Fluid fine tailings processes
Disposal, capping, and closure alternatives

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Purpose

To examine the current state of oil sands tailings management against criteria that would provide low-risk, sustainable mine closures with minimal need for excessive long-term maintenance.
Presentation Outline

Tailings production & processing

Deposition, capping, & performance

Water & the closure landscape

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Growing Tailings Footprint

Active Area (including structures)

Water Surface

1985-2009 - water surface prorated

1986-87, 1999-2006 area interpolated

km²
Myths or Misconceptions

• The Athabasca River – over used?
• Terrestrial surface cover on deep, soft-soil deposits - lower risk than pit lake?
• Process water loaded with persistent toxins?
• Zero discharge – always a good thing?
Rivers - Average Flow

1000 m$^3$/s

- Amazon
- Mississippi
- Columbia
- Rhine
- Nile
- Athabasca
- North Sask.
- Bow
Rivers - Average Flow

\[ \text{m}^3/\text{s} \]

- Athabasca
- N. Saskatchewan
- Bow
Athabasca River Recorded Flows

Log Scale

10000
1000
100
10
1

m³/s

All Time
Max Flow

15 June 1971
4700 m³/s

Annual
Average
630 m³/s
Ft.McM

All Time
Min Flow
2001
75 m³/s

Oil
Sand
Use
2014
3.2 m³/s
Athabasca River Recorded Flows

Linear Scale

**All Time Max Flow**

- 15 June 1971: 4700 m³/s
- Annual Average: 630 m³/s

**All Time Min Flow**

- 2001: 75 m³/s

**Oil Sands Use**

- 2014: 3.2 m³/s
Tailings Production

- Starter Dyke
- Tailings Discharge to Sand Beach
- Recycle Water
- Cell Construction
- Compact Shell
- MFT Formation
- Aurora Tailings Pond
- Tailings Production

Aurora Tailings Pond

Recycle Water

Cell Construction

Compacted Shell

MFT Formation
Conventional Tailings

Sand discharge to beach

The balance of fines remain in the runoff water and slowly settle to form MFT

Repelling forces in clay particles resist further densification

Additional fines are trapped as sand over-beaches MFT, and silts settle at the toe

Some fines remain in the sand voids as the sand settles
Settling Pond: MFT Solids % and Clay Concentration (Clay Content by Methylene Blue)
Clay, Fines and Mineral Densities, kg/m³

Depth from Surface, m

- 2 µm LD
- 44 µm LD
- Total Mineral
- Clay MBI-Sethi

2015 MRM ETF
Increasing Fines Slows Drainage

A Challenge to Compaction

MFT spiking

Low fines - well drained cell
CT – Composite Tailings

Tailings From Extraction
≈ 45% - 55%wt Solids

Cyclones
(one of many fed thru a distributor)

Cyclone Overflow
to Pond

Gypsum

Mix Tank

MFT ≥ 30% Solids
from Tailings
Settling Pond

CT Deposit

≈ 62 %Solids
CT – Outcomes Summary

• 4:1 SFR recipe
  – Competes for use of sand
  – Occupies a lot of pit volume
  – Limited use for some sites

• Segregation – some fines not captured in sand
  – Clay balance to quantify true capture rate
    (is 80% fines capture 80% clay capture?)
Thickener

Power
Flocculator

FeedWell

Fines from Extraction

Rakes
Thickening: Polymer flocculants cluster the fines for settling and water removal
Thickened Tailings Process

Mining → Truck Haul → Crusher

- Warm Water to Extraction
- Polymer Flocculation
- Thickener
- Thickened Tailings to Deposit
- Thickening Process
- Cyclone Overflow to Flotation
- Lean Flotation Froth
- Primary Separator
- Bitumen Froth
- Hydro-transport to Extraction
- Slurry Preparation
- Surge Pile
- Sand Tailings
Thickener – Outcomes Summary

• Test deposit success not replicated at commercial scale
  – Segregation - shear in transport pump/pipeline
  – Variable feed from extraction
• Reductions in MFT generation not realized
• Search continues for remedies
  – Including end of-pipe-treatment
Centrifuge – Outcomes Summary

• Consistent operations attainable
• High $CAPEX
• 30 wt% MFT densifies to ≈ 55 wt% solids
• Truck transport - flexible, $costly
• Pump transport limits cake density
• Deep deposit benefit over in-line treatment??
  – Both will have centuries of settlement
MFT/ Clearwater Overburden Co-Mixing

