Dewatering of oil sands tailings using Cross Flow Filtration

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ABSTRACT
Segregation of total tailings upon deposition has lead to the accumulation of significant volumes of fluid fine tailings by the oil sands industry. Sufficient dewatering prior to deposition may prevent this segregation leading to the formation of a stable deposit upon deposition. Crossflow filtration (CFF) of tailings streams may offer a simple alternative for dewatering these tailings streams. Limited work has been conducted using CFF methods to dewatering tailings streams. Therefore, laboratory trials were conducted to assess the feasibility of CFF to dewater a simulated oil sands total tailings stream. A simple, closed-circuit pumping loop utilizing 3 m of porous or slotted pipe as the filter medium was constructed to evaluate CFF. Mixtures of oil sands tailings sand, kaolinite and tap water, at various concentrations were used as a surrogate for the total tailings stream. The effect of tailings composition, solids concentration, system pressure, and filter properties on the filtrate quality and quantity were evaluated. Preliminary trials indicate CFF may be able to sufficiently dewater the total tailings stream preventing segregation while producing a filtrate with <0.25 % solids by weight. The maximum filtrate flux rate achieved during the experiments was 0.012 L/s/m^2.

RÉSUMÉ
La ségrégation des produits de queue totaux lors du dépôt a pour mener à l'accumulation des volumes significatifs de produits de queue fins liquides par l'industrie de sables d'huile. L'asséchage suffisant avant le dépôt peut empêcher cette ségrégation menant à la formation d'un dépôt stable lors du dépôt. La filtration de croisement de flux (CFF) des jets de produits de queue peut offrir une alternative simple pour assécher ces jets de produits de queue. Le travail limité a été conduit en utilisant des méthodes de CFF aux jets d'asséchage de produits de queue. Par conséquent, des épreuves de laboratoire ont été conduites pour évaluer la praticabilité du CFF pour assécher les jets totaux de produits de queue de sables d'huile. Une boucle de pompage simple et à circuit fermé utilisant 3 m de pipe poreuse ou encochée comme milieu de filtrage a été construite pour évaluer le CFF. Les mélanges d'huile ponce des produits de queue sable, kaolinite et l'eau du robinet, à de diverses concentrations ont été employées en tant que substitut pour tout le jet de produits de queue. L'effet des produits de queue composition, la concentration en solides, la pression de système, et les propriétés de filtre sur la qualité et la quantité de filtrat ont été évalués. Les épreuves préliminaires indiquent que le CFF peut pouvoir assécher suffisamment tout le jet de produits de queue empêchant la ségrégation tout en produisant un filtrat avec <0.25 % de solides en poids. Le taux maximum de flux de filtrat réalisé pendant les expériences était 0.012 L/s/m^2.

1 INTRODUCTION

Mining and mineral processing ultimately lead to the production of waste by-products including waste rock and a finer grained slurry called "tailings". The tailings streams are typically discharged into constructed impoundments. During deposition, segregation may occur leading to a concentration gradient of size fractions along the beach. The coarse fraction will typically settle out near the discharge point and the fines remain in suspension and flow to the pond where they settle with time. The final density of the fines fraction will depend upon the sedimentation and consolidation properties of the fines. In the oil sands industry, approximately 650 million m^3 of fluid fine tailings (35% by wt) are currently impounded (Nelson, 2006). Due to the extremely slow consolidation process, containment of the tailings will be required centuries. To reduce long term liability of fluid containment the industry wants to move from wet tailings storage towards a dry landscape – reduced use of settling basins and their elimination during reclamation. In order to achieve this vision, new methods of dewatering the tailings stream must be investigated.

Dewatering of high solids content slurries can be achieved with physical or mechanical processes such as mechanical thickeners, centrifuges, belt filter presses, and vacuum filtration (Bussiere, 2007). Filtration methods are often difficult and expensive to operate due to cake build up and maintenance of the equipment. Crossflow filtration (CFF) may offer a simple alternative to conventional dead end filtration techniques. Variations of CFF have been attempted previously to dewater mine waste slurries. Farrnand and Sawatzky (1988) used a laboratory scale crossflow microfiltration apparatus to dewater a sample of de-oiled oil sands tailings sludge from 6 wt% to 37.5 wt% solids. Crossflow filtration was also used to dewater gold slimes using a braided steel hose resulting in an increase in solids content of 9 % in 100 m of hose (Yan et al., 2003). Previous research has shown the potential for CFF to dewater tailings streams. Therefore, it may be possible to sufficiently dewater oil sands tailings to create a non-segregating deposit negating the need for conventional fluid containment. It is proposed to use CFF with macro porous or slotted rigid pipe to dewater the total tailings stream so that a non-segregating, stable deposit may be produced.

