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Co-processing of fresh oil sand tailings and fluid fine tailings

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Abstract

This paper describes co-processing of fresh tailings (i.e. whole tailings), such as coarse tailings and flotation tailings from the oil sand extraction plant, and legacy fluid fine tailings (FFT) in line with a polymeric flocculant to produce paste tailings without the use of thickeners and cyclones. The objective of the project is to develop an efficient and low-cost tailings management technology to accelerate the creation of trafficable landforms that are ready for terrestrial reclamation. The idea for co-processing is that increasing the sand-to-fines ratio (SFR) will increase the hydraulic conductivity of the co-processed deposit, thus accelerating its consolidation rate. Compared to composite tailings (CT) with SFR of 3–5 and FFT centrifuge cake or flocculated FFT (fFFT) with SFR of 0–0.1, the target SFR of co-processing is 1–3 with an optimal SFR of 2. In a broader definition, the co-processing could become the treatment of whole tailings when the FFT supply is shut down or switch to the flocculated FFT process if the fresh tailings are diverted for conventional beaching operation. This paper highlights the advancements in co-processing technology development from laboratory-scale to small pilot-scale. It discusses learnings from large strain consolidation (LSC) and beam centrifuge testing of the co-processed deposits to assess its long-term consolidation within the context of final reclamation and closure. Results to date show that co-processing of fresh tailings and FFT is a promising technology for achieving terrestrial closure of oil sand tailings.

Keywords: *co-processing, fresh tailings, FFT, whole tailings, paste tailings, flocculant, SFR, hydraulic conductivity, LSC, beam centrifuge, terrestrial, trafficable landform, reclamation*

1 Introduction

The co-processing technology deals with the treatment of mixtures of fresh tailings, such as coarse tailings and flotation tailings from the extraction plant, and legacy FFT in line with a polymeric flocculant to produce paste tailings without the use of thickeners and cyclones. The objective of the project is to develop an efficient and low-cost tailings management technology to enable faster creation of trafficable landforms that are ready for terrestrial reclamation. The idea of the project is that increasing SFR could increase the hydraulic conductivity of the co-processed deposit. Compared to CT with SFR of 3–5 and centrifuge cake/flocculated FFT (fFFT) with SFR of 0–0.1, the target SFR of co-processing is 1–3, with an optimal SFR of 2.

In 2012, Syncrude Research and Development (R&D) conceived the concept of co-processing of fresh tailings and FFT and proposed a test plan to conduct the proof-of-concept lab tests. A provisional patent application was filed with the US Patent and Trademark Office in 2012 (Yuan & Siman 2012). Alberta Innovates-Technology Futures (AITF) was contracted to conduct the laboratory flocculation and settling tests under the contract terms and conditions that secured the Syncrude intellectual property during the tests. The main objectives of the initial tests were to evaluate the feasibility of co-processing of fresh tailings from oil sands extraction and FFT and to find the optimal process conditions such as the co-processing feed density and SFR, polymer type, dosage, and concentration required for flocculation.

It was found in the 2012 laboratory tests that the concept of co-processing of fresh tailings and FFT was feasible. Two polymers (SNF3335 and SNF3338) out of eight polymers tested, on average, gave the best flocculation performance. The best flocculation was obtained at feed solids content of 13–25% and feed SFR values of about 1.5–2 with the polymer dosage of 200~250 g/t of dry solids. Under these conditions, a supernatant of <0.5% total solids after 10 min settling and a sediment of 50~53% solids at 24 hours were obtained. No significant segregation was observed in the sediments within the target SFR range of 1–2 and a 13–25% initial solids content. The feed solids contents from 25–50% solids and SFRs from 2–3 need to be further tested, but it is unlikely that segregation would occur at the high initial solids content compared to the lower range at 13–25%.

Following the successful laboratory tests, small continuous pilot tests were conducted at a feed rate of 20 L/min (1.2 m^3/h) in CANMET Devon in 2013. At the same time, flume and 2 m high column tests were conducted to evaluate the co-processed deposit performances. The small pilot tests showed that co-processing of fresh tailings and FFT with a polymer can be reliably and robustly operated in a continuous process. The co-processed deposit in the 2 m column consolidated to 75–82% solids in three months. The deposit with about 60 cm thickness in the flume consolidated to 70–82% solids in <3 months. The test results were promising. A technical gap assessment conducted in 2015 by Syncrude R&D determined that it would be useful to conduct geotechnical measurements on a wide range of co-processed deposits with SFRs from 0–3. The geotechnical tests included Atterberg limits and large strain consolidation (LSC) tests to measure the compressibility and permeability of the co-processed deposits.

The LSC data validated the idea that increasing SFR did increase the hydraulic conductivity of a co-processed deposit. It was found that the hydraulic conductivity of co-processed deposits at SFR 2 is more than three orders of magnitude higher than that of flocculated FFT with SFR 0.05 (Yuan 2019). Afterwards, a confirmatory LSC test and a beam centrifuge test were conducted to simulate the consolidation performance of a 50 m deep co-processed deposit over a period of 150 years. The beam centrifuge simulation demonstrated that the co-processed deposit with SFR 2 could reach the end of consolidation in <3.5 years, while the cohesive FFT deposits (i.e. flocculated FFT and FFT centrifuge cake) with SFR 0.05 and equivalent geometry (50 m initial thickness) would take >50 years to complete consolidation. These test results further proved the idea that increasing SFR increased hydraulic conductivity of co-processed deposits, accelerated the deposit consolidation rate, and reduced the consolidation time. Meanwhile, co-processing of fresh oil sand tailings and FFT was awarded a Canadian patent in 2017 (Yuan & Siman 2017). Based on work to date, co-processing is a promising technology that warrants further development.

A second technical gap assessment was conducted in 2020 by Syncrude R&D. The technical gap assessment recommended the need to resolve the following technical uncertainties before moving from laboratory scale to next stage of tests:

- Optimal pipeline flow regimes/velocities post polymer injection.
- Dynamic mixer scale-up parameters.
- Optimal feed density/solids content.
- Feed mineralogy sensitivity effect.
- Static and dynamic segregation.
- Different chemical recipes.
- Effect of release water on bitumen extraction.
- Geotechnical assessment LSC and beam centrifuge tests.
- Geochemical assessment of impact on porewater.

To resolve the technological uncertainties identified above, a test plan was developed to be executed in two phases – phase 1: laboratory tests and phase 2: small pilot tests.

In a broader definition, the co-processing could become the treatment of whole tailings when the FFT supply is shut down. For whole or coarse tailings flocculation, preliminary laboratory tests were conducted with Syncrude tailings materials (Dang-Vu et al. 2014). It was found that 99% of the fines were captured with negligible segregation. In another configuration, the co-processing could switch to the flocculated FFT process if the fresh tailings are diverted to conventional beaching operations. This paper will highlight the advancements in co-processing technology development from laboratory-scale to small pilot-scale. It also discusses learnings from LSC and beam centrifuge testing of the co-processed deposits to assess its long-term consolidation performance within the context of final reclamation and closure.

