Computational Simulation and Evolution of HLW Pipeline Plugs

Deanna Mariel Moya (DOE Fellow) Email: dmoya@fiu.edu

Romani Patel, Dr. Georgio Tachiev

Objective

- This project develops a finite element model of fluid flow in a pipe to provide analysis of pipe plugging which has been reported during transfer operations at DOE sites.
- The model uses a multi-physics simulation software, COMSOL, to simulate and predict the plug formation process in a high-level waste pipeline in a stepwise approach.
- The objective is to provide better understanding of the interactions between critical flow velocity, chemical reaction with formation of solids, and solids settling, and ultimately plug formation.
- Initial simulations were conducted for fluid flow, chemical reactions and solids settling using 2D multiphase simulations.
- The work will be used to provide analysis of the environmental factors causing plug formation.

Numerical Approach

Flow Modeling

Mass Equation

$$\nabla \cdot \rho \mathbf{u} = 0 \qquad \text{steady state}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{u} = 0 \qquad \text{transient}$$

Momentum Equation

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot \left[-p\mathbf{I} + \mu\left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right) - \frac{2}{3}\mu(\nabla \cdot \mathbf{u})\mathbf{I} \right] + \mathbf{F}$$

Chemical Reaction Modeling

$$\frac{\partial c}{\partial t} - \nabla \cdot (D\nabla c) + \mathbf{u} \cdot \nabla c = R$$

Two Phase Modeling

Mass Equation

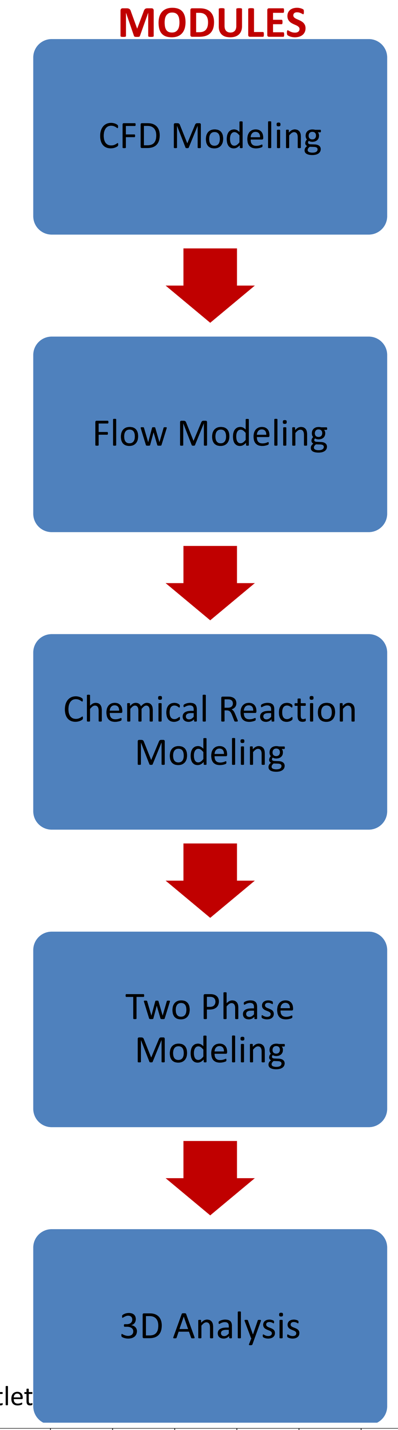
$$(\rho_c - \rho_d)\left[\nabla \cdot (1 - c_d)\mathbf{u}_{slip} - D_{md}\nabla\phi_d) + \frac{m_{dc}}{\rho_d}\right] + \rho_c(\nabla \cdot \mathbf{u}) = 0$$