2 OVERVIEW OF OIL SANDS TAILINGS MANAGEMENT

The following section is reproduced from Beier and Sego (2007). The Athabasca region of northern Alberta, Canada, is home to massive deposits of oil sands, estimated to contain approximately 300 billion barrels of recoverable bitumen. These oil sands are composed of bitumen (~12 wt%), sand, silts, clays (mineral content ~85 wt%) and water (3 - 6 wt%). The clay component is comprised of mainly kaolinite (50-60 %) and illite (30-50 %) with some montmorillonite (Chalaturnyk et al. 2002; FTFC, 1995).

In the Fort McMurray area, there are currently three oil sands mining and extraction operations; Suncor Energy (Suncor), Syncrude Canada Ltd. (Syncrude) and Albian Sands, with several more mines under development. Production of the bitumen is based on open pit mining and oil sands processing using a water extraction process (FTFC 1995; Masliyah et al. 2004). The extraction process utilizes warm to hot water, steam, and process aides such as caustic (NaOH) to assist in extracting the bitumen from the sand matrix. Typical bitumen recoveries range from 88 to 95 % depending on oil sands grade and origin. Tailings include a mixture of water, sand, silt, clay and residual bitumen. This tailings slurry is approximately 55 wt% solids (82 wt% sand and 17 wt% fines < 44 μm). Historically, the tailings were pumped into large settling basins where the sand fraction settled out rapidly to form beaches. Some fines were trapped within the sand matrix of the beaches. However, the remaining thin slurry of fines and water (8 wt%) flowed into the settling basin where the solids settled gradually to form a densified zone of fine tailings at depth. Released water was recycled back to the extraction plant. After a few years, the fines settle to 30 to 35 wt % and are referred to as mature fine tailings (MFT) (Chalaturnyk et al. 2002; FTFC, 1995). Typical grain size distributions of various oil sands tailings streams can be found in Figure 1 (Matthews et al., 2002; Tang, 1997). Further consolidation of the MFT is expected to take centuries.

On average, for every barrel of crude oil produced, approximately 1 m^3 of sand and 0.25 m^3 of MFT are produced (FTFC 1995; Mikula et al. 1996). An average 200,000 barrel per day operation can produce up to 800,000 m^3 of total tailings per day (Mikula and Omotoso, 2006). Tailings management practices in the last four decades have resulted in massive inventories of MFT (650 millions m^3) requiring long term storage within fluid containment structures (Nelson, 2006). In an effort to deal with the massive inventory of MFT and provide a stable landscape in a timely manner, the industry has moved towards the use of non segregating tailings by implementing CT technology (Composite tailings – Syncrude, Consolidated tailings – Suncor). CT tailings are a mixture of coarse sand, gypsum (coagulant) and MFT at sand to fines ratios of approximately 4:1.

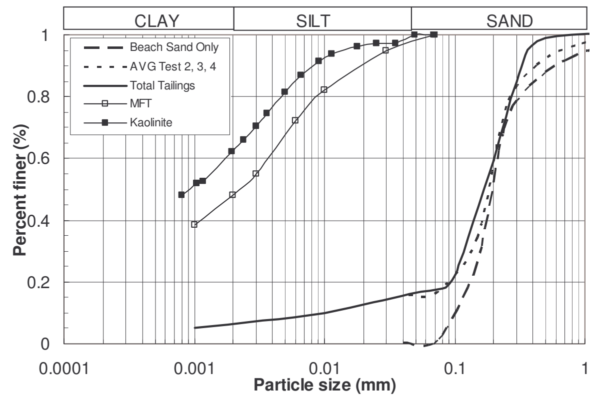

Figure 1. Typical grain size distributions for various oil sands tailings streams.

CT provides an opportunity to consume the current inventories of MFT and also releases water rapidly for reuse (Matthews et al. 2002). Lower than expected dewatering rates and segregation upon deposition were preventing the CT deposits from reaching the strength required to support reclamation.

Under the current tailings management schemes, fine tailings are still being accumulated within surface impoundments resulting in long term risk for the operators. New methods of managing the tailings stream are required if the industry wants to achieve a “dry” landscape. An ideal technology would be one that could dewater the tailings stream prior to deposition. By removing enough water and increasing the solids content sufficiently prior to deposition, the tailings stream can become non-segregating. Coagulant addition, at doses much less than currently used, after mechanical dewatering may also assist in developing a non-segregating deposit. Rapid recycle of water and heat energy may be achieved through the use of dewatering technology such as CFF.