2 Experimental

2.1 Test materials

The test materials included Syncrude fresh tailings and FFT from the Mildred Lake Settling Basin. The water used for preparing polymer solution and feed dilution is recycle water (RCW) from the Syncrude Mildred Lake site. The FFT contains 97–99% <44 µm fines with D50 of 4.5–4.6 µm. The fresh tailings contain 13.2–13.8% <44 µm fines with D50 of 156.7 µm. The FFT, fresh tailings and RCW were mixed at a given ratio to prepare the co-processing feed for the laboratory and small pilot tests.

2.2 Co-processing feed preparation

The solids contents and SFRs of FFT and fresh tailings were measured using the improved Syncrude in-house rapid wet sieving method. This method measures solids content, SFR, and <44 µm fines content of a tailings sample in less than 30 minutes compared with the conventional Dean-Stark method for oil/water/solids (OWS) analysis and Coulter particle analysis (CPA) that may take days. With the measured solids contents and SFRs of FFT and fresh tailings, the weights and volumes of the two tailings and RCW can be calculated for preparing a target volume (e.g. 18 L for lab test, or 1.7 m^3 for the small pilot test), solids content (e.g. 35% wt.) and SFR (e.g. 2.0) of a co-processing feed. The mixture was poured/pumped and mixed in the co-processing feed preparation tank with an agitator. The solids content and SFR of the co-processing feed were verified with the rapid wet sieving method to ensure they were within the target ranges before the flocculation or the pilot tests.

2.3 Chemicals

The anionic polymeric flocculant used in the co-processing laboratory and pilot tests is SNF3338. It was prepared at 0.4% wt. using RCW and the polymer solution hydrated overnight (i.e. 24 h) before use. The flue gas desulphurisation (FGD) solids (mainly comprised of calcium sulphite hemihydrate, calcium hydroxide, and calcium sulphate dehydrate), a byproduct from Syncrude flue gas desulphurisation (FGD) process, with 68.04% solids or the Mountain gypsum powder with 88.01% solids were added and premixed with the co-processed feed for at least 15 minutes before adding polymer solution. Liquid alum with Al of 4.0–4.5% wt. (provided by Kemira) was diluted 20 times with RCW before use. In this paper, except where specified, all chemical dosages are on a <44 µm fines basis.

2.4 Procedures for the laboratory tests

In general, about 1 L co-processing feed was taken from the feed preparation tank and poured into a flocculation test tank shown in Figure 1. The diameter of the 2.5 L tank, T, is 120 mm. The flat blade turbine impeller has six blades with a diameter, D, of 84 mm. The D/T ratio of the impeller is 0.70.

For polymer-alone recipe tests, the feed was premixed at 300 rpm in the stainless-steel flocculation test tank for about 1 minute. With the mixer running at 300 rpm, the pre-measured polymer solution was gradually injected during a period of 20 seconds with 60 ml syringes through the polymer injection tube on the tank (Figure 1). Then, 10 ml water was quickly injected to rinse the polymer solution in the tube and mixed for additional 10 seconds. The mixer was stopped, the flocculated material poured into a 1 L beaker, and photos of the floc structures in the beaker were taken. The yield stress of the flocculated material was then measured in the 1 L beaker. The CST (capillary suction time) of four duplicates was determined by filling the CST cells with the flocculated material using a spoon. Whatman 4 filter paper was used for the CST tests. Two tubes of the flocculated material were taken to run the laboratory centrifuge at 3,000 rpm for 2 minutes. The rest of the flocculated material was poured into a 2 L graduated cylinder, followed by monitoring the cylinder settling and taking supernatant samples at 10 minutes and 24 hours. The supernatant water was decanted and the solids contents of top, middle and bottom of the sediment after 24 hours settling were determined.

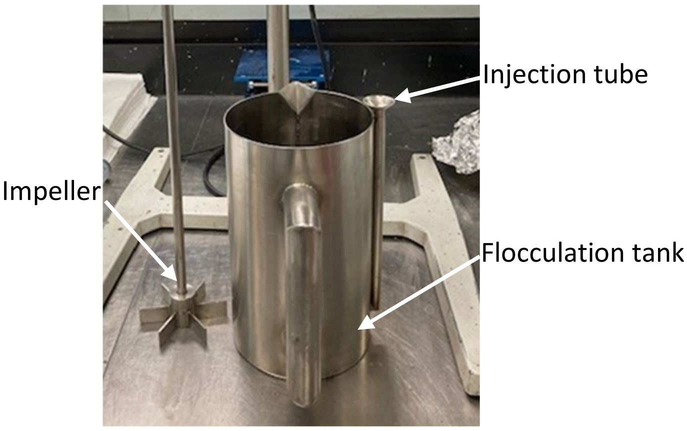


Figure 1 Laboratory stainless-steel flocculation test tank and a six-blade flat blade turbine impeller

For tests of the recipe of FGD solids + polymer, or gypsum + polymer, FGD solids or gypsum powder was added to the stainless-steel mixing tank and premixed for 15 minutes before adding polymer solution. The rest of the test procedures and key performance indicator (KPI) measurements of the flocculated materials were the same as those for polymer alone.

In addition, the flocculation-coagulation (FC) process was compared with the conventional coagulation-flocculation (CF) process by just changing the sequence of chemical addition. For the FC process, the solution of alum was added to the top of the slurry vortex and mixed at 300 rpm for 20 seconds in the mixing tank following the polymer addition and mixing. For the conventional CF process tests, alum was added first followed by the polymer solution. Moreover, the flocculation-coagulation-flocculation (FCF) process was validated by adding a small amount of flocculant to strengthen the FC processed materials (Yuan & Shaw 2007; Yuan 2011). The flocculated material was poured into a 1 L beaker to perform the same KPI tests as those for the polymer-alone tests.

2 L graduated cylinder settling tests with duplicate flocculated materials using the optimal flocculation test conditions were performed to evaluate static segregation by measuring the solids contents and particle size distributions of top, middle and bottom of sediments after 24 h of settling.

2.5 Flow sheet and procedures for the small pilot tests

The flow sheet for the small pilot tests of co-processing of fresh tailings and FFT with different chemical recipes is depicted in Figure 2. Similar to the lab bench tests, the solids contents and SFRs of the fresh coarse tailings and FFT were pre-determined by the wet sieving method. The weights of coarse tailings, FFT and RCW were pre-calculated for a given volume/weight of co-processing feed in the feed tank and a target solids content of 35% and SFR of 2. The feed tank with an agitator sat on a digital scale, so the weight of slurry in the tank could be measured and monitored during the pilot tests. The feed solids and SFR in the tank were checked to make sure the slurry in the feed tank was homogeneously mixed and on-spec of the target solids content and SFR before starting the pilot tests.