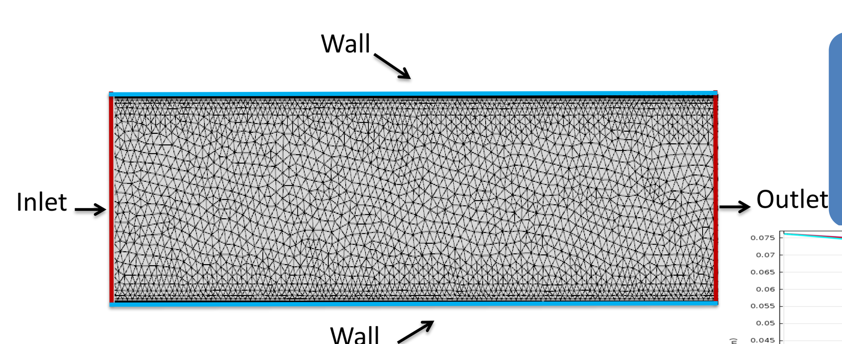
Momentum Equation

$$\rho u_t + \rho(u \cdot \nabla)u = -\nabla p - \nabla \cdot \tau_{Gm} + \rho g + F$$

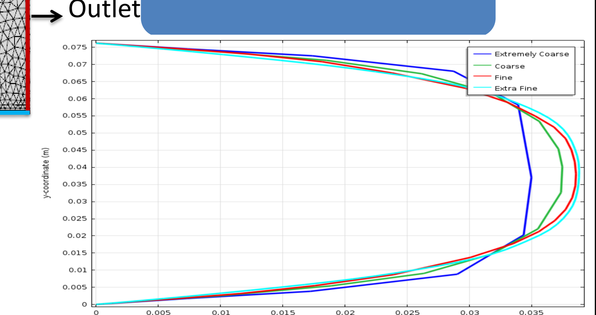
$$-\nabla \cdot \left[\rho c_d (1 - c_d)\left(u_{slip} - \frac{D_{md}}{(1 - c_d)\phi_d}\nabla\phi_d\right)\left(u_{slip} - \frac{D_{md}}{(1 - c_d)\phi_d}\nabla\phi_d\right)\right]$$

MODULES





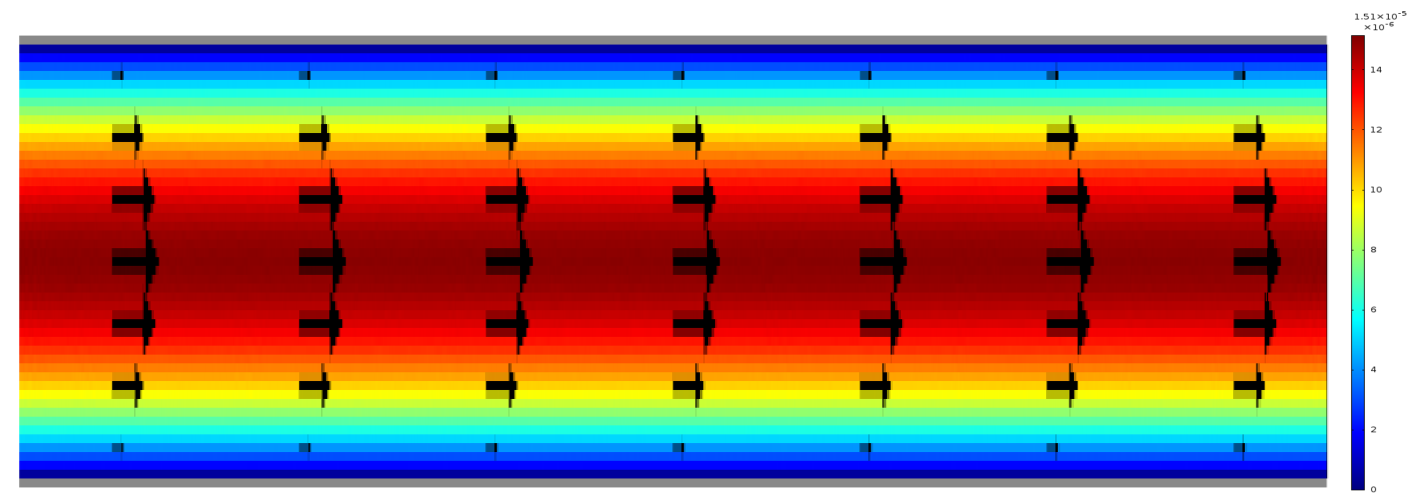
Triangular mesh applied over model domain