3 CROSS FLOW FILTRATION

Filtration dewatering of slurries can be achieved through conventional “dead-end” filtration or CFF. Due to the build of cake on the filter medium in dead end filtration, the filtration rate reduces with time and slows the dewatering process. Crossflow filtration as a dewatering method can offer improvements over dead end filtration. Crossflow filtration is a pressure driven filtration process that can be used for dewatering slurries of fine particles. It is typically used with microporous membranes in the size range of 0.02 to 20 μm (Ripperger and Altmann, 2002). In CFF, the slurry would flow parallel to the filter material. A filter cake will develop on the pipe surface. However, due to shear of the flowing slurry, the build up of cake will reach an equilibrium thus maintaining a relatively constant filtration rate (Richardson and Harker, 2002) (Figure 2). Richardson and Harker (2002) report in many cases it may not be possible to reach a steady rate of filtration due to cake formation dynamics. Depending on the degree of scour and erosion, layers deposited during CFF can themselves become dynamically formed membranes.

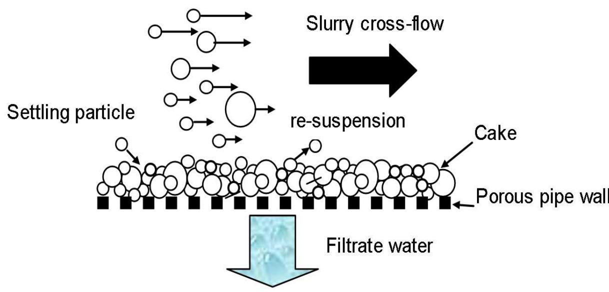

Figure 2. Schematic of cross flow filtration (modified from Ripperger and Altmann, 2002).

Therefore, the CFF system rejection and permeation characteristics can be a function of both the cake and membrane.The initial stages of cake formation in these cases are then particularly important. If the initial rates of filtration are high, plugging of the filter media with fines may result leading to a very high resistance to flow. Additionally, particle orientation of the initial cake layers may appreciably influence the structure of the whole filter cake. Richardson and Harker (2002) suggest it is desirable for the particles forming the filter cake to be as large as possible to maximize the filtrate flux.

3.1 Cross Flow Filtration Dewatering of Tailings

Cross flow microfiltration of oil sands tailings was previously investigated by Farnand and Sawatzky (1988). They used a bench scale CFF microfiltration apparatus for the rapid removal of water from de-oiled tailings pond sludge. A 0.1 µm, Nylon membrane with an effective surface area of 52.2 m^2 was operated under 50 to 100 kPa at 5 L/min. The tailings sample consisted of de-oiled pond sludge diluted with distilled water to 6.1 wt % solids with particle sizes less than 250 µm. They were able to increase the solids content of the retentate to 37.5 wt% and achieve a filtrate flux of 0.51 to 0.74 $m^3/m^2/d$. The results were scaled to a 100 m^3/d operation for order of magnitude costing purposes. Cross flow using microporous membranes was estimated to cost between \$5.00 and 7.00/m^3 of de-oiled sludge. Flow rates used in the experiments and design are significantly lower than typical total tailings flow rates of 4000 m^3/hr (Chalaturnyk et al. 2002). The system also required the removal of residual bitumen prior to filtration to prevent fouling.

The only applicable work completed to date with CFF using large pore size hose or rigid pipe on coarse slurries was conducted by Dahlheimer et al. (1970) and Yan et al. (2003). Crossflow filtration experiments conducted by Dahlheimer et al. (1970) used 1 inch diameter woven hose and kaolin or fly ash slurries at solids contents ranging from 0.3 to 8 % by weight. They found it was possible to produce clear water at high production rates under moderate pressures. The authors did not report on the final solids content of the reject stream. Yan et al. (2003) looked at using a woven, flexible steel hose to dewater fine gold tailings with a D_{80} of 35 µm and solid density of 2730 kg/m^3. Using a feed solids content of 28 %, a small lab scale system consisting of 4.3 m of woven hose was operated under a pressure of 150 kPa at 4.17 L/s for 24 hours. The filtrate flux achieved was 0.077 $L/s/m^2$. The laboratory experiment was expanded to 96 m of woven hose and operated under 160 kPa at 2.17 L/s for 15 hours. Filtrate flux achieved from the longer woven hose was 0.058 $L/s/m^2$. Up to 9% increase in solids content was achieved along 96 m of hose. No information was provided about the solids recovery in the filtrate and limited information was provided on the woven hose properties (no apparent pore size given).

In the current study, rigid pipes with relatively large pore sizes (40 – 250 um) will be used as the filtration media. Due to the large pore size a dynamic cake consisting of coarse particles is required to prevent fines from escaping in the filtrate. This is essential to the dewatering of the oil sands tailings because fines within the recycle water (filtrate) will reduce efficiency in the bitumen extraction process. Yuan and Shaw (2007) report the filtrate recycle stream must be less than 0.5 % solids to prevent detrimental effects on bitumen recovery.

