FIELD PILOT PERFORMANCE RESULTS FOR FLOCCULATED FLUID FINE TAILINGS UNDER THREE DEPOSITIONAL VARIATIONS

Dale Kolstad and Ben Borree, Barr Engineering Co.; Jason Song, O’Kane Robert Mahood, Shell Canada Energy
OUTLINE

■ Brief Overview of Atmospheric Fines Drying (AFD) Technology
■ AFD Field Pilot
  ■ Goals and Objectives
  ■ Test Deposits
  ■ Monitoring Results
■ Conclusions and Recommendations
AFD TECHNOLOGY AT SHELL

■ **Timeline**
  - Initiated in 2008 in response to growing FFT inventory, regulatory requirements of ERCB D074
  - Field demonstration in 2010; scaled to commercial beginning in 2012
  - *Field pilot deposition 2012 – 2013, monitored through 2015*

■ **Technology Basis**
  - Dewater fluid fine tailings (FFT) primarily through a combination of flocculation/sedimentation (initial dewatering) and atmospheric drying
  - Premised on deposition of thin lifts, generally less than 30 cm
  - Dried material removed and disposed in waste dumps or other DDAs on an annual basis
**AFD PROCESS**

- FFT from MRM ETF
- In-line flocculation with HPAM polymer
- Treated MFT conditioning in pipe & earthen mixing box
- Deposition in sloped cells
- Produced water removal
- Drying and consolidation

Focus of Field Pilot

Stage 1: Delivery Piping of MFT

Stage 2: Flocculant Solution Injection

Stage 3: Flocculant Mixing

Stage 4: Floc Conditioning

Stage 5: In-situ dewatering of flocs in Disposal Area

Stage 6: Evaporation and Deep Percolation of Water from MFT Layer
GOALS & OBJECTIVES OF FIELD PILOT

Goals:
- To assess the short-term (1- to 2-year) dewatering and resultant strength gain performance of thin-lift layering versus deep stacking depositional approaches
- Inform decision as to which was a better tailings management strategy to pursue using the AFD process

Objectives:
- Compare the amount of fines processed per unit area to peak shear strength of 5kPa in 1 year
- Quantify and assess the relative contribution of evaporative drying and consolidation towards deposit dewatering
- Compare the potential for freeze-thaw dewatering
AFD FIELD PILOT CELLS

- Top sectional area/footprint of 2,000 m$^2$ to 3,000 m$^2$ each, sloped at 1-2%, and a depth between 4 and 5 metres
- Contained cells with 6,000 m$^3$ to 10,000 m$^3$ of treated tailings
- Foundation material: native ground (upper McMurray Formation). Shallow groundwater was present.
- Perimeter/separating berms: constructed using lean oil sands (LOS)
MONITORING OF AFD FIELD PILOT CELLS

- Instrumented with over 700 probes mounted on several posts located throughout the three test cells
- Profiles of pore water pressure and volumetric water content
- Total pressure at the base of the deposit
- Surface temperature and albedo, tailings temperature, and settlement

Sampling during and post-deposition: over time 300 sample test results.

- During deposition: Shell key performance indicators (KPIs) – yield strength and filtration constant, others
- Deposit testing: in situ eVST for strength measurement and core sampling for laboratory testing of water content, density, PSD, MBI, Dean Stark, Atterberg & shrinkage limits, specific gravity.
- Samples for consolidation and SWCC testing were also collected
POURING OF AFD FIELD PILOT CELLS
**COMPLETED AFD FIELD PILOT CELL DEPOSITS**

- Placement started August 2012, completed August 2013
- Winter suspension

![Diagram showing layers and dimensions of deposits](image)

- **Thin Multi-Lift**:
  - 0.4 meter
  - 1.1 meter
  - 0.6 meter
  - 0.5 meter
  - 0.5 meter
  - 0.5 meter
  - 0.9 meter

- **Thick Multi-Lift**:
  - 1.2 meter
  - 1.9 meter
  - 1.0 meter

- **Deep Stack**:
  - 4.5 meter

*Poured in 2013*  
*Poured in 2012*
Material meeting KPIs: entirety of the Deep Stack, Thick ML layers 1 and 2, and Thin ML layers 1, 2 and 4. Material not meeting KPIs was on average 75% & 40% of yield strength & filtration constant targets.

Specific gravity was slightly higher for ML deposit tailings. Deep Stack deposit had higher bitumen content.

Equivalent footprint loading of 1.4 to 1.5 tonnes dry fines/m² achieved

<table>
<thead>
<tr>
<th>Deposit</th>
<th>Lifts that met KPIs</th>
<th>Feed SC (% total mass)</th>
<th>Fines (&lt;44 um, by mass)</th>
<th>Clay (&lt;2 um, by mass)</th>
<th>MBI (g MB/kg solids)</th>
<th>Bitumen (% by mass)</th>
<th>Specific Gravity²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin ML</td>
<td>3 of 7</td>
<td>38</td>
<td>86</td>
<td>22</td>
<td>28.0</td>
<td>4.4</td>
<td>2.28</td>
</tr>
<tr>
<td>Thick ML</td>
<td>2 of 3</td>
<td>38</td>
<td>86</td>
<td>21</td>
<td>28.4</td>
<td>4.7</td>
<td>2.25</td>
</tr>
<tr>
<td>Deep Stack</td>
<td>1 of 1</td>
<td>37</td>
<td>91</td>
<td>21</td>
<td>24.9</td>
<td>6.2</td>
<td>2.16</td>
</tr>
</tbody>
</table>

¹ Lifts meeting KPIs had yield strength greater than 150 Pa and/or filtration constant greater than 1.
² Additional testing by Shell is on-going
Observed precipitation and site potential evaporation (PE), over the monitoring period were relatively similar to and consistent with the long-term climate database for northern Alberta.