Source: Syncrude and Patent Application # US20140119833A1
MFT/Overburden Co-Mixing

- Estimated for Kca-MFT Mixture

- Increasing proportion of overburden

- Undrained Shear Strength (KPA)

- Solids of Kca-MFT Mixture (wt%)
MFT/Overburden Co-Mixing
– Outcomes Summary

• Deposits – ready for surface reclamation in months
• High $ Cost method
• Useful supplemental method
Three-Stage Flocculator

In-Line Flocculant Mixing

FFT

Polymer Solutions

In-Line Injector/Mixer

Polymer Solution

MFT
MFT In-Line Flocculation

MFT $\approx 30\%$ Solids from Tailings Settling Pond

Deposition alternatives:
- Deep in-pit deposit
- Drying beds & re-handling to overburden cells
- Shallow layered deposit for in-place reclamation
Thin-Lift Dewatering/Atmospheric Drying
In-Line Floc/Thin Lift Drying – Outcomes Summary

• Area/time requirements to attain stackable strength constrain that depositional strategy
• Re-handling material to overburden dump cells
  – High $ Cost - comparable to centrifuge
  – Large area requirement
• Useful supplemental method
MFT \approx 30\% \text{ Solids from Tailings Settling Pond}

Deposit flows to Shallow Slope \(< 1\%\)

Water Removal from Deposit

Surge/Mix Pond

In-Line Mixer

Polymer Solution
Cell ready for pour in 2009

View of MFT surface around instrumented pole, July 6, 2010 (ten months after pit filling).

July 6, 2010
In-Line Floc/Deep Deposit – Outcomes Summary

• Consistent process control yields densities approaching centrifuge cake in a short time
• Relatively low process cost
  – Fines containment volume efficiency 2 – 3 times CT
• Ditch-drain final deposit to create dense surface
  – will not re-fluidize under water cap
Froth Treatment Tailings – Characteristics

• Pyrite
  - Potential acid rock drainage
    if not below phreatic surface

• NORM
  - Concentrations can approach occupational limits

• Methanogenesis
  – From naphtha or paraffin solvent in tailings
Froth Treatment Tailings – Characteristics and Options

Characteristics
- Pyrite – Potential for acid rock drainage if not below phreatic surface
- NORM concentrations can approach occupational limits
- Methanogenesis – from naphtha or paraffin solvent in tailings

Options
1. Current practice – discharge into main tailings pond
2. Increase naphtha recovery - blend into whole tailings
3. Segregate/densify for in-pit disposal
   (Co-dispose with overburden?)
The quest for a game-changer

• Sequester all fines
  – w/o site limitations or economic barriers
• Deposit behaviour
  – permeable, geotechnically competent
• Low-cost slurry transport – non-segregating
• Clear release water – short time to release quality
Deep Fines Deposit Settlement Time

Interface height (m) vs Years

10 metres to go
Degree of Excess Pore Water Dissipation (%)

Settlement (%)

1000 years after fill

100 years after fill
Landform design means taking the following steps...

1. Declaring your strategy
2. Adopting a real adaptive management program
3. Setting out a DBM
4. Designing the deposition, deposit, capping, reclamation
5. Constructing as per design
6. Monitoring and maintaining
7. Enacting pre-designed contingencies as needed
Examples of DBM goals, objectives, & criteria

OPERATIONAL GOALS
- Safe and efficient tailings operations
- Manage cost, dam safety
- Meet closure requirements
- Meet MFT volume requirements.

LAND GOALS
- Achieve useful, self-sustaining, locally common, beautiful boreal forest
- Build landforms that can receive reclamation certification
- Design pit lakes with adequate watersheds.