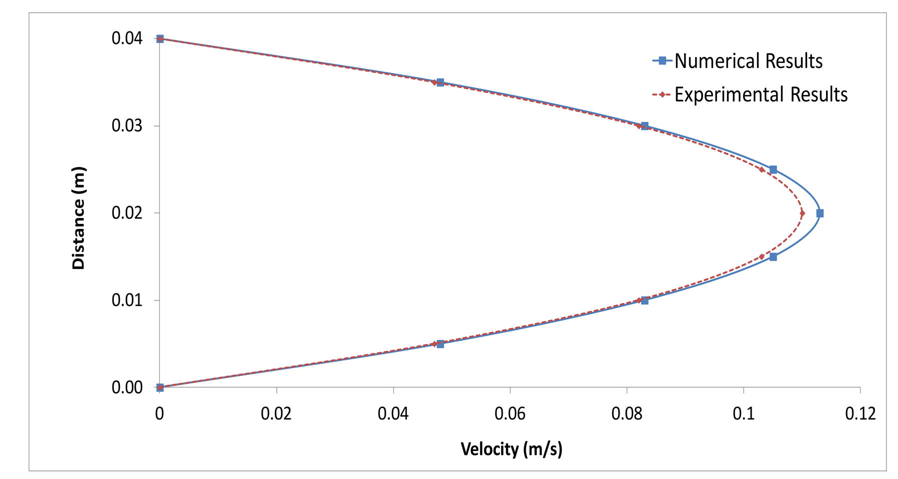
Mesh optimization study

Discussion

Steady State Flow

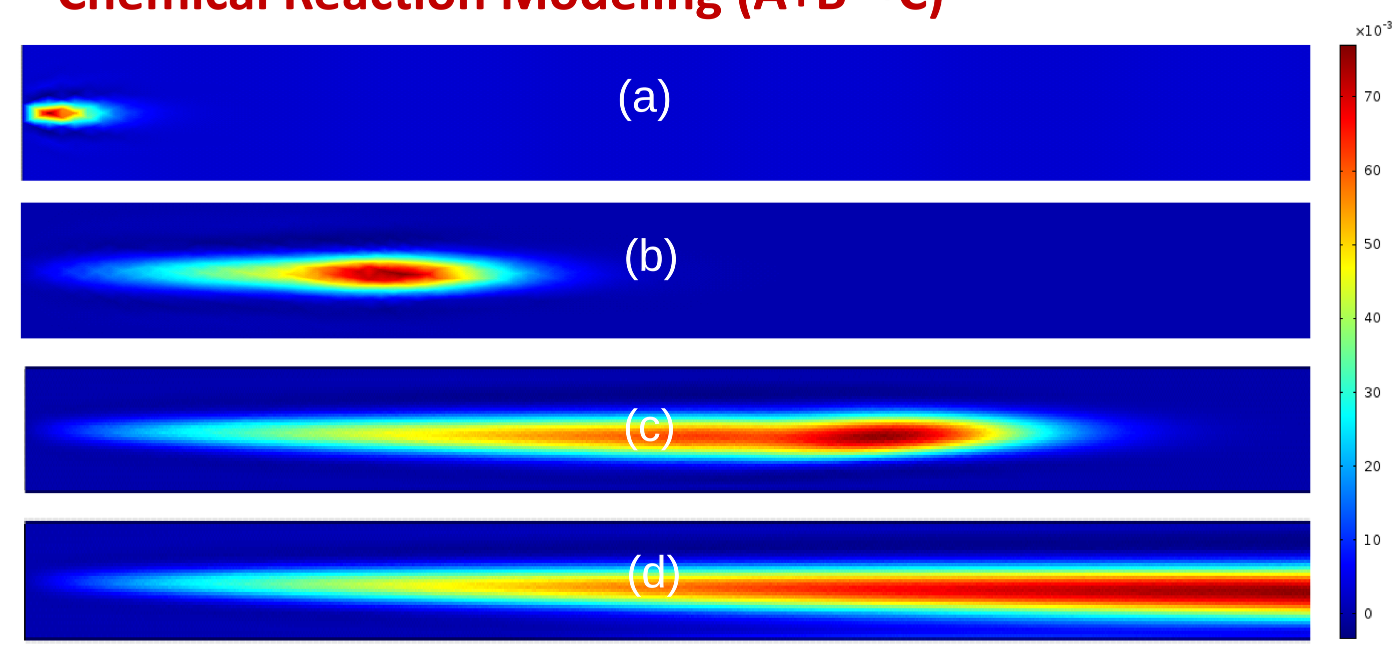


Velocity profile

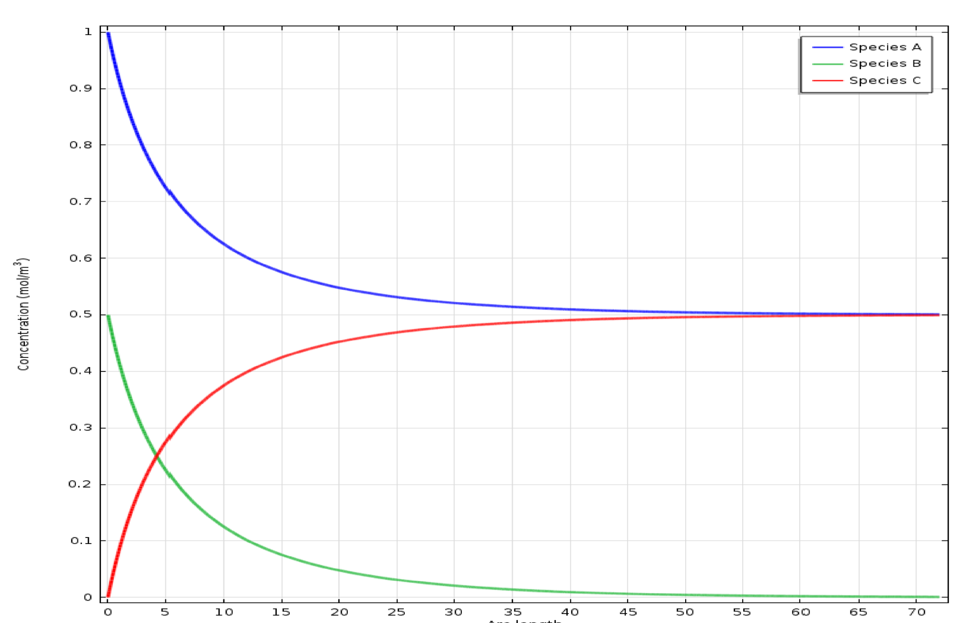


Numerical vs. experimental velocity validation