Oil sand tailings are classified as heterogeneous or settling type slurries (Sanders et al., 2004). Due to their settling nature of the tailings particles, slurry flow in pipelines may result in two quasi layers flowing at different velocities. Therefore, oil sand tailings pipeline transport can be represented by the Saskatchewan Research Council (SRC) Two Layer Model (Sanders et al., 2004). The lower layer can be thought of as a slow moving, sliding bed containing a high percentage of solids. The upper layer will travel at a higher velocity and contain a lower percentage of particles. Fines will be carried fully suspended in the slurry as a viscous fluid (Abulnaga, 2002). Based on the flow and settling characteristics of the tailings, it is expected that a cake of coarse particles will develop at the base of the pipe. Cake formation on the side and top of the pipe will be mainly finer grained sands, silts and clays.

In order to create a non segregating tailings deposit the tailings must be dewatered sufficiently so they move from the extraction tailings region on the ternary diagram to below the segregation line (Figure 3). Based on Gs of 2.65, this will require the removal of about 50 % of the water from the tailings stream. At a solids content of 55 %, the CFF system must be able divert about 20% of the total slurry flow as filtered water.

4 EXPERIMENTAL SETUP

4.1 Equipment and Materials

A series of filtration experiments were conducted at the University of Alberta Geotechnical Centre to investigate the use of CFF to dewater oil sand tailings. The experimental apparatus will consist of a simple closed circuit pipe loop. A progressing cavity slurry pump delivered the tailings slurry to the filter pipe. Dewatered tailings from the end of the pipe were discharged into a collection hopper (reject stream). A trough below the filter pipe collected and conveyed filtrate to the collection hopper (filtrate stream). The collection hopper was used to supply the feed tailings and collect the discharge slurry and filtrate (Figures 4 and 5). The collection hopper was outfitted with a paddle mixer to homogenize the tailings and prevent segregation prior to circulation.

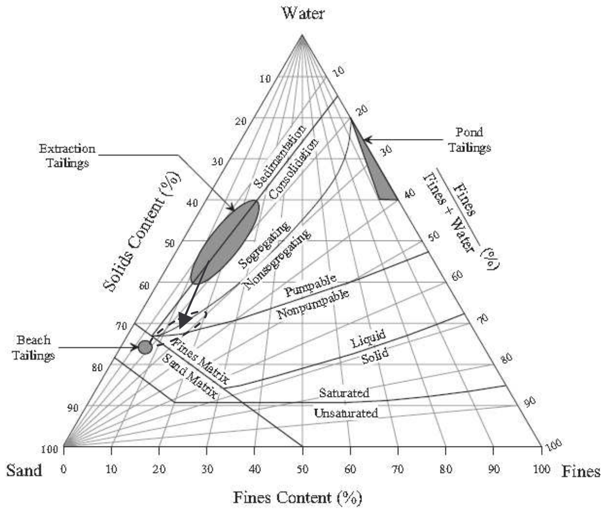

Figure 3. Ternary diagram of oil sand tailings (modified after Azam and Scott, 2005).

The filter pipe section consisted of rigid 50 mm I.D. slotted PVC (2.9 m long) or porous polyethylene (3.1 m long). The slotted rigid pipe was mechanically slotted at the base of the pipe. The slots were 254 µm wide, 55 mm long, at regular 3.175 mm spacing. The filter surface area/meter of pipe (FSA) was 0.46 m^2. The porous pipe was manufactured with nominal 40 µm pores in the pipe walls and had a total FSA of 0.49 m^2. A photo of the two pipes can be found in Figure 6.

A pressure meter and sampling port positioned upstream of the filter pipe were used for pressure measurements and sample collection. A gate valve and pressure meter situated at the pipe discharge was used to develop back pressure along the filter pipe and for head loss measurements. Increasing the pressure should lead to an increased filtrate flux. However, increased fines may be lost within the filtrate as the pressure is increased. An optimal backpressure should exist with a balance between filtrate flux and quality. Filtrate was collected into the trough and sampled as it discharged into the hopper.

The experimental slurry consists of tap water, beach sand from an oil sands tailings impoundment, and kaolinite. The grain size distribution of the tailings slurry is included in Figure 1. The D_{50} grain size of the beach sand and total tailings (sand and kaolinite) stream was 195 µm and 175 µm, respectively. The D_{95} of the kaolinite was 20 µm. A summary of test conditions are included in Table 1.

4.2 Experimental Procedure

All flow measurements were based on the time required to fill a container of known volume. The maximum flow rate (water only) of the pump was measured to be 2.59 L/s. The flow resistance of the filter pipes was determined by closing the discharge valve and measuring the filtrate flow rate and line pressures. No resistance to flow was measured for both dewatering pipes as the maximum flow rate (water only) could be diverted through the slots/pores of the pipe with little back pressure (<6 kPa). Water, sand, kaolinite, and or recycled

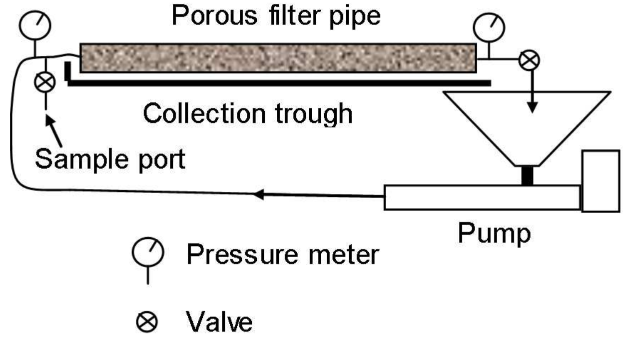

Figure 4. Porous pipe dewatering pumping loop schematic.

