Computational Simulation and Evolution of HLW Pipeline Plugs at Hanford

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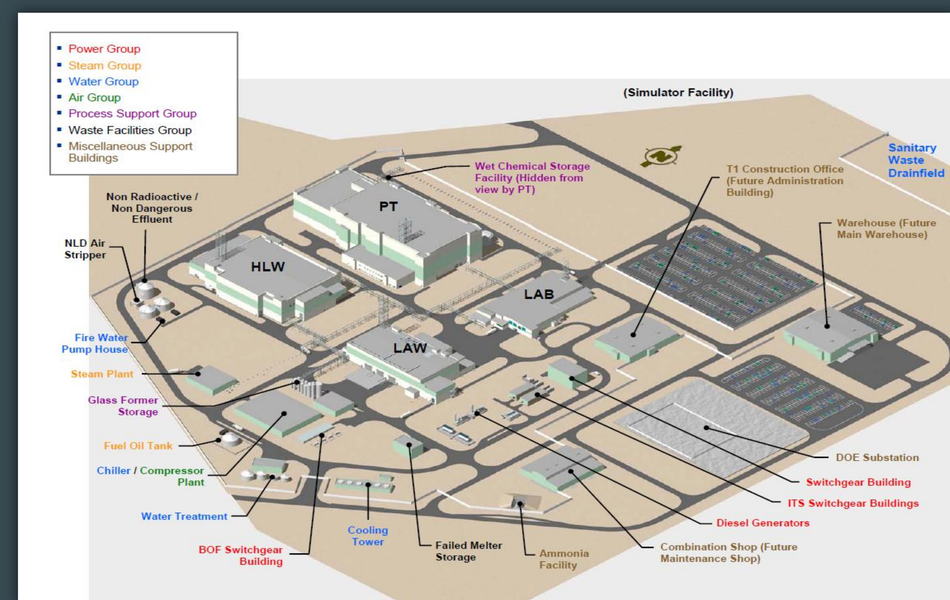
Introduction

Today, DOE sites such as Hanford and Savannah River are actively engaged in the transfer of radioactive liquid and sludge waste with the purpose to clean out and decommission stored nuclear waste. During transfer operations, millions of gallons of waste are retrieved from underground storage tanks and transported via underground pipelines for treatment or disposal. However, as previously reported, transfer operations may be accompanied by serious transfer line disruptions due to blockage formation of nuclear waste slurries. This is known as pipeline plugging.



Factors that ultimately lead to the occurrence of pipeline plugging are:

1) settling of solid particles
2) crystallization of the waste, and
3) gelation of the waste.

Task

- Analyze the mechanisms of pipeline plugging
- Identify the correlation between the geometric design of pipeline systems and its affect on the pipeline flow
- Develop multi-physics computational models that will simulate the formation of a pipeline plug using COMSOL Multiphysics 4.3 - 3Dimensional Finite Element software

