Vertical Hydraulic Transport
for deep sea mining
a study into flow assurance

Jort van Wijk
Can the riser get blocked?

- Which flow regimes can be expected?
- How does a blockage develop?
- What is the wall friction between a plug and the riser?
- How to model transient mixture flow in the VTS?
Which flow regimes can be expected?
How does a blockage develop?
Intermezzo: is axial dispersion important?
What is the wall friction between a plug and the riser wall?

Wall friction of coarse grained sediment plugs transported in a water flow through a vertical pipe

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\[ \tau_s = \frac{D}{4} \cdot \left[ (\rho_s - \rho_f) \cdot c_v \cdot g \right] \cdot \left[ 1 - \frac{D}{4 \cdot \mu_k} \cdot \frac{1 + \sin \Phi}{1 - \sin \Phi} \cdot \frac{1}{L} \cdot \left( 1 - e^{\frac{4 \cdot \mu_k}{D} \cdot \frac{1 - \sin \Phi}{1 + \sin \Phi} \cdot L} \right) \right] \]
How to model transient mixture flow in vertical transport systems?

\[
\frac{\partial \rho_m}{\partial t} + \frac{\partial (\rho_m \cdot v_m)}{\partial z} = 0
\]

\[
\frac{\partial (\rho_m \cdot v_m)}{\partial t} + \frac{\partial (\rho_m \cdot v_m^2)}{\partial z} = \frac{\partial p}{\partial z} - \frac{4 \cdot \tau_m}{D} \rho_m \cdot g + \sum \frac{\partial p_e}{\partial z} - \cdots
\]

\[
\frac{\partial}{\partial z} \left[ (1 - c_v) \cdot \rho_f \cdot (v_m - v_f)^2 + \sum_{k=1}^{K} c_{v,k} \cdot \rho_{s,k} \cdot (v_m - v_{s,k})^2 \right]
\]

\[
\frac{\partial c_v}{\partial t} + \frac{\partial c_v \cdot v_s}{\partial z} = \frac{\partial}{\partial z} \left( c_z \cdot \frac{\partial c_v}{\partial z} \right)
\]

To crawler (Blue Mining reference case)
Conclusies

• The 1D continuum model enables calculation of the vertical transport of slurries. It excludes density waves and the transport of flat particles.
• Layered sediment plugs exert much wall friction.
• Layered sediment plugs are able to block the VTS.
• Besides the development of layered plugs, also flat particles are a risk for riser blockage.
• It seems that density waves are not to be expected to occur in the VTS.
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