Geotechnical Performance and Water Balance of Centrifuged FFT During a One-year Field Trial at Shell Albian Sands Operations

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Background

Shell Canada conducted a field trial during 2014-15 to evaluate geotechnical performance of centrifuge-dewatered FFT ("cake"). Four test cells were filled with cake between Aug. 31 and Sep. 9, 2014. The deposits were periodically sampled, tested and monitored over a one-year period.

BGC Engineering Inc. (BGC) and O’Kane Consultants Inc. (OKC) were commissioned by Shell to provide technical and execution support.

Objectives:
- Measure transient changes of cake deposits over 1-year monitoring period through instrumentation and sampling/testing (lab and in-situ).
- Capture major water balance components.
- Use findings for tailings deposition planning and optimization.
Outline

- Centrifugation Process
- Test Cells Design, Instrumentation and Filling
- Test Deposit Monitoring
- Geotechnical Sampling and Testing
- Water Balance Evaluation
- Conclusions
Centrifugation Process
Feed FFT and Cake Characteristics

- FFT, typically of ~30% solids content, is treated with a flocculant and then processed through decanter centrifuges.
- The resultant higher-density product, known as “cake”, has a solids content of ~46% [i.e. a volume reduction of ~40-45% from centrifugation].
- Cake is transported to a dedicated disposal area through a pipeline (300mm diameter and ~800 m long) with a positive displacement pump.
- The centrifuge cake had approximately 90% fines (<44 µm), with a liquid limit of approximately 70% and a plastic limit of approximately 22%.
Test Cells Design, Instrumentation and Filling
Layout of Test Cells

Open-Ended Cell

Closed-Ended Cell

Environmental-Test Cells
# Test Cells Design

<table>
<thead>
<tr>
<th>Cell Name</th>
<th>Dimensions (m)</th>
<th>Initial Deposit Thickness (m)</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-Ended</td>
<td>80 x 15</td>
<td>Varies from approximately 1.6 m to 0.3 m</td>
<td>Characterize depositional nature of cake deposits. Provide deposit with varied initial deposit thickness that sheds surface waters.</td>
</tr>
<tr>
<td>Closed-Ended</td>
<td>30 x 50</td>
<td>2.4 m</td>
<td>Characterize geotechnical properties of thick cake deposit that only partly freezes during the winter. Puddles and ponds on deposit surface remain in place longer.</td>
</tr>
<tr>
<td>1m Enviro Cell</td>
<td>12.2 x 2.4</td>
<td>1.0 m</td>
<td>Quantify water removal from deposit that may freeze completely during the winter.</td>
</tr>
<tr>
<td>2m Enviro Cell</td>
<td>12.2 x 2.4</td>
<td>2.15 m</td>
<td>Quantify water removal from cake deposit that only partly freezes during the winter.</td>
</tr>
</tbody>
</table>
Measured Parameters and Instrumentation

- Rainfall and evaporation – Weather Station
- Cake water (solids) content – TDR Sensors
- Under-drainage – Flow Tipping Buckets
- Surface runoff – Pump with Flow Meter
- Deposit settlement – Sonic Ranger, Ruler
- Consolidation – Total Earth Pressure Cell, Vibrating Wire Piezometers
- Frost penetration – Thermistors
- Net radiation and albedo – Radiomater
- Visual changes – Time Lapse Camera
Cells Filling

- Centrifuge Cake was pumped into the Open and Closed-Ended Cells using a positive displacement pump and through extension of the 300mm diameter pipe.
- An excavator that collected cake within its bucket from the pipe discharge into DDA was used to transport and place the cake in the Environmental Cells.