Chemical Reaction Modeling (A+B→C)

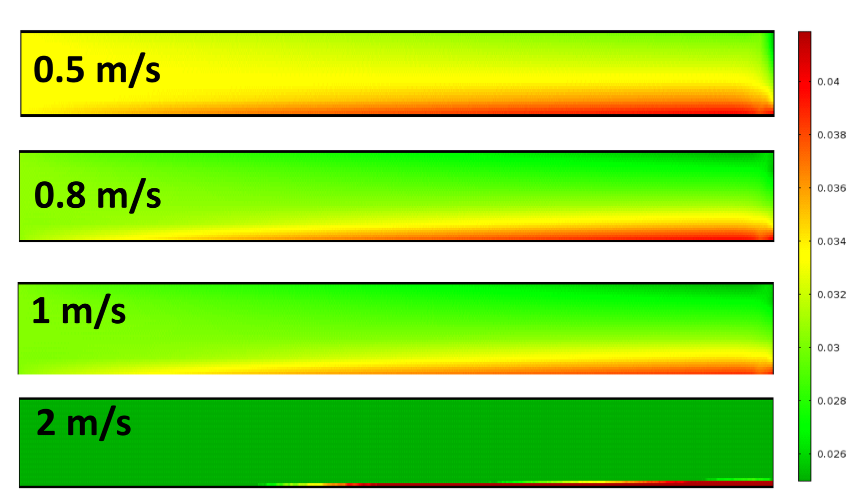


Concentration of product C being formed along the pipe length at a) 0 sec, b) 10,000 sec, c) 100000 sec and d) 300000 sec



