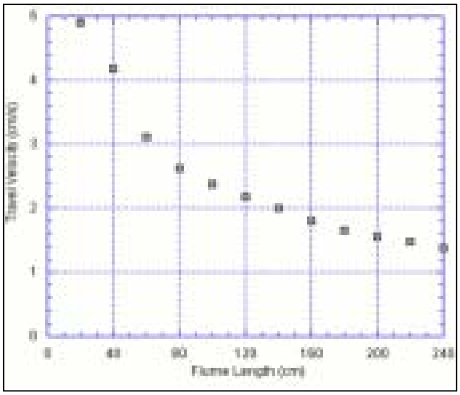

Figure 33: Flow velocity vs. distance for underflow CT materials in test CT3.

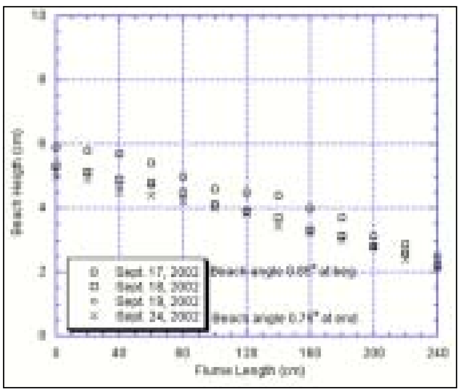

Figure 34: Beach height vs. distance for underflow CT material in test CT3.

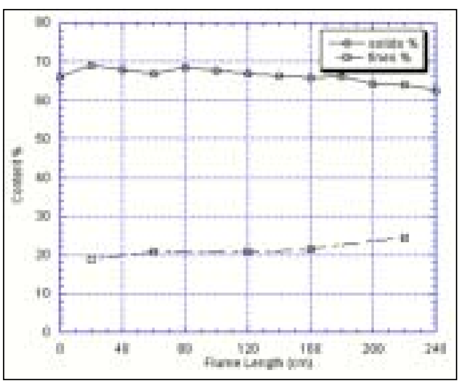

Figure 35: Solids and fines content profile along the flume length after CT material CT3 deposition.

7. Summary

A fully instrumented 1m diameter research thickener has been developed at the University of Alberta to explore the geotechnical physics associated with paste and thickened tailings behavior within a thickener environment. The paper has presented preliminary test results generated in the research thickener for dewatering of consolidated tailings. Research is continuing with the thickener to better understand the evolution of effective stresses within the sedimenting/consolidating material within a thickener. The following are general observations from this first series of tests:

- Pore pressure and total pressure cells are effective at tracking the development of effective stress within thickener.
- Integrated tests conducted in parallel with the thickener tests (i.e., standpipe and flume tests) are valuable components for interpreting the behavior of the tailings.
- Even at the scale of the research thickener, rake design requires care as it was observed that the vertical rod attached to the rake showed a cantilever bending deformation pattern as the rake rotated, even for the low solids loading of the research thickener! It is postulated that the high sand content of the slurry induced the bending loads on the rods.
- The new sampler, which worked well, displaced approximately 7 liters of slurry during insertion in to the thickener. This displacement is quite small compared to the thickener volume (the volume ratio is about 0.9%).
- Residual bitumen is an ongoing issue dealing with field oil sands tailings specimens.
- Gypsum was added into the main mixing tank. This approach may contribute to sedimentation/segregation of particles in the mixer itself. Considerable amount of sediment deposit was observed while cleaning the mixing tank after the test.
- The residence time for the slurry in the thickener is about 3 to 4 hours. Considering the results obtained from the standpipe tests, this residence time is too short. In future experiments the residence time will be lengthened by slowing down the feed rate and starting underflow at a higher interface level.

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References

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