Optimizing Tailings Deposition to Maximize Fines Capture: Latest Advance in Predictive Modeling

Luca Sittoni\textsuperscript{1}, A.M. Talmon\textsuperscript{1,2}, J.L.J. Hanssen\textsuperscript{1,2}, H van Es\textsuperscript{2}, J.A.Th.M van Kester\textsuperscript{1}, R.E. Uittenbogaard\textsuperscript{1}, J.C. Winterwerp\textsuperscript{2}, C. van Rhee\textsuperscript{2}.
\textsuperscript{1}Deltares, \textsuperscript{2}Technical University of Delft
Latest advances

Tailings deposition on beach above water – cross section (2DV)

- Beach slope 1% ending in tailings pond – cross section (long flume test)
- 1 m³/s tailings discharge, SFR = 3, Ty = 40 Pa
- Simulating flow and sand segregating behavior along the beach and in pond: SFR, sand concentration, flow velocity
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Objective of this study

Predict flow and segregation behavior during tailings deposition and optimize tailings discharge operations to:

- Minimize production of FFT, or maximize fines capture
- Estimate sand and fines distribution within a tailings deposit to improve final reclamation, e.g.:
  - Total settlement and settlement rates
  - Bearing capacity

Upgrade Delft3D to cover a wide range of tailings characteristics (and their mutual interaction)

Photos from: B. Pirouz, ATC Australia and Google Earth
Delft3D today

Model of alluvial deltas / beaches in Newtonian flow → Existing open source Delft3D (https://oss.deltares.nl/web/delft3d)
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Modeled cross section

Measured cross section
Beaches and deltas – scales and types

Shell Beach, Source: Google Maps

Runoff from cultivated field near Pigeon Point, CA. Source: Gary Parker e-book morphodynamic

Alaska, Source: Flickr - NOAA

Mangoky River, Malagasy Republic. Source: Internet
Beaches and deltas – scales and types

Sand and fines dominated beaches

Top: Shell Beach. Source: Google Maps; right: B. Pirouz, ACT Williams, Australia
Upgrade Delft3D to tailings simulations

Relevant to tailings beaches...

- Shallow water, 3D
- Coupled hydrodynamic, sediment transport and morphology
- Track bed changes and composition
- Multiple grain size (up to 99?), different equations for fines (cohesive) and sand (non-cohesive)
- Variable input in time series, liquid and solids discharge, sediment composition, number of discharges
- Density driven flow, i.e. turbidity currents
- Basic non-Newtonian
- Open source

Upgrade to Delft3D-slurry

- Specific tailings / slurry rheology
- Sheared-induces sand settling
- Laminar – turbulent transition
- Consolidation
- Thixotropy
**Tailings rheology, function of sand & clay**

- Models developed in different fields (natural muds, mining)

<table>
<thead>
<tr>
<th>Rheological Model</th>
<th>Discipline</th>
<th>Authors</th>
<th>Fluid type</th>
<th>Solids effect</th>
</tr>
</thead>
</table>
| 1                 | Nature: mud flats / siltations | C. Kranenburg  
                        | J.C. Winterwerp | Hershel-Bulkley | exponential with Bagnold type linear concentration |
| 2                 | Oil sands tailings | W. Jacobs  
                        | W.G.M. van Kesteren | Bingham | exponential with Bagnold type linear concentration |
| 3                 | Thick slurries | A.D. Thomas | Bingham | Krieger-Dougerty type |

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**Graph: Shear Stress vs. Shear Rate**

- Bingham
- Hershel-Bulkley
<table>
<thead>
<tr>
<th><strong>Rheological Model</strong></th>
<th><strong>Shear Stress and viscosity</strong></th>
</tr>
</thead>
</table>
| **1** Fractal dimension theory | \[
\tau_y = A_y \left( \frac{\phi_{clay}}{\phi_{water} + \phi_{clay}} \right)^{2/(3-n_f)} \exp(\beta \lambda) \\
\mu = \mu_w + A_\mu \left( \frac{\phi_{clay}}{\phi_{water} + \phi_{clay}} \right)^{2(a+1)} \left( \frac{1}{\phi_{clay}} \right)^{3} \exp(\beta \lambda)
\] |
| **2** Water content to the fines (W/PI) | \[
\tau_y = K_y \left( \frac{W}{PI} \right)^{B_y} \exp(\beta \lambda) \\
\mu = \mu_w + K_\mu \left( \frac{W}{PI} \right)^{B_{\mu}} \exp(\beta \lambda) \\
\frac{W}{PI} \approx \frac{W_{clay}}{A_{clay activity}}
\] |
| **3** Viscosity enhancement and empirical fit | \[
\tau_y = C_y \left( \frac{\phi_{fines}}{\phi_{water} + \phi_{fines}} \right)^{p} \left[ 1 - \frac{\phi_{sa}}{k_{yield} \phi_{sa max}} \right]^{-2.5} \\
\mu = \exp \left( D \frac{\phi_{fines}}{\phi_{water}} \left[ 1 - \frac{\phi_{sa}}{k_{visc} \phi_{sa max}} \right]^{-2.5} \right)
\] |
Sheared-induced sand settling

\[ w_{s,\text{eff}} = w_{s,0} (1 - k\phi_{\text{sol}})^n = \alpha \frac{(\rho_s - \rho_{\text{cf}})gd^2}{18\mu_{\text{apparent-cf}}} (1 - k\phi_{\text{sol}})^n \]

Curtesy: Arno Talsma
Tailings characteristics: \( Cs_w = 40 \% \); SFR = 0.25; \( Ty = 40 \ Pa \); \( \rho = 1330 \), similar to TT?

Discharge 1 \( m^3/s \), 1\% slope, profiles along the slope.

### 1DV model verification

- Flow Velocity
- Sand Settling Velocity
- Sand Concentration
1DV model verification

Flow velocity in line with theory and experimental data; sand concentration in line with experimental observations

* B. Pirouz data on half open pipe
** Sanders and Speelay open channel tests
Latest Advances

- Fresh tailings over old stronger tailings
- $1 \text{ m}^3/\text{s}$ tailings discharge, $\text{SFR} = 5$, $\text{Ty} = 20 \text{ Pa}$, over $\text{Ty} = 40 \text{ Pa}$
- Run computation time: ~ 10 mins
  - Fresh tailings go over old tailings, initially;
  - Fresh tailings slowly erode strong tailings
  - Sand settling produce fines in pond
  - Coarse tailings flow plumbs into fresh tailings in pond

Sand concentration

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This model can **potentially be applied** to (some application may need throughout testing and possible model enhancement):

- **Optimization of deposition operations** to:
  - Maximize fines capture
  - Maximize deposit capacity
  - Assess effect of water pond elevation or subaqueous deposition
  - Assess variation of tailings stream properties, or discharge
  - Evaluate effect of cell geometry, containment, etc

- **Evaluate co-deposition or co-mixing** of coarse tailings into fluid tailings (ponds)

- **Evaluate erosion** of existing tailings by flushing or deposition of additional tailings

Delft3D standard is **open source**. This version of Delft3D-slurries will be open source as soon as properly tested. **Delft3D-slurry 3D follows soon**.