Method

➢Use the Multiphase Transport Evaluation Loop (MTEL) Facility at PNNL to gather additional data to first calibrate then validate the ParaFlow software

- First set of tests will focus on confirming sensor capability and test repeatability
- This as well as previously gathered data will be used to calibrate the physical attributes of the simulant as it forms a bed in the pipe

➢Perform ParaFlow model enhancements required to model the two-phase phenomenon of slurry transport with sufficient accuracy to predict critical deposition velocity and bed formation in pipeline configurations

- Similar to Lattice-Boltzmann codes, ParaFlow employs a new technique called Lattice-Kinetics. Its framework readily allows for transient multi-phase modeling, scales linearly from desktop to supercomputers, and captures flow behavior in greater detail than is available with previously existing software

➢Perform blind predictions with the updated ParaFlow architecture using a simulant and operational parameters that differ enough from the first set of tests to allow for validation of the ParaFlow's ability to simulate non-cohesive slurry behavior

➢Confirm ParaFlow's predictive capability by performing follow-up testing in MTEL

➢Rely on SRNL to perform pipeline flushing experiments and glass frit plugging evaluations with a collective objective between PNNL and SRNL to reduce flush volumes to minimum acceptable levels, thus maximizing solids transport and minimizing contribution to overall liquid waste stream

§ The Lattice-Kinetics Code ParaFlow

Accomplishments

Developed a general highly-parallel multiphase flow simulation program (ParaFlow) based on the lattice kinetics algorithm developed at PNNL. Program features include:

- Turbulence models (RANS, LES)
- Dynamic sediment bed modeling
- Equilibrium chemistry model
- Hierarchal grid structure
- Erosion/Deposition
- Dynamic lithostatic model
- Cohesive solids, Non-Newtonian
- 92% parallel efficiency on 4096 processors

The increased computational power from parallelization may be used to:

- Use more physically realistic models
- Use a more detailed mesh to describe the geometry
- Run extended transients in a reasonable amount of time

The simulation capabilities of the program has been demonstrated on a number of applications:

- LMFBR wire-wrap bundle
- Catalytic reactor
- Pulse jet mixing
- Ultrafiltration
- Slurry pipe transport
- Tank waste mobilization and mixing

§ The Multiphase Transport Evaluation Loop (MTEL) Facility at PNNL

Componentry and Capabilities

➢**Nominal loop configuration comprised of 3" sch. 40 stainless process piping**

➢**66 gallon loop volume (not including vessels)**

➢**GIW 2x3 Slurry Pump (single, two available)**

- **0.9"x1.2" solids passage capability**
- **330 – 390 gpm achievable transport (open or sealed and pressurized)**
- **50 psig loop ΔP possible (30 Pa, 30 cP fluid no issue)**

➢**450 gallon baffled mixing vessel**

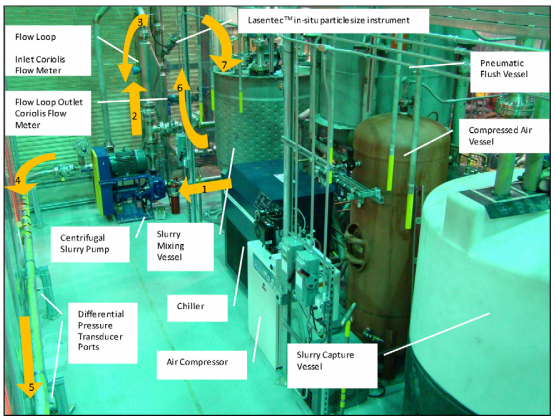
- **15 hp in simulant mixing mechanical energy**
- **Bottom or dip-tube feed**
- **Bypass capable**

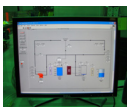
➢**High resolution imaging system**

- **4 µm – 1000 µm visual detection capability**

➢**Multiple visualization sections and configurations available**

- **High pressure (<182 psi @ room temp.)**
- **Low pressure (<85 psi @ room temp.)**





➢**Ultrasonic Transducer Technologies developed and successfully applied**

- **PulseEcho (PE)**
- **Ultrasonic Doppler Velocimetry (UDV)**
- **Ultrasonic Attenuation (UA)**

➢**600 gallon pressurized flush capability**

- **130 psi flush achievable for mechanical plug removal**
- **600 – 1000 gpm achievable**
- **Heated acid or caustic flush for chemical plug removal evaluation**
- **Reversible flush possible (forward & backward)**

➢**Pressure differential sensing capability ranging from 1psi to 300 psi ΔP**

➢**Lasentec focused beam reflectance measurement (FBRM) sensor - real-time length scale measurement**

➢**Electrical Resistance Tomography system - non-intrusive flow state determination device**