The nominal feed flow rate was fixed at 150 L/min (9 m^3/h) with solids content of 35% wt. and SFR of 2. Four chemical recipes were tested, which included polymer only (SNF 3338), FGD + polymer, gypsum + polymer, polymer + alum. For the tests with FGD or gypsum, the FGD solids or gypsum was premixed in the feed tank for at least 15 minutes before the pilot tests. The feed slurry was pumped through the first inline dynamic mixer and mixed with polymer solution while the second inline dynamic mixer was turned off. For the tests with polymer and alum, the second inline dynamic mixer was also turned on to mix in the alum solution. The mixing intensity of both mixers, the polymer and alum dosages, feed solids content and SFR were tested. After the optimal test conditions were obtained with the 5 m short pipeline, the 40 m long pipeline loop tests were conducted to evaluate the impact of pipeline shear on segregation. The optimal test conditions with the 40 m long pipe loop were used for the flume tests (0.5 m wide × 0.6 m high × 7m long) to evaluate dewatering behaviour and segregation in the flume.

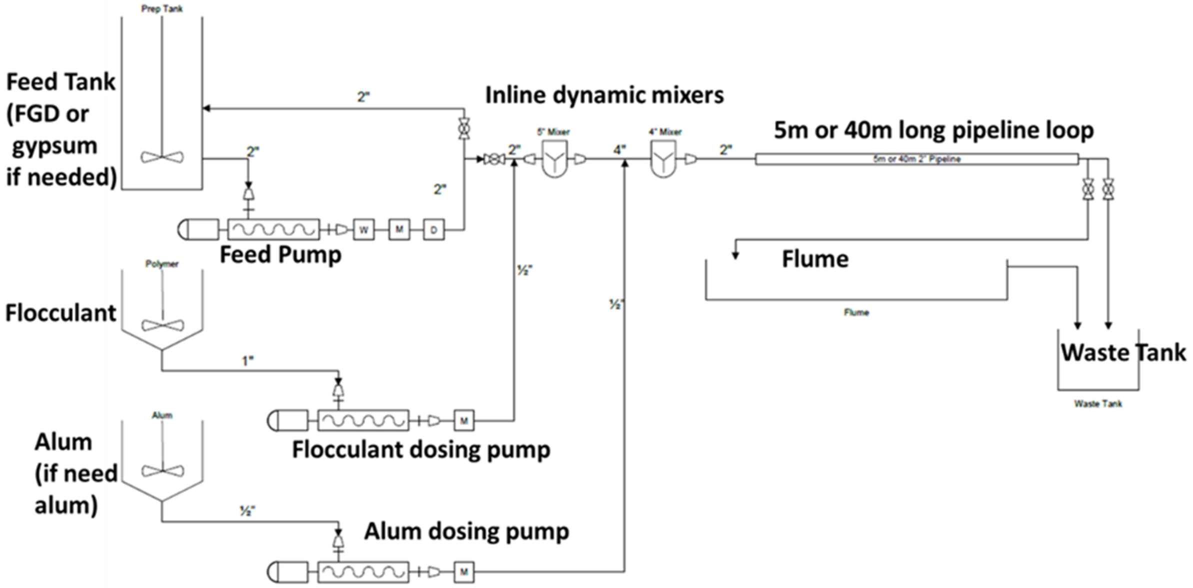


Figure 2 Flow sheet for the pilot tests of co-processing with different chemical recipes

3 Results and discussion

3.1 Lab test results

3.1.1 Feed solids content tests

In this series of tests, the fixed test conditions were SNF3338 dosage of 1,000 g/t and the target feed SFR of 2.0. The feed solids contents were changed from 20 to 45% with the purpose of finding out the optimal feed solids content for co-processing. The test results are shown in Figures 3–5.

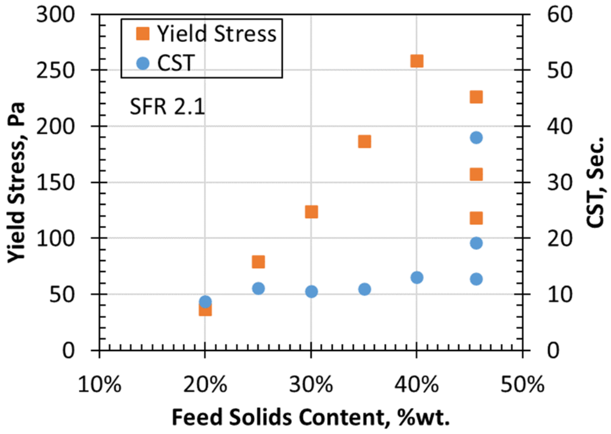


Figure 3 Effect of feed solids contents on yield stress and CST of flocculated materials

Figure 3 shows the effect of feed solids contents on yield stress and CST of flocculated materials. When the feed solids contents were increased from 20 to 40%, the CST values did not change very much at about 10 seconds, which indicated good flocculation and fast dewatering. However, it was difficult to mix the flocculant and the slurry at 45% solids. As a result, the flocculation performance was not consistent as indicated by the inconsistent CST data at 45% solids. When the feed solids contents were increased from 20 to 40%, the yield stress increased from 40 to 260 Pa. The yield stress was not consistent at 45% solids. These test data showed the optimal feed solids content could be 35–40%.

Figure 4 shows the effect of feed solids contents on supernatant solids contents. The 10 minute supernatant solids contents did not change very much when the feed solids contents increased from 20 to 40%. However, it increased significantly at the feed solids content of 45%. The feed solids content varying from 20 to 45% did not have clear effect on the 24 h supernatant solids contents, which was less than 0.5%.

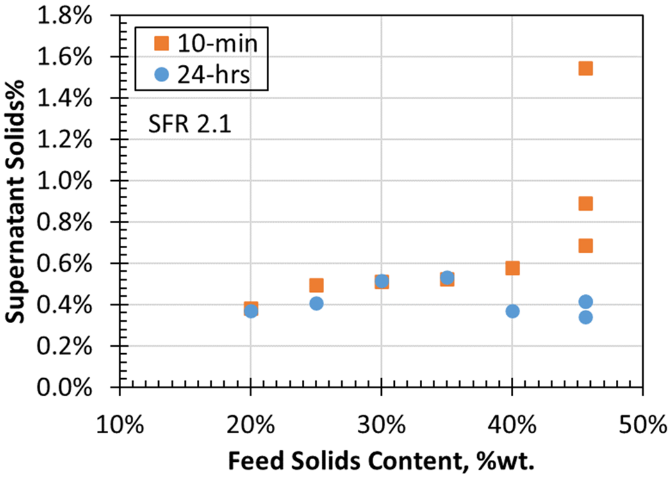


Figure 4 Effect of feed solids contents on supernatant solids contents

As shown in Figure 5, the feed solids contents increasing from 20 to 45% did not have significant effect on sediment solids contents, varying from 52 to 55%. The solids contents of the bottom of sediments are always higher than those of the top of sediments. In summary, the optimal feed solids content was found to be 35–40% at SFR of 2.