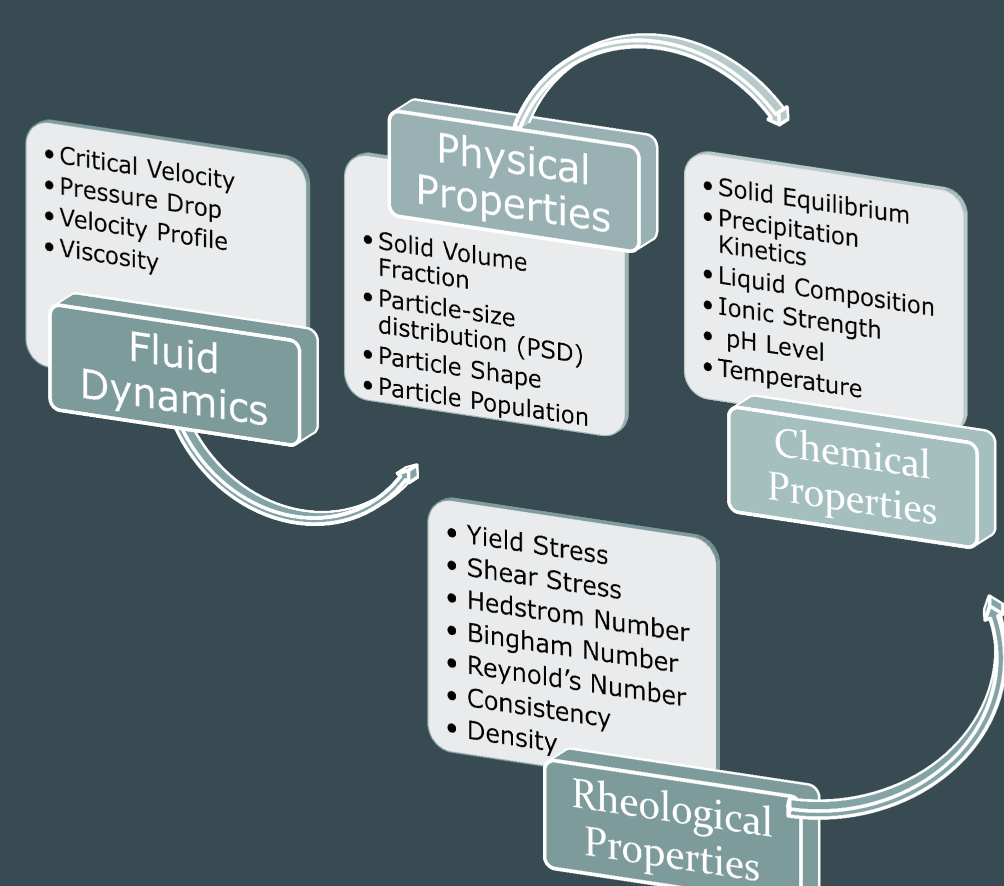
Purpose

- To investigate the challenges associated with minimizing the risk of a plugging event
- To provide a better understanding of HLW's chemical, rheological, and mechanical properties and their correlation with the pipeline's geometry/design configurations that may influence plug formation during the transfer process