<table>
<thead>
<tr>
<th>Cell Name</th>
<th>Dates of Filling (2014)</th>
<th>Approx. Initial Volume (m³)</th>
<th>Deposit Initial Thickness (m)</th>
<th>Solids Content of Cake at Plant (%) (number of tests)</th>
<th>Peak Yield Stress of Cake at Plant (Pa) (number of tests)</th>
<th>Remolded Yield Stress of Cake at Plant (Pa) (number of tests)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-Ended</td>
<td>August 31</td>
<td>1,000</td>
<td>1.5 at Post 1*, 1.29 at Post 2</td>
<td>48 (36)</td>
<td>860 (4)</td>
<td>660 (4)</td>
</tr>
<tr>
<td>Closed-Ended</td>
<td>September 1 to 2</td>
<td>3,000</td>
<td>2.4 at Post 3, 2.27 at Post 4</td>
<td>48 (45)</td>
<td>780 (8)</td>
<td>600 (8)</td>
</tr>
<tr>
<td>1m Enviro Cell</td>
<td>September 9</td>
<td>30</td>
<td>1.02 (South), 0.95 (North)</td>
<td>48 (12)</td>
<td>700 (12)</td>
<td>560 (12)</td>
</tr>
<tr>
<td>2m Enviro Cell</td>
<td>September 6</td>
<td>60</td>
<td>2.15</td>
<td>48 (16)</td>
<td>740 (16)</td>
<td>560 (16)</td>
</tr>
</tbody>
</table>
Open-Ended Cell
Environmental Test Cells
Test Deposits Monitoring
Weather and Frost Penetration

Weather:

- Mean Monthly Temperature: -17°C in Feb to +18°C in July
- Mean Daily Temperatures below freezing from November 8, 2014 through April 7, 2015
- Rainfall: Total 233 mm, with 93 mm during July.

Frost Penetration:

- Freezing of the test deposits started early-November 2014 and reached its maximum depth (0.73m to 0.87m) by late-February.
Deposit Thickness

*The deposit thickness decreased rapidly from 1.5 m to 1.25 m after pouring due to the open design of the cell*
2m Environmental Test Cell


Geotechnical Sampling and Testing
Laboratory and In Situ Tests

- Laboratory testing of produced cake (particle size distribution, plasticity, consolidation, hydraulic conductivity, moisture retention, Dean Stark)
- Monthly test deposit inspections and automated data downloads
- In situ sampling and strength testing; laboratory testing (solids content and pore water chemistry); deposit surface survey [November 2014; August 2015]
- Thaw strain values of frozen core samples ranged from 12% to 37%.
Solids Content and Shear Strength Profiles

- Freezing-induced suctions resulted in densification of the unfrozen cake immediately below the frozen crust.

November 2014 to August 2015 solids content and shear strength profiles, Closed-Ended Cell test hole CE-2.
## Initial and Final Solids Content and Yield Stress

<table>
<thead>
<tr>
<th>Cell</th>
<th>Average Initial Solids Content (%)</th>
<th>Average Initial Yield Stress (kPa)</th>
<th>Average Final Solids Content (%)</th>
<th>Average Final Undrained Shear Strength (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-Ended Cell</td>
<td>48</td>
<td>0.9</td>
<td>64-67</td>
<td>7</td>
</tr>
<tr>
<td>Closed-Ended Cell</td>
<td>48</td>
<td>0.8</td>
<td>56-57</td>
<td>3-4</td>
</tr>
<tr>
<td>1 m Enviro Cell</td>
<td>47.5</td>
<td>0.3</td>
<td>73</td>
<td>14</td>
</tr>
<tr>
<td>2 m Enviro Cell</td>
<td>47.6</td>
<td>0.2</td>
<td>64</td>
<td>8</td>
</tr>
</tbody>
</table>
Solids Content and Shear Strength Profiles in Vegetated Area

Dry Root Biomass (mg/g) / Shear strength (kPa) / Solids Content (%)

Depth (m)

Dry Root Biomass (mg/g)
Shear strength (kPa)
Solids Content (%)

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Water Balance Evaluation
The calculated water storage change matched very well with water storage change obtained from TDR measurements.

The average solids content increased from ~46% to 62%. The calculated solids content on August 10, 2015 was approximately 61%, compared with the average solids content of approximately 63% obtained from in situ sampling on that day.
Conclusions
Conclusions

- Centrifuge cake, like FFT, remains a compressible, slowly-consolidating material.
- After one year of exposure to the environment, the average solids content/undrained shear strength increased to approximately 57 percent/3-4 kPa in the Closed Ended Cell, up to approximately 72 percent/16 kPa in the 1m Environmental Cell.
- Evaporation and freeze-thaw contributed significantly to dewatering and densification of the exposed test deposits.
- During the winter of 2014/15, frost penetrated the deposits to a maximum depth of 0.8 m to 0.9 m. In the case that use of thin lifts is considered in the tailings management plan, lift thicknesses no more than 1.0 m are recommended to allow for freeze-thaw over the full lift thickness.