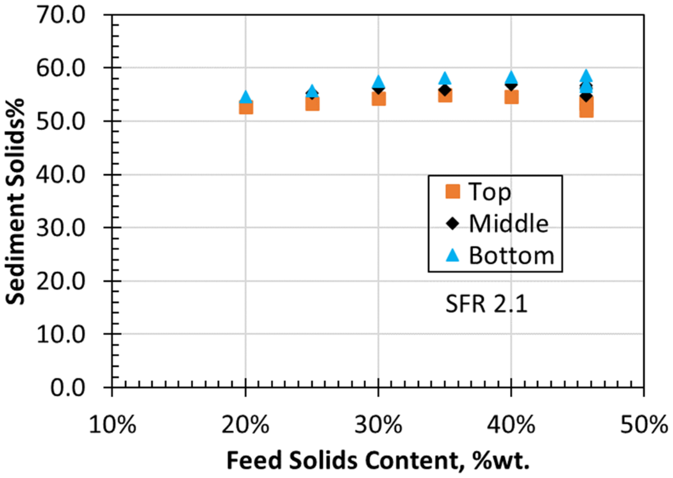


Figure 5 Effect of feed solids contents on sediment solids contents

3.1.2 Polymer dosages

The fixed test conditions for this series of tests were the target feed solids content of 35% and SFR of 2.0. The polymer dosages of SNF3338 were tested from 600 to 1,200 g/t of <44 µm fines. It was found that there was no flocculation if the SNF3338 dosage was equal to or less than 700 g/t. The effect of polymer dosages on supernatant solids contents is shown in Figure 6. The supernatant solids contents at 10 minute settling decreased with the polymer dosage increase from 700 to 900 g/t, and then stabilised around 0.5% when polymer dosages were changed from 1,000 to 1,200 g/t. However, the 24 h supernatant solids content did not change very much around 0.5% for polymer dosages varying from 700 to 1,200 g/t.

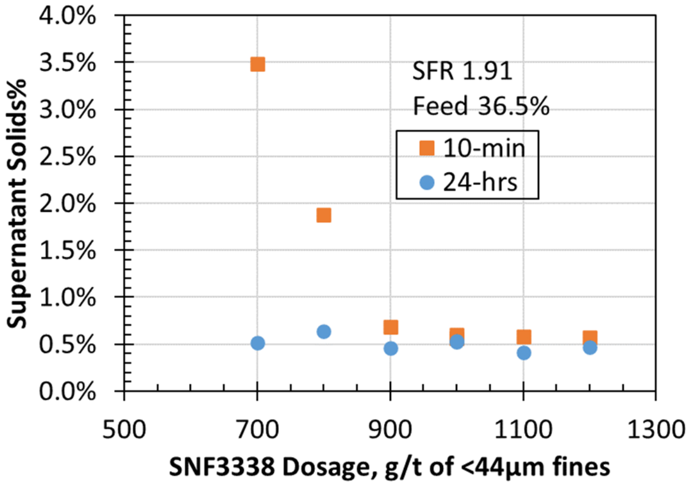


Figure 6 Effect of polymer dosages on supernatant solids contents

In summary, the optimal SNF3338 dosage was found to be 1,000–1,100 g/t of <44 µm fines for the target feed solids content of 35% solids and SFR of 2.0. Poor flocculation and sand segregation appeared for SNF3338 dosages equal or less than 700 g/t of <44 µm fines.

3.1.3 FGD + polymer

Different chemical recipes, in addition to polymer alone, were tested. In this series of tests, the fixed test conditions were the SNF3338 dosage of 1,000 g/t of <44 µm fines, the target feed solids content of 35% and SFR of 2.0. The dosages of FGD solids were tested from 1,000–5,000 g/t.

Figure 7 shows the effect of FGD solids dosages on yield stress and CST of flocculated materials. The CST values did not change at about 10 seconds when FGD solids dosages were increased from 0 to 4,000 g/t, and then went up to 22 seconds at an FGD dosage of 5,000 g/t. This means the FGD + polymer recipe performed equally as well as the polymer-alone recipe when the FGD dosage was equal to or less than 4,000 g/t. Too high a FGD dosage of 5,000 g/t is detrimental for flocculation. The addition of FGD from 0–5,000 g/t just slightly increased the yield stress from 190 to 240 Pa.

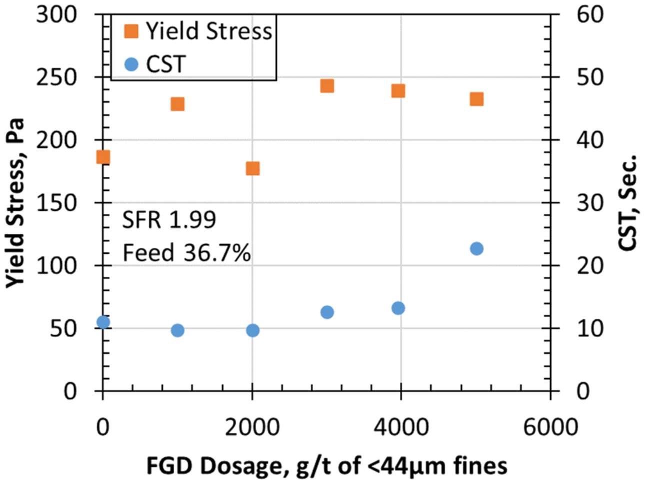


Figure 7 Effect of FGD solids dosages on yield stress and CST of flocculated materials

3.1.4 *Gypsum + polymer*

In this series of tests, the fixed test conditions were the SNF3338 dosage of 1,000 g/t of <44 µm fines, the target feed solids content of 35% and SFR of 2.0. The dosages of gypsum were tested from 500–2,000 g/t. Figure 8 shows the effect of gypsum dosages on yield stress and CST of flocculated materials. The CST values did not change at about 10 seconds when gypsum dosages were increased from 0 to 2,000 g/t. This means the gypsum + polymer recipe performed equally well as the polymer-alone recipe when gypsum dosage is at 500–2,000 g/t. The addition of gypsum from 0–2,000 g/t only slightly increased the yield stress.