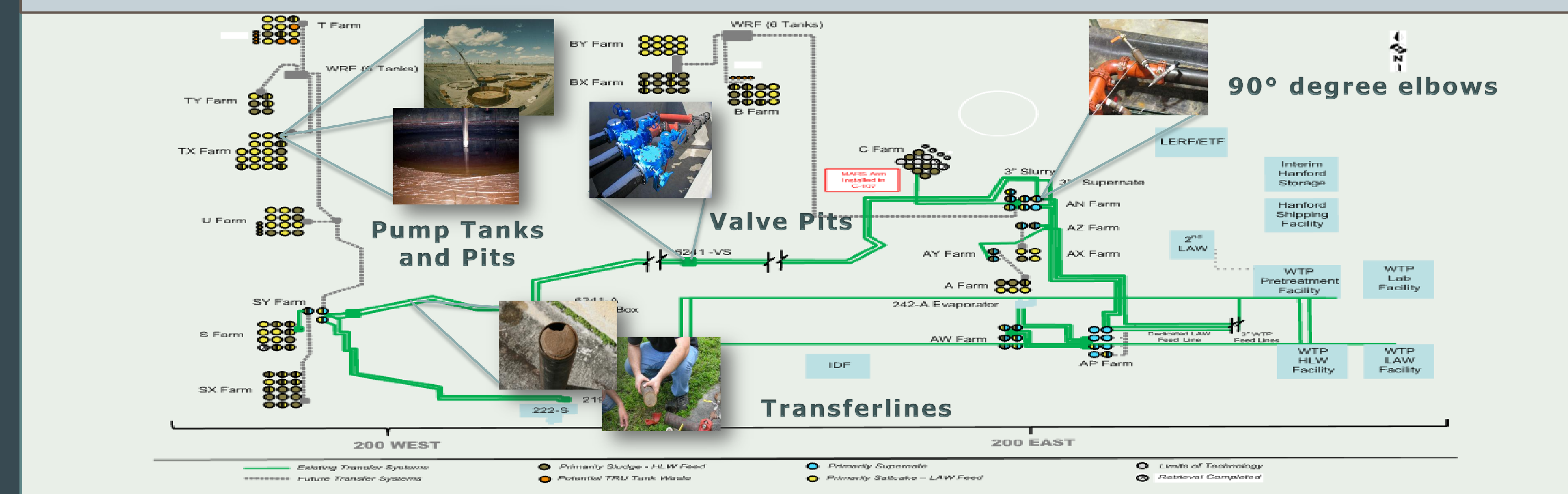
Pipeline Plugging Formation

Reported Plugging Mechanisms

Plugging Mechanism	Location /Potential Location of Occurrence	Limiting Conditions
1. Solids settling, static PSD	Cross-site transfers of sludge water slurry	Flow velocity, solids volume fraction, solids density, solids PSD, temperature
2. Solids settling, dynamic PSD	Cross-site transfer or sludge-supernatant slurry and salt-well pumping	Flow velocity, solids volume fraction, solids density, solids PSD, precipitation rates, chemical reaction rates, agglomeration rates, temperature
3. Surface deposition and crystallization, static and dynamics PSD	Evaporator lines at Savannah River. Solutions containing silica and alumina	Surface deposition rates, crystallization rates, flow velocity, temperature
4. Bulk of slug plugging	Salt solutions containing phosphate	Flow velocity, flow regime, metastable state formation kinetics, temperature
5. Packed bed in vertical flow	Vertical legs leading to Waste Treatment Plant	Flow velocity, solids volume fraction, PSD, solids density, temperature
6. Depositions at elbow	PUREX connectors, orifices in valve pits	3-D velocity field, flow velocity, solids volume fraction, solids density, solids PSD, precipitation rates, chemical reaction rates, agglomeration rates, temperature



Common Plugging Locations



Computational Simulation of HLW Pipeline Plugs

Early Model Developments

In 2002, researchers at DIAL-MSU created a 1-D CFD model using PHOENICS. The main aim for this development was to produce a model that predicts:

- The formation of a plug and time needed to form
- Location of a plug, and
- Values of fluid dynamic variables in relation to its behavior and waste chemistry

In 2009, PNNL developed a new model using a more advanced simulation tool. The main aim for this development was to produce a model that would:

- Be capable of modeling multiphase and chemically complex flows without being limited to particles of uniform density, simple particle size distributions and simple geometries.

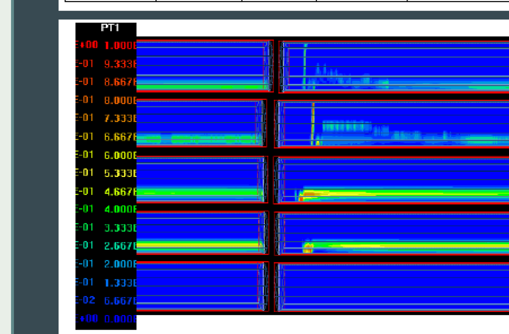
DIAL-MSU SX-104 Waste Simulant & CFD Models

Table 1. Characteristics of SRS slurry C simulant used by FIU

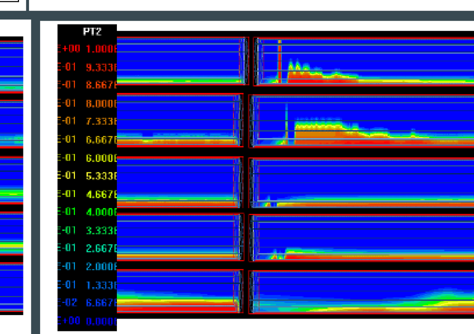
	Density (kg/m^3)	Viscosity (cP)	Diameter (µm)	Concentration (% volume)
Carrier fluid	1005	0.913		92.4
Particle 1	3147		45	2.9
Particle 2	3147		220	4.7

Table 2. Entrance flow velocity for simulation cases

Case number	Case 1	Case 2	Case 3	Case 4	Case 5
Flow velocity (m/s)	0.5	0.8	1.1	1.2	2.5