- **4' Linear mixing vessel probe**
- **2", 2.5", & 3" inline probes available**

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Pipeline Plugging Prevention

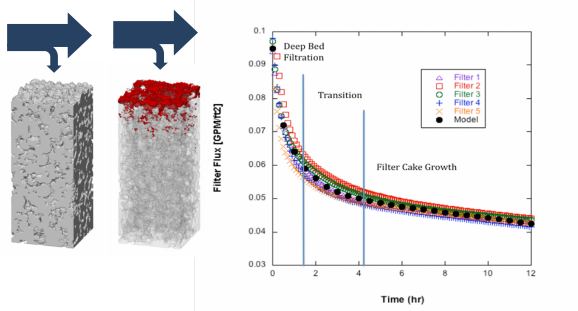
Dave R. Rector • Jagan R. Bontha • Richard C. Daniel • Harold E. Adkins

Objective

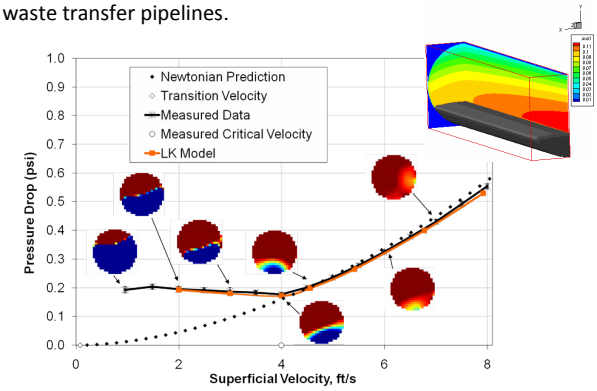
To demonstrate effective pipeline transport waste volume reduction techniques, perform experiments to understand the operational parameters necessary to prevent pipeline plugging, develop methodologies to reduce flushing requirements, incorporate new models into an existing multi-phase computational tool to address waste slurries, and validate the tool using the experimental data to provide a predictive tool to allow for enhanced waste throughput while avoiding plugging.

Results to Date

Eulerian/Lagrangian multi-phase simulations track the paths of individual suspended particles. This technique was used along with the Eulerian Mixed approach to simulate the Waste Treatment Plant (WTP) ultra-filtration process.



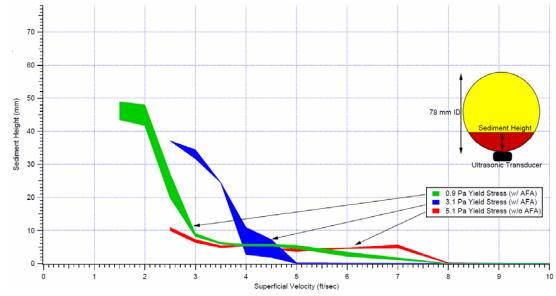
Eulerian-Eulerian (solid-liquid two-fluid multiphase) and **Eulerian-Mixed** (transported solids scalar field) used to simulate dynamic sediment bed erosion/deposition and transport of suspended solids for applications such as simulated plugging of waste transfer pipelines.



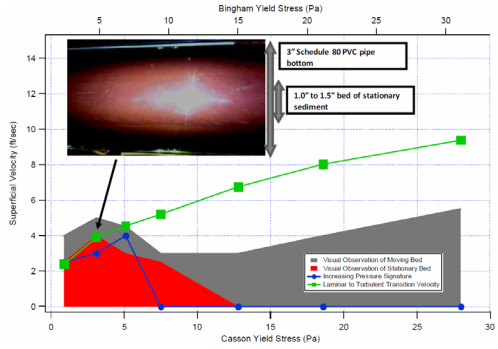
Campaigns Supported & Conclusions

WTP M-1 Critical Settling Evaluation:

- Investigated critical deposition velocity for slurries with wide range of properties to mimic large cross section of Hanford waste to be processed (WTP-RPT-175, Rev 0)
- Investigated influence of complex piping geometry (WTP-RPT-178, Rev 0)
- Investigated critical deposition velocity for representative (highly engineered) complex simulants (WTP-RPT-189, Rev 0)
- Investigated possible flushing techniques (WTP-RPT-175, Rev 0)
- Developed correlations and a stability map relationship for broad-spectrum slurry transport (WTP-RPT-175, & -189, Rev 0)