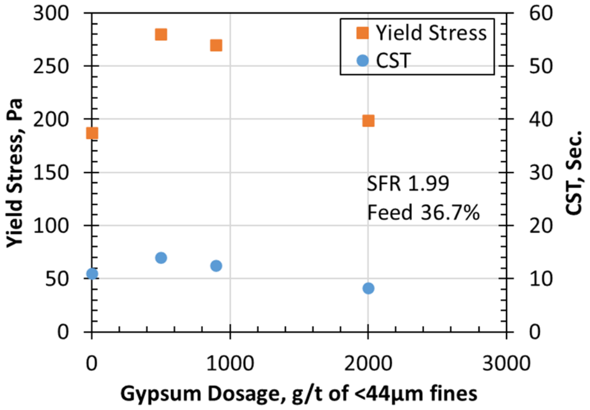


Figure 8 Effect of gypsum dosages on yield stress and CST of flocculated materials

3.1.5 *Polymer + alum, CF versus FC and FCF process*

In this series of tests, the fixed test conditions were the SNF3338 dosage of 1,000 g/t of <44 µm fines, the target feed solids content of 35% and SFR of 2.0. Alum was tested from 0–500 g/t on Al basis. The flocculation tests were conducted using the FC process compared with the conventional CF process by just changing the sequence of chemical addition. For cationic polymeric coagulants, previous studies have shown that FC, FCF and coagulation-flocculation-coagulation (CFC) processes significantly outperformed the conventional CF process (Yuan & Shaw 2007; Yuan 2011). For soluble cationic inorganic coagulants, such as alum and poly-aluminium, this study is the first to evaluate the FC and FCF process versus the CF process for co-processing feed with SFR of 2.

Figure 9 shows the effect of alum dosages on yield stress of flocculated materials for the FC versus CF process. When alum dosage was increased from 100 to 500 g/t on Al basis, the yield stress of the materials treated with the FC process was much higher (i.e. 120 versus 20 Pa) than that of the materials treated with the conventional CF process. It was also noticed that the addition of alum clearly decreased the yield stress compared to without alum.

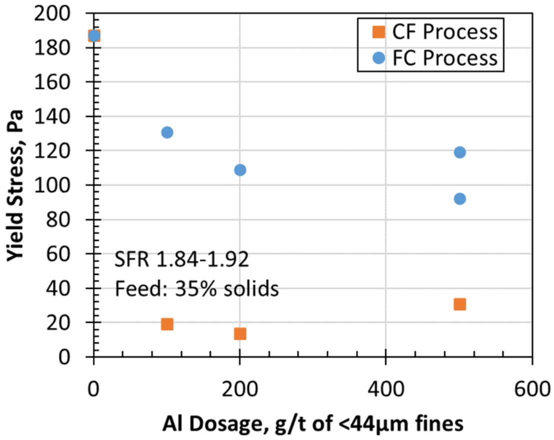


Figure 9 Effect of alum dosages on yield stress of flocculated materials for the FC versus CF process

Figure 10 shows the effect of alum dosages on CST of flocculated materials for the FC versus CF process. When the alum dosage was increased from 100 to 500 g/t on Al basis, the CST of the materials treated with the FC process was much lower (i.e. 5–12 s versus 40–55 s) than that of the materials treated with the conventional CF process. It means that the materials treated with the FC process dewaters much faster than those treated with the conventional CF process with alum and polymer.

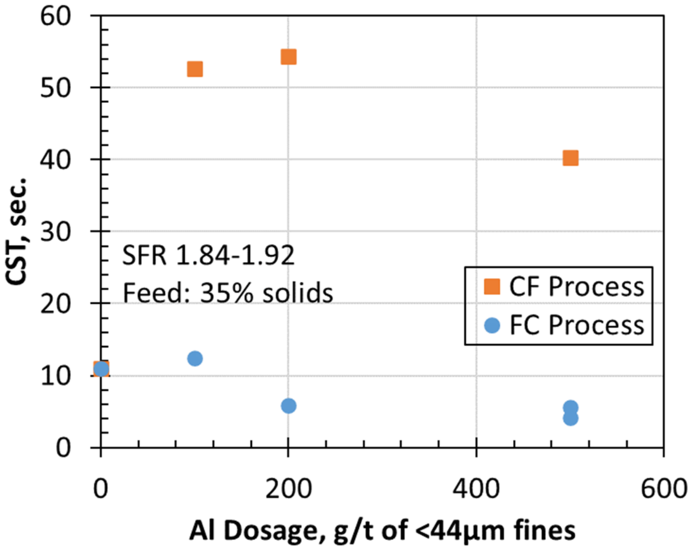
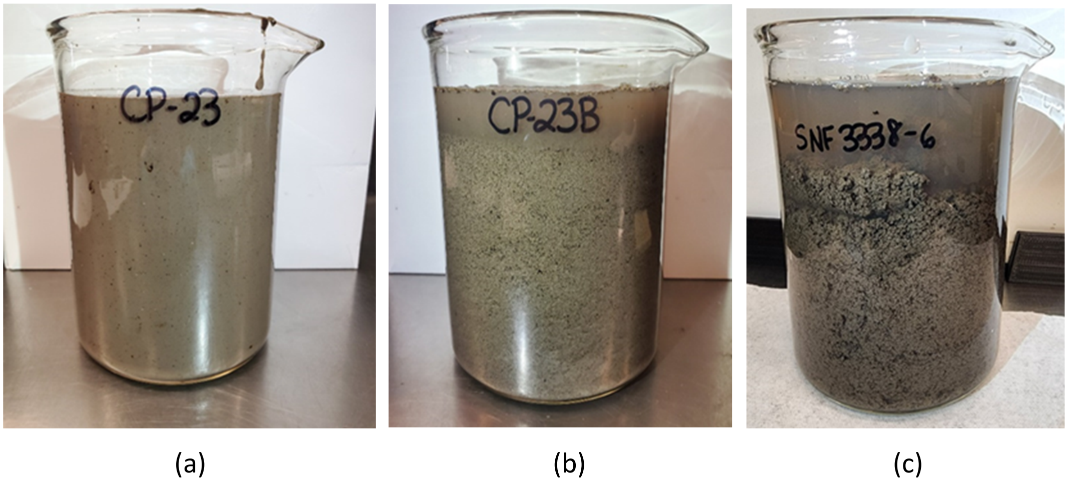


Figure 10 Effect of alum dosages on CST of flocculated materials for the FC versus CF process

Figure 11 depicts the floc structures of the CF versus FC and FCF processes. As shown in Figure 11, large flocs for the FC process were formed compared with the tiny flocs for the conventional CF process. For the FCF test, a small amount of 200 g/t SNF3338 was added to the FC process, which strengthened the flocs structures of the sand and fines matrix as indicated by the yield stress of the flocculated materials.



