RHEOLOGICAL AND GEOTECHNICAL CHARACTERISTICS
JAMIE SPIERS

Methods for Treatment of Mine Tailings
16 - 17 November 2010
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Mining Industry is responding to pressure to develop innovative methods for tailings disposal which include –

- Less water to treat, manage and discharge to environment
- Water conservation from thickening for reuse in the mill
- A reduced need for large, expensive, unstable dams
- More potential sites to choose from - topographic containment not an issue.
- Reduced potential for seepage from tailings impoundments into local groundwater supplies
- Less environmental impacts - seepage, groundwater contamination
Thickened Tailings – Increasing Prevalence
Thickening Process

- Mechanical process involving dewatering of a low solids concentrated slurry
- Achieved by using compression thickeners or a combination of thickeners and filter presses.
- Thickened tailings are defined as tailings that have been significantly dewatered to a point where they will form a homogeneous non-segregated mass when deposited from the end of a pipe.
- When placed layer by layer the thickened tailings will dry to near its shrinkage limit and become dilative under dynamic shaking, thus preventing the possibility of liquefaction.
Water recovery at the thickener

Thickened tailings: recover the water I can afford.

<table>
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<th>Water (Thousands)</th>
<th>Tailings (Thousands)</th>
<th>Solids Content</th>
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<td>221 667</td>
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<td>11</td>
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Thickened Tailings Characteristics

- Tailings is dewatered to maximise water recovery at the plant
- Higher storage densities achieved compared to conventional methods
- Does not segregate once discharged
- Flow is highly dependant on rheology of the slurry
- Settles rapidly – Increases Stability
- Quick shedding of superficial water due to beach slope
- Most of geotechnical characteristics are similar to conventional tailings when settled
Rheology - Introduction

Fresh

Deposition of the slurry is characterised according to its moisture content

Deposited

‘dessicating’

Dry
Viscosity is a measure of the resistance of a fluid which is being deformed by either shear stress or tensile stress. The minimum shear stress needed to start sustainable flow is known as the yield stress. Shear rate, denoted by $s^{-1}$, indicates how fast the fluid is being sheared.
Rheology: types of fluid

**Conventional tails**

What is a *Newtonian fluid*?

\[ \tau = \mu \frac{dV}{dY} = \mu \gamma \]

**Thickened tails**

What is a *non-Newtonian fluid*?

\[ \tau \neq \mu \gamma \]

Stress versus strain rate curve is linear and passes through the origin - fluid continues to flow regardless of forces acting on it

Relation between the shear stress and the shear rate varies, viscosity difficult to define.
Thickened tailings can be classified as non-newtonian fluids, therefore the rheology corresponds to a viscoplastic behaviour.
Viscoplastic Model

Bingham Model for thickened tailings:

\[ \tau_{xy} = \tau_y + \mu \frac{dx}{dy} \]

This simplified model is useful to describe thickened tailings flow – i.e. beach angle estimation.
How to measure viscosity?

**Viscosimeter**

- Shear rate is estimated from geometry of the vane/bob-cup and velocity. This is normally controlled by computer.
- Shear stress is measured from torque.
- Lightweight.
- It is not always clear transition from laminar to turbulent flow.
Yield stress

- Slurry yield stress increases with density.
- Determines reology of the tails ranging from Slurry to Filter Cake
- Implications upon transport of material—Pump sizes and conveyors
Typical yield stress values

Different ores will exhibit different rheology.
Other methods...

**Slump method**

These methods give approximations of yield stress – are useful for site control
SHOULD NOT BE USED FOR DESIGN

Abrams cone

Boger cylinder
Lessons learnt – Tailings rheology

- No theoretical models exist to determine rheological parameters WITHOUT test data
- The most widely used model is the two parameter Bingham plastic model
- Rheometer tests must be carried out at appropriate shear rates. Implications upon:
  - Thickening process
  - Piping and pumping design
  - Beach flow characterisation
- Tests must be done for a range of solids concentrations, size distributions and include all variables that may influence rheology
- Rheology is sensitive to variations in slurry ‘ingredients’ – a small change in slurry properties could result in a large change in rheology
Geotechnical Characterisation

- It is not very different than conventional characterisation
- Some of the tailings properties don’t change with water content:
  - SG
  - PSD
  - Atterbergs
- Other properties (transient) change such as:
  - Settling – consolidation
  - Dry density
  - Porosity
- Geomechanical characteristics change with tailings fabric
  - Mohr – Coulumb
  - Cyclic shear strength mobilisation
  - Elastoplastic characteristics (E,G )
Specific Gravity

- ASTM D854-05
- This is one of the most important properties: needs to be tested!
- It is not likely to change with milling
- It varies with ore – important when orebody is not homogeoneous
Particle size distribution (PSD)

- ASTM D422
- Change with milling
- Change with ore
- Fine contents: crucial to establish thickening rate
- Permeability can be estimated (Hazen or Kozeny-Karman) - don’t use for design!
- Internal friction angle can be estimated (Dhawan) – don’t use for design!
- It can be used for drainage design – interface material design.
Tailings settled density

- Settling test – 24 h (or more) – drained and undrained
- SG is needed
- Atterbergs
- Shrinkage limit
- Further change in density: Consolidation
Settled Density – fresh tailings

Density - Moisture relationship

- SG = 2.75
- Shrinkage Limit
- Plastic Limit
- Liquid Limit
- Settling test
- Thickener Underflow
- Consolidation
- Next layer
Embarkment Geomechanical Characteristics

Field Scale Triaxial Tests to establish the shear strength properties of the embankment materials
Field Tests - The Unconventional

- Esperanza Project - Chile
- 95,000 tpd dry product to be stored, total 500 Mt capacity storage.
- SRK undertook the design of the facility
- Design dependent upon accurate estimation of beach slope (target 4%) to ensure that sufficient capacity was available for storage over the life of mine.
Esperanza Tailings Project - Growth

Target Upstream beach angle: \( i = 8\% \)
Target Deposition beach angle: \( i = 4\% \)
Esperanza Field Testing

- The following tests have been performed by SRK to assess the flow and settling characteristics of thickened tails material
- Thickening Plant Testing – Four single riser cone deposition tests carried out in the facilities of the CIMM.
- Pilot Plant Testing – Single cone riser deposition test carried out in nearby desert to evaluate the effect of local weather conditions on deposition.
- In-situ desiccation test - Tails from pilot plant deposited so that spreading and desiccation characteristics could be observed.
- Flume Tests – Determine flow characteristics of tails material
Pilot thickening
Pilot in-situ disposal
Pilot in-situ disposal
Pilot in-situ disposal
Pilot insitu disposal
Pilot insitu disposal
Pilot insitu disposal
Pilot in-situ disposal
Other tests – Flume
Other tests – In-situ desiccation

- Water Retention Curve
- Moisture Content [%] vs. Pressure Head [-cm water]
- Data points and curves for different materials:
  - Tailings
  - Alluvium_mod
  - Alluvium
Applications Thickened Tails

- Beach slope estimation
- Infiltration assessment
- Stability
- Deformation
- Liquefaction
Beach slope estimation

\[ R^2 = 0.91 \]

\[ R^2 = 0.90 \]

\[ R^2 = 0.86 \]
Infiltration analysis

30 days after deposition

Moisture (w%)

- From 29% to 18%
- From 1% to 4%
- No variation

[Graph showing moisture distribution over depth]
Deformation analysis – Flac 3D
Liquefaction analysis
Discussion - Questions