DESIGN OBJECTIVES
- Tailings supports intended cap
- Sustainable long-term settlement
- Supports wetlands and upland forests
- Acceptable water quality for wetlands
- Minimize salinization

SUPPORTING DESIGN CRITERIA
- Soft tailings strength >25 kPa
- Minimum 2 m thick cap
- Supports loaded 100T truck on ridges
- Post-reclamation settlement < 1 m
- Upland water table 2 m down
- Withstand 1/1000-year earthquake
- TDS downstream <1000 ppm.
<table>
<thead>
<tr>
<th>Issues &amp; hazards</th>
<th>Ease of operation</th>
<th>Potentially mobile material</th>
<th>Fines density storage</th>
<th>Trafficability</th>
<th>Support topo relief</th>
<th>Settlement</th>
<th>Pore-water quality</th>
<th>Erodibility</th>
<th>Water cap?</th>
<th>Coke cap?</th>
<th>Sand cap?</th>
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Trafficability / cappability
Support topographic relief
Avoid excessive settlement
No dam breach
No unsustainable lakes
Design criteria:
- <2m settlement
- open water <10% catchment
- no standing water in buffer zone
Design criteria not met

- >2m settlement
- Open water >10% catchment
- Buffer zone violated
Accommodating settlement in the field
Managed drainage outlets (with a nod to Dr Ed McRoberts in 1998)
Example post-reclamation settlement criteria:

- **Fen**: <0.2m
- **Marsh**: <0.2 to 0.5m
- **Shallow-water wetland**: <2 m
- **Lake**: >2 m

![Graph showing settlement criteria](https://example.com/graph.png)

- Dried MFT 80%
- Centrifuged MFT 50% solids
- Untreated MFT

- uFFT
- cFFT
- TT
- dFFT-70%
- dFFT-80%
- NST

Years from end of filling

Height (m)
How to avoid excessive settlement

- Ensure settlement is complete within a couple decades
- Deposit at final solids content (track-package tailings)
- Keep deposits thinner than a few metres.
How to accommodate settlement

- Embrace water capping
- Overbuild / dome and let it settle
- Top up settlement over time
- Allow erosion & deposition will top it up
- Allow peat accumulation will top it up
- Managed drainage outlets
- Use hummocks to keep lake in safe zone
- Maintain lake and dykes forever
  - Ensure large watershed feeding lake
  - Install wick drains to shorten settlement time
  - Build rock drain outlet?
- Write off area as unreclaimable
Then just what do we need, really?

**WHAT WE DON’T NEED...**

- Too much volume
- Nagging toxicity
- Too low density
- Too weak
- Too hard to cap
- Too long to reclaim
- Too much settlement
- Too long to settle
- Too much risk of breach
- Poor efficacy ($$)

**FOUR SOLUTIONS WE NEED...**

- **Water cappable and water capping**
- **Fast consolidating**
- **Track-packable**
- **Effective adaptive management for deposition, capping, & landform evolution**
Embrace water capping
FAST consolidation

Tailings sand

PL = 20
Cu = 150 kPa
LL = 60
5 kPa

10 years
100 years
1000 years

60% solids
80%

Graphs from Pollock 1988

Terrestrial reclamation

80% solids
Making **track-packable** tailings

- Thermal drying
- Cement-amended tailings
- Thin-lift drying with landfarming
- Filtered tailings
- Various co-mixing / co-disposal
- Staged processes
Effective adaptive management

1. Form the deep deposit team
2. Establish governance
3. Create DBM: clearly define... Goals, design objectives, & design criteria
4. Design the deposit
5. Assess risks
6. Develop contingencies
7. Construct landform (containment, bulk infilling, capping, reclamation)
8. Monitor performance
9. Implement contingencies
10. Annual audit

Diagram:
- Normal operations
- Contingency operations
Examples of new tailings design criteria

- Hydraulic conductivity $>10^{-6}$ cm/s; full settlement in 20 years
- East to cap and reclaim.
  - Track-packable.
  - Operational shear strength $>25$ kPa
  - Cappable with hydraulic sand placement
  - Can support hummocks.
- Easy to delicense dykes
- Post-reclamation settlement $<0.5$ to $4$ m (depending)
- Open-water $<10\%$ of watershed
- Acceptable pore-water quality.
Water Issues in the Mine Closure Landscape

Three old guys who give a damn
and have nothing left to lose
Mistakes made (ignoring consolidation)
Doing it wrong again (ignoring consolidation)
Hydrology of the Closure Landscape

- Type of vegetation
- Landform evolution
- Impacts on receiving streams
- Dams in the closure landscape
Sources of Process Water (PAW) in the Closure Landscape

1. Residual tailing transport water collecting in ponds
2. Pore water of sand saturated tailings deposits
3. Residual water in unsaturated tailings sand deposits after drain down
4. Pore water of treated FFT deposits
PAW Pathways