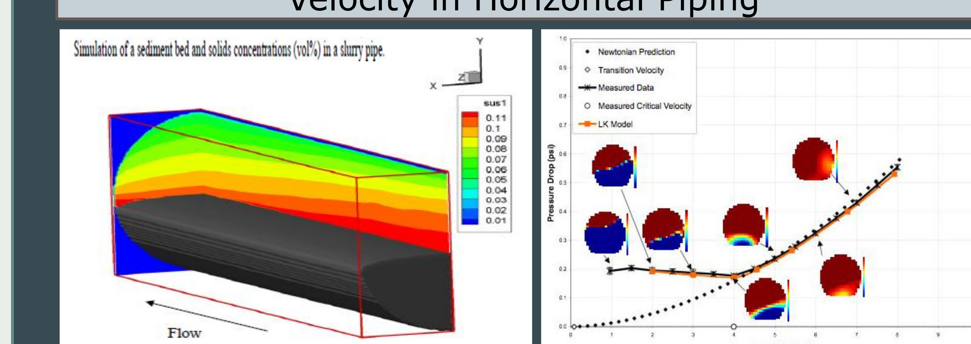


A 45-µm particle concentration along the transfer pipe center line as a function of flow velocity at the entrance, U = 0.5, 0.8, 1.1, 1.2 and 2.5 m/s.



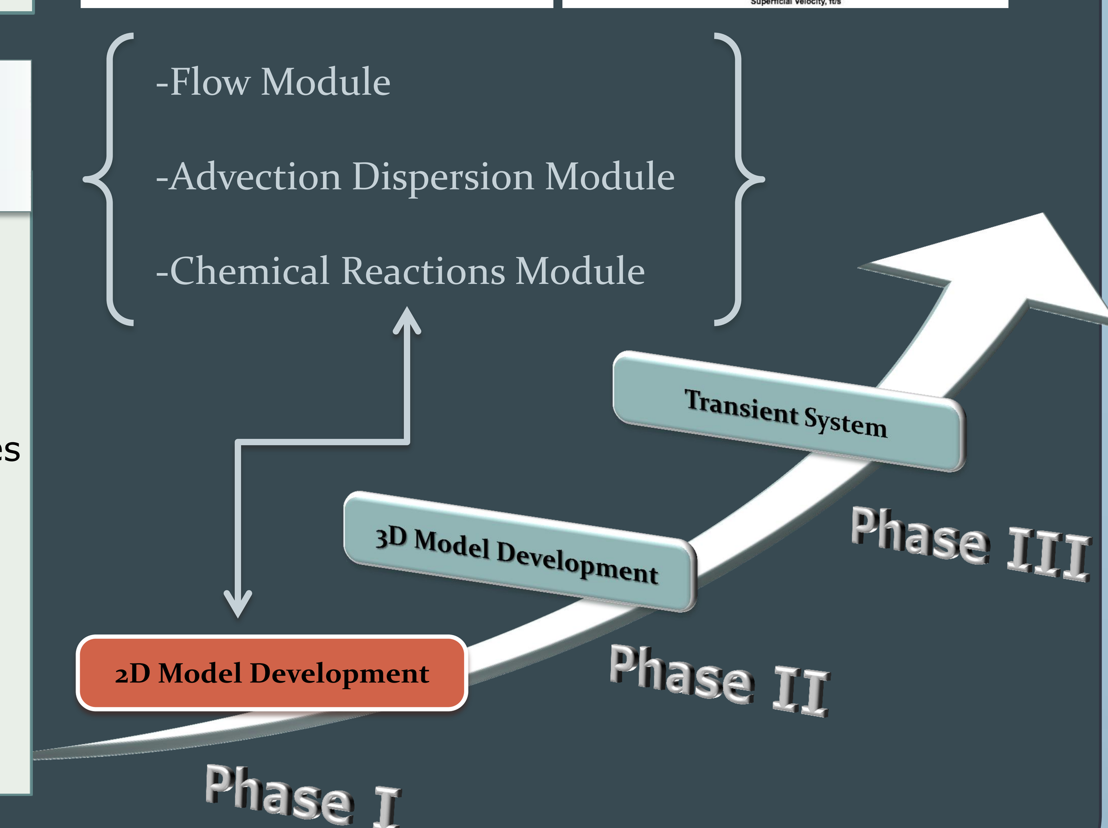
A 220- (or 400-) µm particle concentration along the transfer pipe center line as a function of flow velocity at the entrance, U = 0.5, 0.8, 1.1, 1.2 and 2.5m/s.