Figure 5. Photo depicting the pumping loop setup.

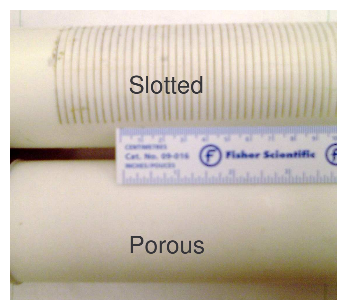

Figure 6. Photo of the Dewatering Pipes

Table 1. Summary of Experimental Conditions.

Test	wt% Solids / % Fines*	Dewatering Pipe	Feed Flow Rate (L/s)	Test Time (min)
1	13/0.5	Slotted	2.5	73
2	52/15.3	Slotted	2.05	160
3	54.9/15.3	Porous	2.36	240
4	70.2/16.3	Porous	2.14	235

* fines measured as a percentage of total dry solids mass

experimental tailings were added to the hopper at the required mass to meet the target solids concentration. Sand/kaolinite was slowly added to the water in the hopper and mixed with the paddle mixer. Experimental tailings from Test 2 were recycled Test 3 and again for Test 4. After thorough mixing, the slurry pump was activated to convey the slurry to the filter pipe. Samples were collected on approximately 15-30 minute intervals from upstream of the filter pipe, the discharged reject and the filtrate streams for solids content determination. At each sample event, flow rate was measured from the filtrate and reject streams. The discharge gate valve was partially closed or opened to induce the required backpressure along the pipe. Pressure was monitored throughout the experiment. Temperature measurements were also collected during the experiments. Due to friction within the system, heat generation is expected. Heat generation within the laboratory setting is advantageous because the field tailings will be operating at higher temperatures as well (~40-50 ^{o}C). Following termination of the experiments, cake deposits within the dewatering pipe were collected and characterized. A pressure washer was used to clean excess cake by spraying from the outside of the pipe inward.

5 EXPERIMENTAL DATA

Upstream pressure (P), filtrate flux rates (q; filtrate flow/FSA; L/s/m^2) and measured weight percent solids of the filtrate are included in Figures 7, 8, and 9 respectively. A composite sample of the slurry water from Tests 2, 3, and 4 was analysed for soluble ions and pH. Results are included in Table 2.

Table 2. Major ion concentrations and pH for tailings pore fluid from Tests 2, 3, and 4.

ion	pH	Ca^{2+}	Mg^{2+}	K^+	Na^+	Cl^-	SO_4^{2-}
(mg/L)	7.33	68.7	20.5	3.8	12.4	12.1	284

5.1 Test 1 - Slotted Pipe

Experimental tailings for Test 1 consisted of only beach sand and tap water at 13 % solids by weight. Discharge pressures were not measured due to a faulty meter. A constant pressure was not held for sufficient time periods to determine the drop in q at constant pressure. The maximum q acheived was 0.052 L/s/m^2 (Figures 7, 8).

Three filtrate samples were collected at regular intervals to assess the quality of the expelled water (Figure 9). Very little solids passed through the slots after the cake was developed (3 min). The filtrate solids content was less than 0.2 % for each sample collected. A cake was formed along the bottom of the pipe above the slots however no physical measurements or samples of the cake were collected.

5.2 Test 2 - Slotted Pipe

Experimental tailings for Test 2 consisted of beach sand, kaolinite (15.3% of dry total mass) and tap water at a target of 55.1 % solids by weight. The actual solids content was approximately 52% based on seven samples collected from the feed sample port and pipe discharge. Discharge pressures were measured during the test. Pressure drop along the 2.9 m of slotted pipe was approximately 17 kPa. After 50 minutes of operation it is evident from Figures 7 and 8 that filtrate flow decreased with constant pressure.

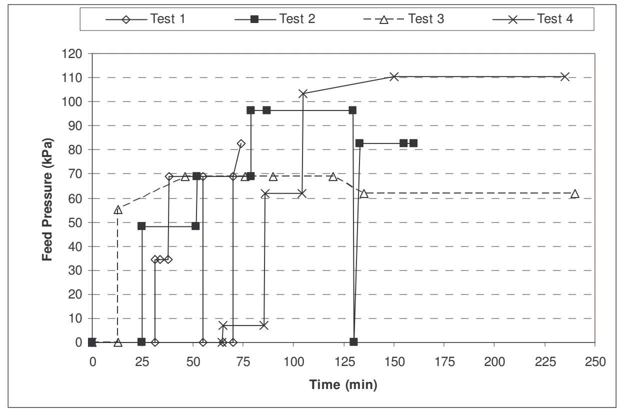

Figure 7. Summary of Feed Pressures.