Surface water was removed from the test cells in an effort to enhance the benefits of evaporative drying and replicate run-off conditions in commercial cells.
TAILINGS DEWATERING PERFORMANCE

Approach

- A water balance method was used to quantify water balance elements contributing water to, or removing water from, the field test cells.

- A combination of methods (estimates from models, measurements, calculations) were used to quantify dewatering mechanism contributions toward solids content increase and densification of the deposit.

- Initial dewatering phase: result of the flocculation and sedimentation processes. Inflection point in settling curve was used to establish timeline.
Solids Content Gain (absolute) by Dewatering Mechanism (applied to entire deposit)
TAILINGS DEWATERING PERFORMANCE

- **Solids Content Increase**: Average SC increase from 38% to 62% in 2 years following completion of deposits.
- **Material meeting KPIs had superior initial dewatering performance**. Initial dewatering was the largest contributor (9.5%) to overall dewatering in the Deep Stack.
- Higher self-weight consolidation in ML cells occurred due to more water being available & higher specific gravity of the tailings – but took longer due to presence of buried crusts, smaller driving head during stacking
- **Evaporative drying results** were similar overall at ~6%; slow to realize benefit in Thin ML due to frequent deposition.
- **Downward-drainage** was a little higher for the Deep Stack; presumably due to higher permeability in the lower portion of the deposit when the driving head was the highest compared to the ML cells. Rates appear to slow significantly after one year of pouring as tailings densified.
- **F-T consolidation** contributed a small amount to overall SC increase (<2%). SC gain from F-T dewatering declined with time, which indicates the benefit diminishes with each subsequent F-T cycle.
Deep Stack developed a characteristic ‘C’ shape as the result of downward-drainage and evaporation impact in the lower and upper one metre, respectively.

ML deposits have both higher solids content crusts and densified layers and lower solids content regions that resulted from incomplete consolidation or drying prior to subsequent lift placement.
Entire profile of the Deep Stack exceeded 5 kPa peak shear strength within one year of deposition and was between 18 kPa and 25 kPa in 3 years.

60% and 55% of the Thick ML and Thin ML deposit profile exceeded the strength goal within one year, and had strengths generally between 5 kPa and 25 kPa after 3 years.

Remoulded strengths were generally between 2 and 6 kPa, with the average sensitivity for all test deposits being approximately four.
DEPOSIT SETTLEMENT AND CONSOLIDATION

- Deposits settled to approximately two-thirds of their original heights, with up to one-half of the settlement occurring during initial dewatering.

- Deep Stack had dissipated more excess PWP than the ML deposits had—reducing from as high as approximately 8 kPa to between 1 kPa and 4 kPa after 3 years; ML cells have retained most of its excess PWP (as high as approximately 10 kPa) for 3 years post deposition.

- Only the Deep Stack had meaningful effective stress gains, ranging from 2 to 15 kPa. The effective stresses in the ML cells were generally below 3 kPa.
Field deposit density results bounded by MFT and lab-treated MFT SICT results, indicating field material presumably underwent some breakdown of the flocculated structure during deposition.

LSCT result: sample disturbance suspected due to transport and handling of material.

Outliers in box were shallow material that exhibited over-consolidated behaviour due to wet-dry and freeze-thaw cycling.
Permeability envelope spans two orders of magnitude initially and then narrows at approximately 100 kPa of effective stress (void ratio ~1).

Permeability reduction of approximately one order of magnitude experienced by field deposits over monitoring period.
FIELD PILOT CONCLUSIONS AND RECOMMENDATIONS

- Producing treated tailings at design specifications for deep stacking—to exploit the enhanced drainage attributed to a larger driving head and initially higher permeable material—is a superior approach to multiple layering for deposits focused on short-term (one year or less) dewatering and strength gain performance.

- Multiple layering approaches can be more beneficial than deep stacking if allowed sufficient time to dissipate their excess pore-water pressure and thoroughly dry or freeze-thaw consolidate prior to subsequent lift placement. The operational cycle time will be greater than 30 days for thin lifts and greater than 90 days for thick lifts for this to be realized with this AFD material.

- Despite significant densification, none of the depositional approaches achieved the nominal target for soil-like material for incorporation into a terrestrial landscape within 3 years. Treated FFT product improvement and/or enhanced dewatering methods (e.g., surcharging/capping, sand layering, wick drains, rim ditching, etc.) could be considered to advance these materials toward target end states.
ACKNOWLEDGEMENTS

- Project Owner: Shell Technology Development
- Construction and Field Support: Shell AFD Operations
- Field Investigation & Geotechnical Evaluation, Reporting Lead: Barr Engineering
- Instrumentation & Dewatering Assessment: O’Kane Consultants
- Modelling Support: Golder Associates
- Technical Guidance: David Carrier