PNNL Modeling of Sediment Bed Behavior for Critical Velocity in Horizontal Piping



Future Work

- Efforts will focus on generating a multi-physics module that will be modeled using the multi-physics simulation software, COMSOL.
- The model development will consist of three phases starting with a simple simulant and finishing up with a more complex multi-phase system model
- Simulations will help to investigate how pipeline configurations in its geometry contribute to plug formation and critical flow velocity, and the physical properties of the waste stream



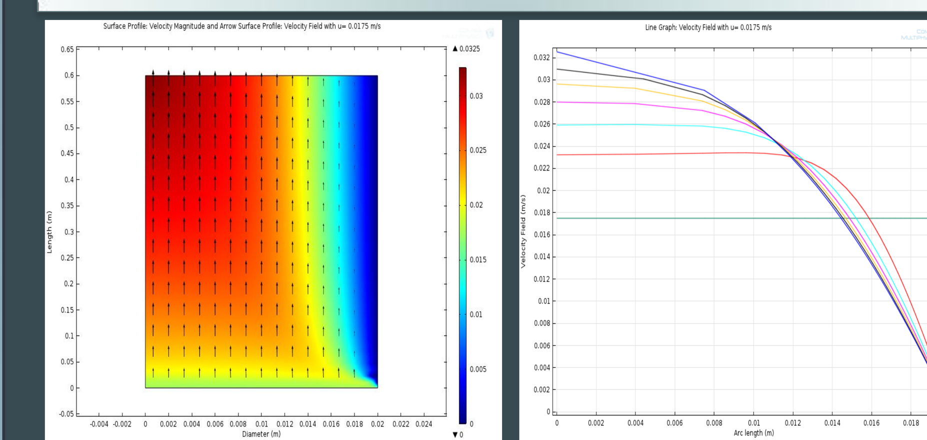
COMSOL Multi-Physics Simulations

Experimental Data: Comparing two Velocity Fields

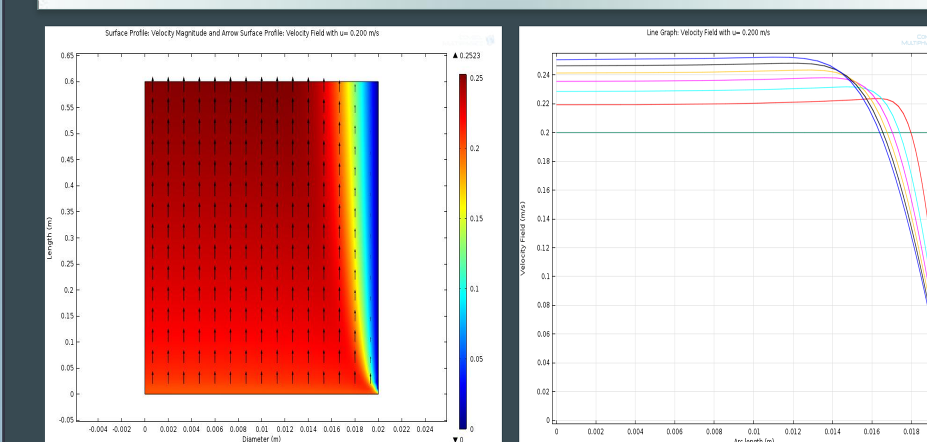
- 6 meter long pipeline
- 0.04 meter diameter

Study 1: u= 0.0175 m/s **Study 2:** u= 0.200 m/s

Study 1



Study 2



Simulation Studies

The above 2D axis-symmetric simulations show development of laminar flow along a pipe. The initial studies focused on verification of the correctness of computed velocities and pressures for steady state flow in a pipe. In addition, with a minimal increase velocity, the velocity distribution expands out more through the pipeline taking a parabolic shape. If the velocity were to increase dramatically, the boundary conditions would change and the flow would considerably be turbulent.

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