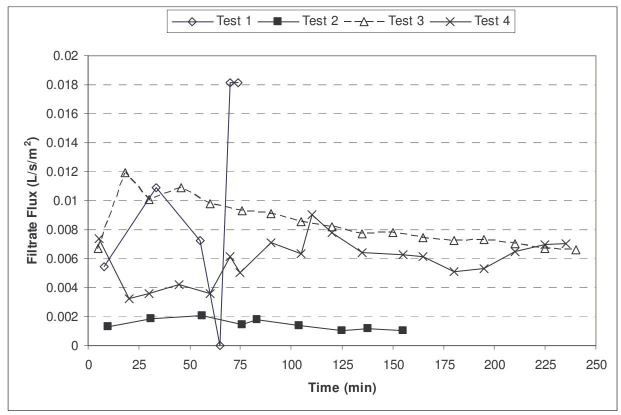

Figure 8. Summary of Filtrate Flux Rates.

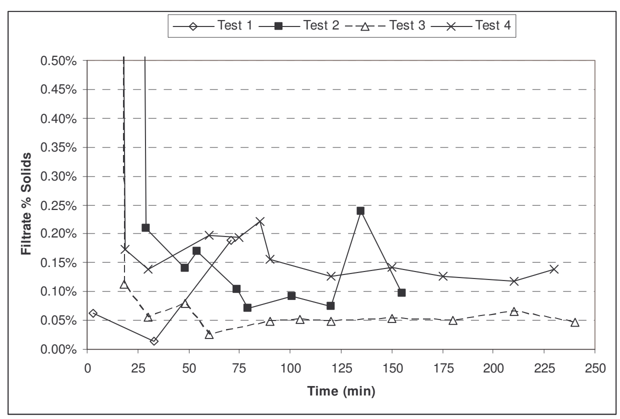

Figure 9. Summary of Filtrate Quality (wt% solids).

An equilibrium filtrate flow rate was not reached during this experiment. The maximum q of 0.006 L/s/m^2 was achieved after 56 minutes (Figures 7 and 8).

Filtrate samples were collected at regular intervals to assess the quality of the expelled water. The initial filtrate was murky due to fines passing through the slots as the cake developed. A filtrate sample was collected after 9 minutes and was found to have 11.1 % solids. Very little solids passed through the slots after the cake was developed and pressure was increased (25 min). The filtrate solids content was less than 0.25 % for each sample collected thereafter (Figure 9).

A cake was formed along the bottom of the pipe above the slots. The cake thickness (L) was approximately 10 mm at the centre and tapered to 1.5 mm at the edges (Figure 10). The slot length was approximately 55 mm. The upper coarser material consisted of residual tailings that settled within the pipe after the pump was shut off. The mean particle size (D_{50}) of the cake was 95 µm with a D_{95} of 150 µm and a fines content (45 µm) of 20 %.

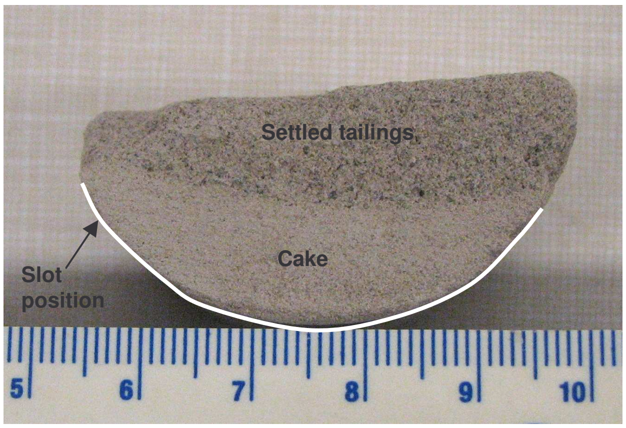

Figure 10. Cross section photo of the filter cake formed during Test 2.

5.3 Test 3 – Porous Pipe

Experimental tailings for Test 3 consisted of recycled tailings [beach sand and kaolinite (15.5%)] and tap water at a target of 55 % solids by weight. The actual solids content was approximately 54.9% based on four samples collected during the experiment. Discharge pressures were measured during the test. Pressure drop along the 3.1 m of porous pipe was approximately 10 kPa. Due to friction in the system, temperatures increased to 46 ^{o}C after 240 min.

Filtrate was expelled from the entire circumference of the porous pipe when back pressure was applied. Pressure was increased slowly to 69 kPa and held relatively constant after 50 minutes of operation. A clear drop in filtrate flow is evident with constant pressure. An equilibrium filtrate flow rate was not reached after 240 min of pumping. The maximum q of 0.012 L/s/m^2 was achieved after 18 minutes (Figures 7 and 8).