(a) (b) (c)

Figure 11 Floc structures and yield stresses of CF (a) 14 Pa versus FC (b) 109 Pa and FCF (c) 341 Pa

In summary, for soluble cationic inorganic coagulant, i.e. alum, the FC or FCF process significantly outperformed the conventional CF process, which is consistent with the previous findings with cationic polymeric coagulants (Yuan & Shaw 2007; Yuan 2011). The mechanisms of these processes were elaborated in literature (Yuan & Shaw 2007). The FC process was also validated for co-processing with other soluble inorganic and organic cationic coagulants, such as poly-aluminium and cationic polymer.

3.1.6 SFR tests

In this series of tests, the fixed test conditions were the SNF3338 dosage of 1,000 g/t of <44 µm fines, with the target feed solids content of 35%. Figure 12 shows the effect of SFR on yield stress and CST of flocculated materials. When SFRs were increased from 1 to 3, the yield stresses were increased from about 100 Pa to about 300 Pa, while the CST was decreased for SFR from 1 to 1.5 and then stabilised at about 10–12 seconds for SFR from 1.5–3. This means that the dewatering rates of flocculated materials increased with increase in SFR.

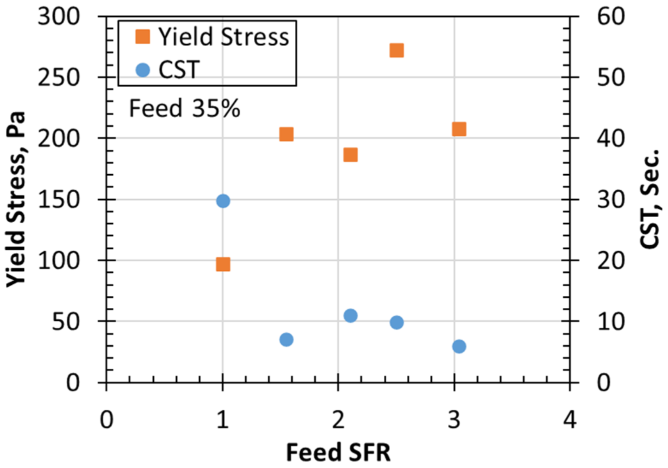


Figure 12 Effect of SFR on yield stress and CST of flocculated materials

Figure 13 shows the effect of SFR on sediment solids capture and net water recovery. The sediment solids capture is defined as the percentage of solids captured in the sediment against the amount of solids in the feed. The net water recovery is defined as the percentage of the supernatant release water from which the volume of added chemical solution is subtracted and then divided by the amount of water in the feed. When SFRs were increased from 1 to 2, the net water recovery was increased from 40 to 62%, and then levelled out at about 62% for SFR from 2 to 3, while the sediment solids captures did not vary at 99%. The test data in Figure 13 indicate that the optimal SFR is 2.

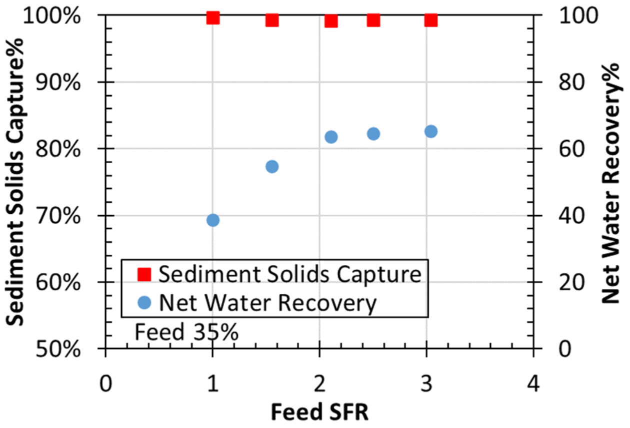


Figure 13 Effect of SFR on sediment solids capture and net water recovery

3.1.7 Static segregation tests

The objective of this series of tests is to verify if there is static segregation of sand from fines in 2 L graduated cylinder settling tests. The 2 L cylinder settling tests were performed using the optimal test conditions obtained above for different chemical recipes. Subsamples were taken from top, middle and bottom of the respective sediment after 24 h of settling for OWS and CPA analyses. Figure 14 demonstrates that the <44 µm fines contents from top to bottom of the sediment are almost identical. This is consistent with visual observation during the settling tests. The test data in Figure 14 proved that there was no static segregation in sediment produced using polymer alone.

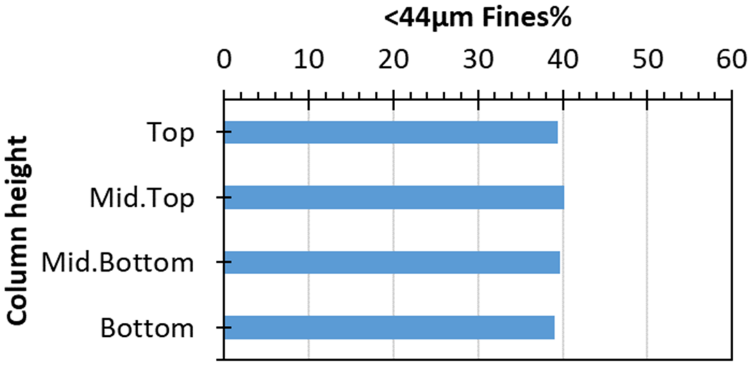


Figure 14 Profile of <44 µm fines contents from top to bottom of sediment for polymer alone

3.2 Highlight of the small pilot tests

3.2.1 Mixing intensity (Kc)

This series of experiments involved varying the speed of the inline dynamic mixer used to blend the polymer with the co-processing feed. The mixer speeds were selected based on a scaling relationship determined in previous work with Syncrude given by Equation 1.

$$K_c = \frac{N^2 D^4}{Q} \tag{1}$$

Where:

N = the mixer speed in revolutions per second.

D = the impeller diameter in metres.

Q = the total flow rate through the mixer in m^3/s.

K_c = a mixing intensity parameter in m/s.

For the polymer mixer, the impeller diameter *D* was fixed at 3.5 inches (88.9 mm) and the nominal flow rate, *Q*, was 150 L/min. Therefore, in this case, the use of this relation essentially meant that there was a square root relationship between the mixer speed, *N*, and the selected mixing intensity, K_c.

Figure 15 shows the sample results for mixer speed tests with polymer only and tests with FGD solids and gypsum as additional additives. The polymer dosage was 1,200 g/t, and where applicable, the FGD solids dosage was 3,950 g/t, and the gypsum dosage was 900 g/t. All dosages were <44 µm fines based. For the three recipes, the trend is similar.

The treated materials generally seemed well flocculated with substantial immediate water release. The CST results were generally very good (<10 s) for all the mixer speeds except the lowest and highest values. The yield stress showed the expected trend of decreasing strength with increasing mixer speed, but at low speeds the results were inconsistent as the material was undermixed. The 10 minute supernatant solids also had inconsistent results at low mixer speeds, with an apparent optimum around K_c 10–25. Higher speeds led to slightly elevated supernatant solids levels, presumably due to the increased shear liberating fines from the flocs. The 24 hour supernatant solids content showed good results (<0.5 wt.%) for all samples, regardless of mixer speed.