- Elevated tailings sand storage areas drain to low areas like swales
- Consolidation of treated FFT causes porewater to seep upwards to the ground surface
- Flow of PAW in swales to pit lake
- Most PAW ends up in the pit lake

- Is the flow in surface drainage harmful to the environment?
- Does process water discharge into surface drainage courses need to be treated?
- Does process water discharge to the pit lake need to be treated before release to the downstream environment?
Flat Terrain (in Pit)

Before settlement
- Sand cap
- Treated FFT

After 2m settlement
- 2m open water
- Sand cap
- Solids
- Pore water
- Treated FFT

No change in water level due to downstream constraint
Sustainable Terrestrial Landforms

1. No dams
2. Stable drainage courses
3. Controlling upward flux of PAW
4. Stable terrestrial areas
5. Surface erosion

Why?
- Man-made materials deteriorate
- Breaching by erosion, piping and overtopping
- Large liability in perpetuity
- Earthfill dams not evident in nature
Sustainable Terrestrial Landforms

- No dams
- Stable drainage courses
- Controlling upward flux of PAW
- Stable terrestrial areas
- Surface erosion

Failure mechanisms
- Beavers
- Excessive erosion caused by diff. settlement
- Channel invert buoyancy in winter

Placing treated FFT at terrestrial reclamation areas is a serious threat to sustainable drainage.
Sustainable Terrestrial Landforms

- No dams
- Stable drainage courses
- Controlling upward flux of PAW
- Stable terrestrial areas
- Surface erosion
Hummock and Swale Terrain

Ridges & hummocks

Swale with good outlet

Blocked swale

Ponded water

Sand cap

Upward seepage flux

Treated FFT
Sustainable Terrestrial Landforms

- No dams
- Stable drainage courses
- Controlling upward flux of PAW
- Stable terrestrial areas
- Surface erosion

Must avoid placing deep deposits of treated FFT at terrestrial areas
Impact of Excessive Settlement

Drowned ridges & hummocks

Open-water, wetlands and lakes

Full lake evaporation
New shoreline
Raised water table

Upward seepage flux

Sand cap

Fish?

Treated FFT

Loss of containment?
Sustainable Terrestrial Landforms

- No dams
- Stable drainage courses
- Controlling upward flux of PAW
- Reducing impacts of PAW discharge
- Stable terrestrial areas
- Surface erosion
Pit Lakes are Essential

- Pit lakes are inevitable at mining operations.
- Pit lakes are essential for treating naphthenic acids in PAW by aerobic degradation. They are required elements of the closure design.
- Pit lakes are beneficial for storing treated FFT under a water cap.
Pit Lakes – Hydrologic Sustainability

Need sufficient drainage area
- To enable hydrologic sustainability
- To provide suitable dilution for PAW from watershed
- To accommodate climate warming

Outflow = Precip – Evap + Runoff + seepage discharge

Where: Precip = 450mm
Evap = 570 mm
Seepage ~ neg.
Runoff = ~100 mm
Water quality of pit lake discharges can be managed

- Naphthenic acids treated by residence time (aerobic degradation)
- Salinity handled by dilution
Storing Treated FFT in Pit Lakes Beneath a Water Cap

- Superior terrestrial reclamation by avoiding highly compressible materials
- Least risk to pit lake is to store treated FFT beneath a water cap because:
  - Reduced depth
  - Reduced river diversion for filling pit lake
  - Reduced inflow of PAW
Pit Lakes – Other Issues

- Shoreline stability
- Entrainment of fines in pit lake water cap
- Meromixis
- Littoral zone
- Too much lake area at mine closure
Managing the Closure Landscape

- Geomorphic approach recommended
- Progressive certification not possible with large future consolidation
- Perpetual maintenance needed for legacy deep deposits of FFT at terrestrial areas
- Non-destructive land use at reclaimed areas
- Regulation for discharge to the environment is long overdue
Key Messages for Sustainable Closure

1. Eliminate dams in closure landscape; no treated FFT above ground.
2. When the oil is gone, all we have is the closure landscape. Agree upon goals and objectives beforehand. Base expectations on what can be done.
3. Acknowledge that CT and deep fines deposits will handle most fluid tailings.
   - Water cap treated fluid tailings – embrace end pit lakes.
   - Other methods are niche applications, not bulk applications.
   - Game changer technologies wanted.
5. Take action on froth tailings
6. Manage salt buildup – Delayed discharge may result in negative impacts to the environment
Thank you for your attention

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