Filtrate samples were collected at regular intervals to assess the quality of the expelled water. The initial filtrate was again murky due to fines passing through the pipe pores as the cake developed. A filtrate sample collected after 5 minutes was found to have 9.8 % solids. Very little solids passed through the pipe pores after the cake developed and pressure was increased (18 min). The filtrate solids content was less than 0.1 % for each sample collected thereafter (Figure 9).

A cake was formed along the inner circumference of the porous pipe. It was approximately 10 mm thick at the bottom of the pipe and tapered to 1.5 mm along the side and top of the pipe. The D_{50} of the cake along the bottom of the pipe was 90 µm with a D_{95} of 200 µm and a fines content (45 µm) of 19 %. Not enough sample material could be collected to fully characterize the cake on the side and top of the pipe. However, observations indicate the material was considerably finer than the bottom cake.

5.4 Test 4

Experimental tailings for Test 4 consisted of recycled tailings [beach sand, kaolinite (16.3%)] and tap water at a target of 70 % solids by weight. The feed solids content was based on nine samples collected from the feed sample port and pipe discharge. Discharge pressures were not measured due to a faulty meter. Temperatures increased to 56 ^{o}C by 235 min due to friction in the system.

Filtrate was expelled from the entire circumference of the porous pipe when back pressure was applied. Pressure was increased slowly to 110 kPa and held relatively constant after 100 minutes of operation. A drop in filtrate flow is evident with constant pressure, however, the flow rate increased slightly at 175 minutes. An equilibrium filtrate flow rate was not reached after 235 min of pumping. The maximum q of 0.009 L/s/m^2 was achieved after 110 minutes (Figures 7 & 8).

Filtrate samples were collected at regular intervals to assess the quality of the expelled water. The initial filtrate was murky due to fines passing through the pipe pores as the cake developed. A filtrate sample collected after 3 minutes was found to have 7.9 % solids. Very little solids passed through the pipe pores after the cake developed (18.5 min). The filtrate solids content was less than 0.2 % for each sample collected thereafter (Figure 9).

Cake formation along the inner circumference of the porous pipe was identical to Test 3. It was approximately 10 mm thick at the bottom of the pipe and tapered to 1.5 mm along the side and top of the pipe as in Test 3. The D_{50} of the cake along the bottom of the pipe was 110 µm with a D_{95} of 400 µm and a fines content (45 µm) of 18 %. Again, not enough sample material could be collected to characterize the cake on the side and top of the pipe. Observations indicate the cake material was considerably finer than the bottom cake.

6 DISCUSSION

A series of investigative experiments were initially conducted to determine suitable dewatering pipe slotting arrangements for the current experiments. Based on these preliminary experiments it was found that filter pipe with 250 µm slotting along the base of the pipe only was optimal. Significant discharge of particles less than 250 µm occurred through slots longer than 55 mm arc length. Based on this observation the required pore size of the porous polyethylene pipe had to be less than 250 µm. It was estimated that a pore size of 40 µm would be sufficient to prevent significant loss of particles from the side and top of the pipe.

The experiments generally behaved as would be predicted from cross flow microfiltration theory (Mikulasek et al., 2004; Richardson et al. 2002). Filtrate flux was found to increase with increasing pressure and q decreased with increasing solids fraction in the feed. Test 1 was conducted to validate the assumption that cross flow filtration of coarse slurries such as oil sands tailings (D_{50} ~150-200 µm) was feasible using large pore size filter media (pore size of 250 µm). A filtrate of acceptable quality was generated during the experiment. Additionally, it was found that applied pressure controlled the q as expected. Filtrate flux increased with pressure and ceased when the applied pressure was reduced (Figure 7 and 8).

Based on the results from Test 1, the experimental program proceeded. The solid and fines content of the experimental slurry were increased for Test 2 and 3 to that of typical oil sand total tailings. These tests were conducted to determine the impact of different filter pipe media (slotted vs porous) on q and filtrate quality. Feed flow rate and pressure were similar for each test. Both pipes were able to produce a filtrate of suitable quality (Figure 9). However, the q was nearly an order of magnitude greater for the porous pipe (Figure 8). Filter cake produced in each test was nearly identical in terms of thickness and particle size. Therefore, the increased q can be attributed to the larger open surface area of the porous pipe. Based on the manufacture's specifications, the porous pipe has an open surface area of 34 % compared to only 3 % in the bottom slotted pipe. To determine the impact of higher solids content on the filtrate properties, Test 4 was conducted at 70 % solids using the porous pipe. Filtrate quality was acceptable (Figure 9). However, slightly higher pressure was required to produce a q similar to Test 3 (Figure 7 and 8).