After the individual test variables were tested with the 5 m short pipeline, the 40 m long pipeline loop with 2 inch (0.0508 m) in diameter was tested. It was found that the long pipeline shearing and the slightly lower polymer mixing intensity at K_c 10 resulted in no segregation of sand in the pipeline. These optimal test conditions were used for the subsequent flume deposition tests. Figure 16 shows the floc structures (left) at the end of the 40 m long pipeline and deposit (right) in the flume for the polymer-alone recipe. It was found that the treated materials dewatered rapidly in the flume and no significant segregation was observed in the deposit as shown in Figure 16.

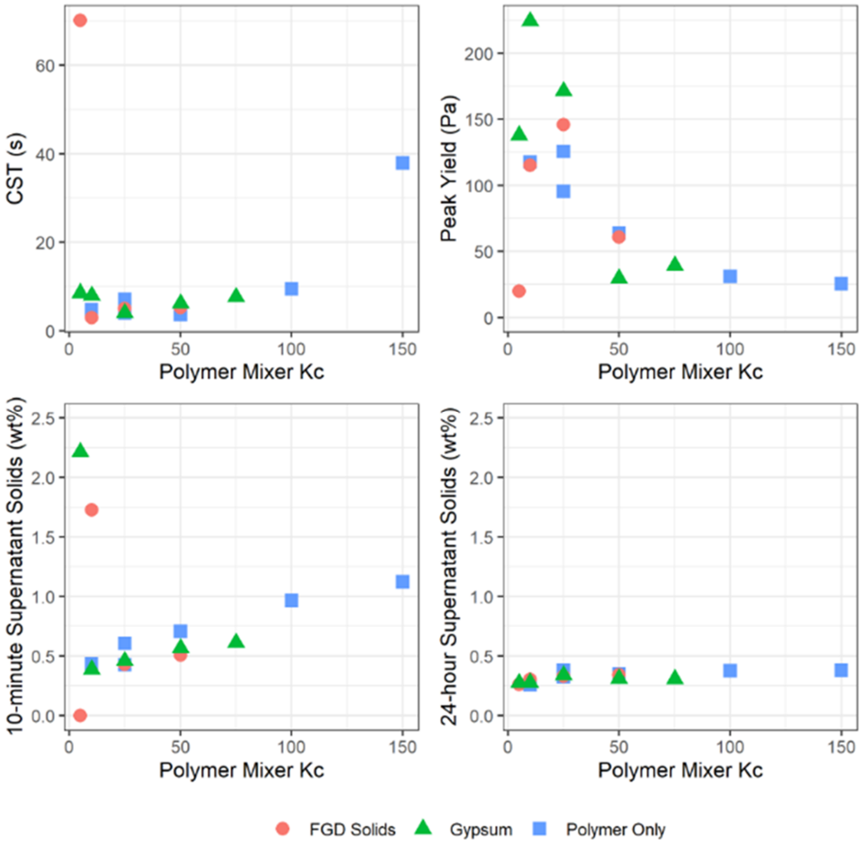


Figure 15 Sample results for mixer speed tests with polymer only and tests with FGD solids and gypsum as additional additives


(a) (b)

Figure 16 Floc structures (a) at the end of the 40 m long pipeline and deposit (b) in the flume

3.3 Large strain consolidation and Atterberg limit tests

Large strain consolidation and Atterberg limit tests were conducted on the co-processed tailings obtained from the small pilot tests. The Atterberg limit tests showed the average liquid limit (LL) of the co-processed tailings at about SFR of 2 was 24.5% regardless of the chemical recipe, which is much lower than that of 62.0% for fFFT with SFR of 0.05. However, the average plastic limit (PL) of the co-processed tailings is about 16.8%, which is close to that of 18.9% for fFFT. The plasticity index (PI = LL - PL) is 7.7% for co-processed tailings and 43.1% for fFFT. A smaller plasticity index for co-processed tailings indicates a faster deposit consolidation rate (Carrier et al. 1983). At the PLs, the corresponding solids content is about 85.6% for the co-processed tailings and 84.1% for the fFFT.

The compressibility of co-processed tailings with SFR of about 2 compared with fFFT with SFR of 0.05 is shown in Figure 17. It was found that compressibility of the co-processed tailings was similar regardless of the chemical recipe used for the co-processing. Compared with the compressibility of fFFT, the co-processed tailings were less compressible, indicating its deposit would result in a much smaller settlement compared to an equivalent thickness of fFFT deposit. This means that a smaller amount of capping material would be placed post deposition and stabilisation to create a terrestrial landform for co-processed tailings compared to fFFT.

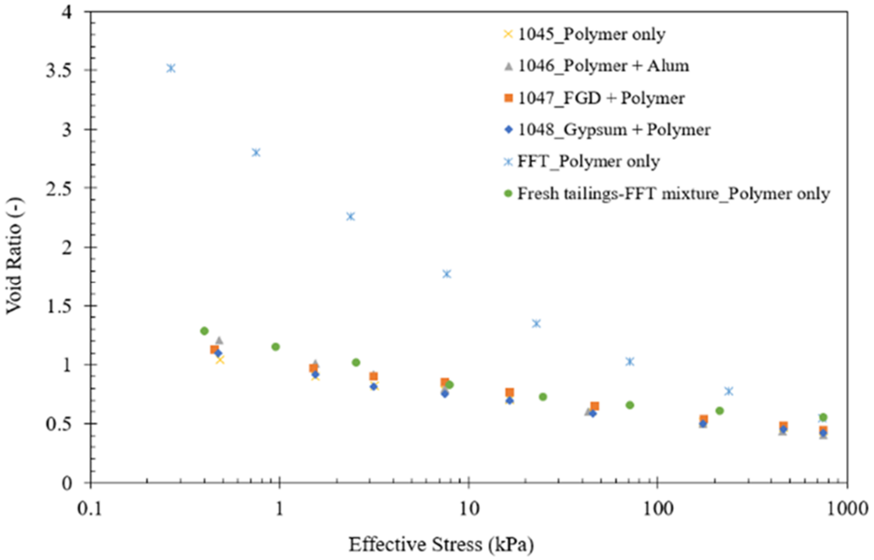


Figure 17 Compressibility of co-processed tailings with SFR of about 2 versus fFFT with SFR of 0.05

The hydraulic conductivity of co-processed tailings with SFR of about 2 compared to fFFT with SFR of 0.05 is shown in Figure 18. It is evident that the co-processed deposits with SFR of about 2 have 2–3 orders of magnitude higher hydraulic conductivity than that of fFFT with SFR of 0.05. This signifies that co-processed tailings deposit will consolidates at a faster rate than an equivalent deposit of fFFT.