Engineered AZ-101 HLW Pretreated Sludge Simulant Settling Characteristics



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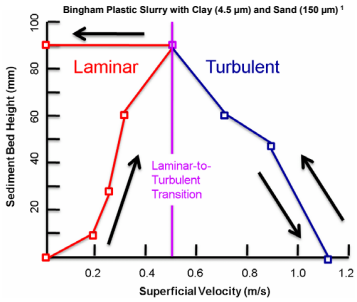
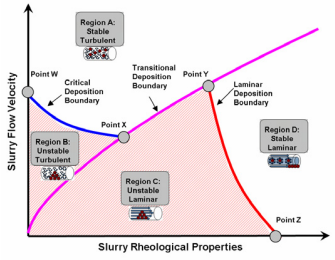
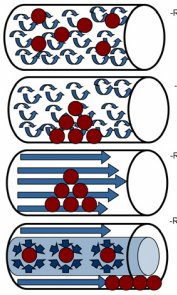
What We've Learned So Far



Paterson & Cooke[3]





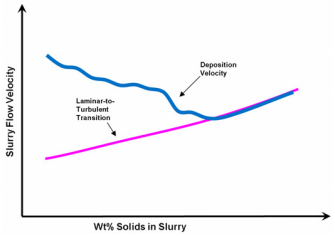
-Regime A: Stable Turbulent
- Turbulent eddy drag forces are sufficient to suspend the particle buoyant mass

-Regime B: Unstable Turbulent
- Turbulent eddy drag forces are not sufficient to suspend the particle buoyant mass

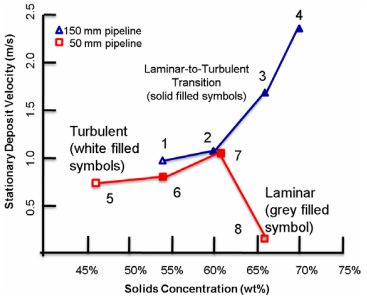
-Regime C: Unstable Laminar
- Turbulent eddy forces are dissipated by viscous forces

-Regime D: Stable Laminar
- Yield stresses dominate the unsheared core region of the pipe flow
- Yield stress supports particles during transfer
- Wall shear stress push particles deposited along pipe wall

- Plot adapted from Mular et al. (2002)[4]
- Increasing solids loading raises rheological properties
- Eventually the flow will become laminar and deposition occurs
- Deposition velocity then follows the transition velocity and increases with solids loading
- Warn of excessive pipe wear at pipe bottom due to moving bed



- Data from Cooke[2] (2002)
- Two pipelines tested
  - 50 mm ~2 in; square symbols
  - 150 mm ~ 6 in; triangle symbols
- Points 1 & 5 exhibit deposition in turbulent flow
- Points 2,3,4, 6, & 7 exhibit deposition at transition from turbulent to laminar flow
- Point 8 shows stable laminar flow in smaller diameter pipe due to increased shear
- Author concludes pipe tests with only 50 mm diameter would incorrectly find that operation at high solids concentrations is safe for larger diameter pipe



[1]Song T. and Y-M Chiew. 1997. "Settling Characteristics of Sediments in Moving Bingham Fluid." *J of Hyd. Eng.*, 123:9, September, ASCE.

[2]Cooke R (2002) "Laminar flow settling: the potential for unexpected problems." BHRG 15th International Conference on Slurry Handling and Pipeline Transport, *Hydrotransport 15*; Banff, June. 121-133.

[3]DOE Slurry Retrieval, Pipeline Transport & Plugging and Mixing Workshop, January 2008.

[4]Andrew L. Mular, Doug N. Halbe, Derek J. Barratt Contributor Andrew L. Mular, Doug N. Halbe, Derek J. Barratt, "Mineral Processing Plant Design, Practice and Control: Proceedings" Published by SME, 2002.

Future Work Required to Develop this Powerful Predictive Tool

- Perform two to three tests with Multiphase Transport Evaluation Loop (MTEL) Facility at PNNL using simple mono-disperse and poly-disperse simulants to gather additional data for enhancement and validation of ParaFlow software.
- Perform ParaFlow model enhancements required to model two-phase phenomenon of slurry transport with sufficient accuracy to predict critical velocity and bed formation in pipeline configurations.
- Perform a small series of blind predictions with updated ParaFlow architecture using a simulant and operational parameters that differ enough from the first set of tests to allow for validation of ParaFlow's ability to simulate non-cohesive slurry behavior.
- Confirm ParaFlow's predictive capability by performing a series of follow-up testing in MTEL and comparing with ParaFlow solutions.

WRPS Waste Certification Loop Technology Development & Evaluation:

- Investigate the application and use of UT devices for detection of critical velocity and onset of settling (PNNL-19441 & -19560, Rev 0)
- PulseEcho & UDV capable of conservatively determining critical settling velocity within 0.1 ft/s of that visually detectable and non-intrusive (PNNL-19441, Rev 0)
- Reinforced that ΔP not necessarily reliable for determining critical settling velocity

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