Filtrate flux rates achieved from Tests 1-4 were an order of magnitude lower than the flux rates achieved by Yan et al. (2003). This could be attributed to the larger flow rates and feed pressures used by Yan et al. (2003) and lower slurry densities. Insufficient data was reported on the woven hose properties. Therefore differences in q between the two experiments may also be attributed to a larger open surface area of the woven hose.

The current experiments were not operated for sufficient time to determine steady state q. The calculated q decline for Test 2, 3 and 4 were nearly identical at approximately 2×10^{-5} L/s/m^2/min. Yan et al. (2003) required at least 8 hours to achieve steady state q. A theoretical q may be calculated with the use of the Kozeny-Carman equation (6.1) for flow through filter cakes (Richardson et al. 2002):

$$q = \frac{1}{180}\frac{n^3}{(1-n)^2}\frac{-\Delta P D^2}{\mu L} \qquad 6.1$$

where n is the cake porosity, ΔP is pressure drop across the filter, D is mean particle diameter, µ is viscosity of the filtrate, and L is the thickness of the cake. Differences from measured behaviour are expected as equation 6.1 was developed for spherical particles and uniform fixed beds. To account for non-spherical particles in the tailings, the Sauter mean particle diameter (Ds) should be used (equation 6.2), where x is the mass fraction of particle size d in the tailings.

$$Ds = \frac{1}{\sum x/d} \qquad 6.2$$

Using equation 6.1, an estimated n of 0.3, Ds of 0.011 mm, average L of 7 mm, and µ of 6.56×10^{-4} Ns/m^2, the flux for test 3 at 240 min was calculated to be 0.5 L/s/m^2. Calculated flux is approximately two orders of magnitude greater than the measured value of 0.0066 L/s/m^2. However, the equation assumes the cake is uniform, when in fact the cake varied in thickness and gradation depending on its location within the pipe. To account for a variable cake, q from two distinct filter zones was calculated and used to determine the estimated flow rate from 3.1 m of porous pipe. One filter zone will consist of a thick (7 mm average) coarse cake (Ds = 0.011 m) formed along the bottom 55 mm of the pipe. The other zone will consist of thin (1.5 mm), fine grained (Ds = 0.0003 mm) cake along the sides and top of the pipe (100 mm width). The calculated total filtrate flow rate from the porous pipe was 0.086 L/s. The filtrate flow rate measured at 240 minutes was 0.0033 L/s. As can be observed in equation 6.1, cake properties such as n and D significantly influence q (orders of magnitude). Differences in calculated and measured q are likely due to the inability to measure these properties accurately in the current experiments.

To size the filter pipe needed to dewater the tailings stream sufficiently to achieve a non segregating deposit (Figure 3), a few assumptions are required. Tests 2, 3 and 4 demonstrate that porous or slotted pipe may indeed be used to dewater total tailings with sufficient filtrate quality. Therefore flux rates measured from the experiments can be used. As the solids content of the tailings stream increases along the filter pipe, increased pressure will be required to maintain a constant filtrate flux and over come head loss. For ease of calculation, we will assume a constant filtrate flux rate along the entire length of pipe. Based on the average feed flow rate of 2.26 L/s and a flux rate of 0.0066 L/s/m^2, approximately 450 m of 50 mm diameter porous pipe is required to dewater the tailings from 55 % solids to approximately 70 % solids. Flow rates used in the lab are considerably lower than typical field rates. Therefore, further work is required to determine how this dewatering method will scale to field operating conditions. It is expected that several, small diameter (10-20 cm) filter pipes operating in parallel will be required to manage the large flow rates experienced in the field.

7 CONCLUSIONS AND FUTURE WORK

Several experiments were conducted to assess the capability of CFF to dewater coarse tailings using macroporous (40-250 µm) filter pipes. The experiments generally behaved as would be predicted from cross flow microfiltration theory. The filtrate flux rates were influenced by the filter properties, solids content and applied pressure. The maximum flux rate achieved during the experiments was 0.012 L/s/m^2. Based on the experimental results, approximately 450 m of 50 mm diameter porous pipe would be required to dewater a total tailings stream at a feed flow rate of 2.26 L/s from 55 % solids to approximately 70 % solids. At 70 % solids, the total tailings stream should behave as a non-segregating deposit.

An experimental program is currently underway to further investigate the influence of operating parameters such as pressure differential and feed flow rate (velocity) on the filtrate flux. The future work will also look at the impact of the feed tailings properties such as particle size distribution, solids content and bitumen content on filtrate flux and cake porosity. The current experiments did not use actual oil sand total tailings and it is expected residual bitumen will influence the flux rate. Other filter media including porous ceramics and sintered steel pipe will also be evaluated. Depositional properties of the dewatered tailings will be measured to assess segregation behaviour and geotechnical stability. Finally, scale effects will be explored to determine how the lab experiments may be scaled to field operating conditions.

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