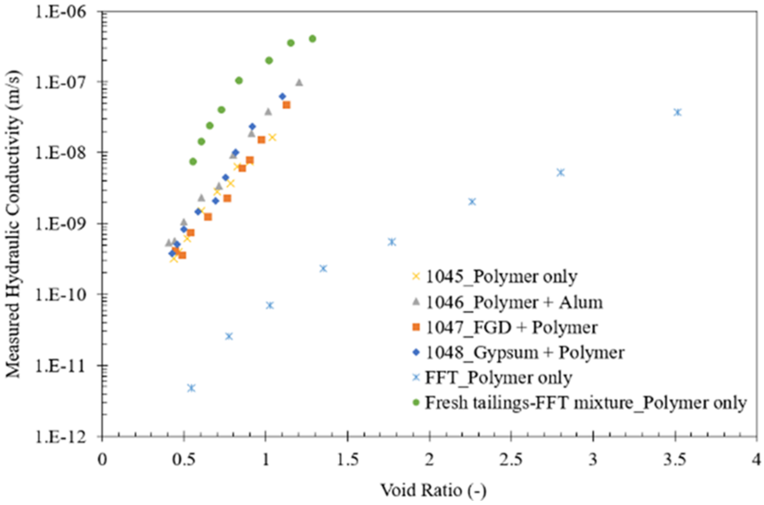


Figure 18 Hydraulic conductivity of co-processed tailings with SFR of about 2 versus fFFT with SFR of 0.05

3.4 Beam centrifuge tests

To predict the long-term consolidation of the co-processed tailings, beam centrifuge tests were conducted to simulate a 50 m deep deposit for 150 years and compared with the test results for fFFT and FFT centrifuge cake deposits. Figure 19 shows the normalised settlements of co-processed deposits compared to fFFT and centrifuge cake deposits. The co-processed tailings deposit at SFR of about 2 consolidated to about 83% solids in <3.5 years, and then the curve levelled out, meaning that the consolidation was completed in less than 10 years. In contrast, the fFFT and centrifuge cake deposits consolidate after 150 years to 65% and 75% solids content, respectively.

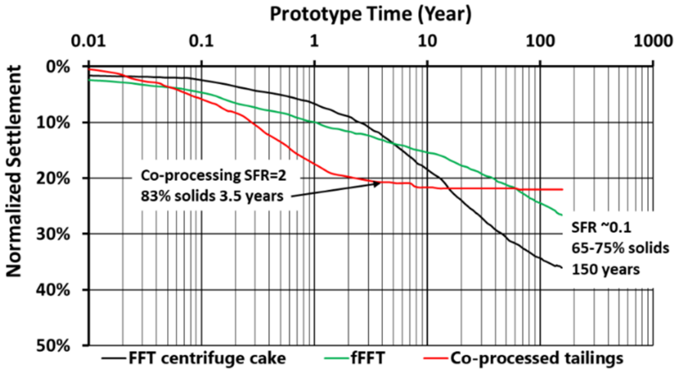


Figure 19 Normalised settlements of co-processed deposit compared to fFFT and centrifuge cake

Figure 20 shows the comparison of t_{90} (based on degree of settlement relative to the ultimate settlement) of consolidation of co-processed deposit compared to fFFT and centrifuge cake. The co-processed deposit could reach 90% consolidation in less than one year, while the fFFT and centrifuge cake deposits will take about 65 years to reach 90% degree of consolidation.

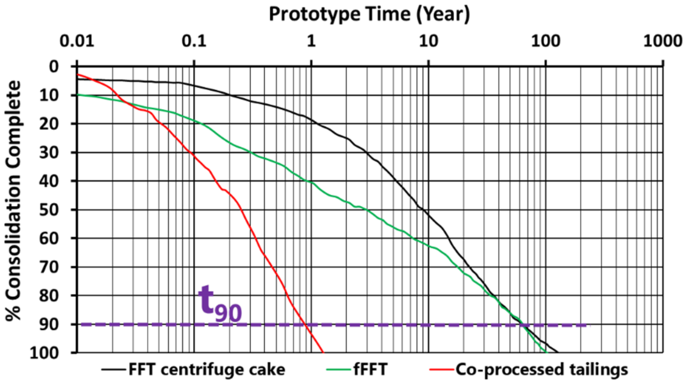


Figure 20 Comparison of t_{90} of consolidation of co-processed deposit compared to fFFT and centrifuge cake

3.5 Prospect of closure and reclamation of co-processed deposit

As shown in Figure 19, at the end of consolidation in the beam centrifuge, the co-processed deposit could achieve the plastic limit solids content, which had an undrained shear strength of 80–120 kPa as measured during the beam centrifuge tests. Once the co-processed deposit consolidates to this shear strength in 3~5 years, capping materials can be placed on the surface of the co-processed deposit and progressive reclamation can be initiated. In this way, the pace of closure and reclamation of disturbed lands can be accelerated, and terrestrial closure landforms required for integration into the overall mine closure landscape can be successfully created.

4 Conclusion

The laboratory tests showed that the optimal feed solids content was 35~40% and the optimal feed SFR was 2. The polymer dosages were 1,000–1,100 g/t on <44 µm fines basis. Four chemical recipes were developed, including polymer alone, FGD + polymer, gypsum + polymer and polymer + alum. FC and FCF processes outperformed the conventional CF process for soluble coagulant. No static segregation was observed. All technical gaps in phase 1 were successfully closed.

The small pilot tests demonstrated that the co-processing technology can be operated robustly and reliably in a continuous mode, and the co-processed materials dewatered rapidly when deposited into the flume. The inline dynamic mixer scale-up model $K_c = N^2D^4/ Q$ was validated and proven to be applicable to co-processing of fresh tailings and FFT at SFR of 2.0. The optimal K_c is 10–25 m/s for polymer only, FGD + polymer and gypsum + polymer recipes, which is similar to that for fFFT for the same type of impeller (pitched blade turbine).

The LSC and beam centrifuge tests validated the idea that increasing the SFR of co-processed tailings could increase the hydraulic conductivity of a deposit. The co-processed deposit with SFR of about 2 could consolidate to about 83% solids in <3.5 years, while the fFFT and centrifuge cake deposits need about 150 years to obtain 65–75% solids. With co-processing technology, timely and progressive reclamation of oil sands tailings to terrestrial closure landforms can be realised, and the pace of closure and reclamation of disturbed lands within the oil sands mine sites can be accelerated.

Results to date show that co-processing of fresh tailings and FFT is a promising technology. Further research and development work is required to verify the processability, reliability and robustness, and long-term deposit consolidation performance before commercial implementation of the co-processing technology.

Acknowledgement

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