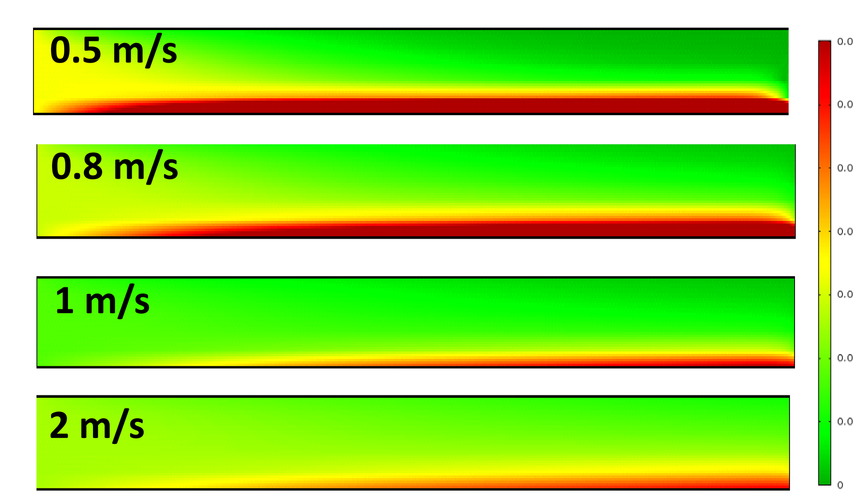
Concentration rofile of the reactants and products

Two Phase Modeling



45 µm Particle Size

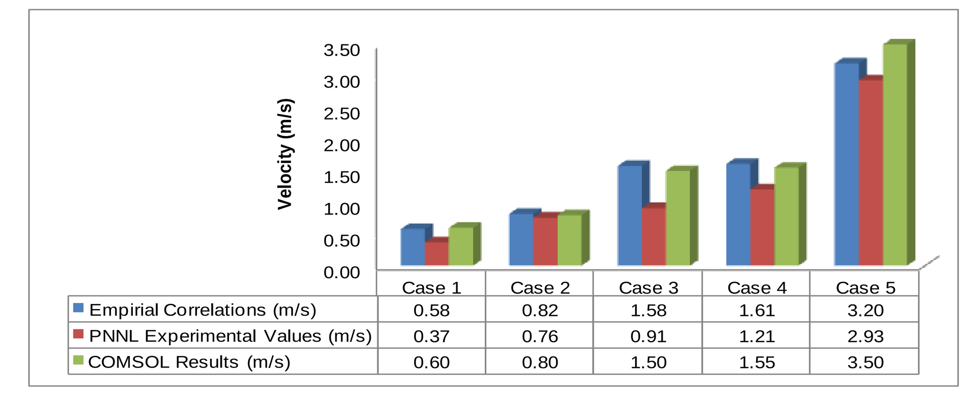
Particle size vs. Critical Velocity



200 µm Particle Size

	Model Verification Study				
Test Configuration	Case 1	Case 2	Case 3	Case 4	Case 5
Particle diameter (µm)	14.4	37.7	129.5	182.3	203.9
Solids Density (kg/m3)	2500	7950	3770	2500	7950
Solids volume fraction (%)	9.8	9.3	8.7	7.4	3.0
Liquid density (kg/m3)	1146	1647	1151	999	1026

Comparison of Numerical vs. Empirical and Experimental Results



Simulation Matrix

Conclusion

- The numerical results were a good match with the experimental results and demonstrated the use of COMSOL Multiphysics 4.3b to accurately simulate the settling physics.
- The two phase modeling simulations show that the 220 µm heavier particles tend to settle fast on the bottom of the pipe, especially at low flow velocities. For flow velocities lower than 1.0 m/s, a stationary bed is observed that eventually causes a plug to form. For velocities greater than 1.0 m/s, the fluid establishes a moving bed regime where the particles move along the bottom of the transfer pipe.
- However, these baseline models do not consider the chemical interactions such as precipitation, particle-particle interactions and how these influence the formation of plugs.
- Moreover, the influence of piping components such as elbows, reducers and pipeline layouts on the plug formation need to be further investigated.

Future Work

- Future work will include simulating plug formation via chemical kinetics and investigating the chemical flow relationships. Model simulations will also serve to evaluate the influence of pipeline geometry on the settling dynamics.

References

- Lindner, J. S. et al. 2002. Dial/MSU Prevention of Solids Formation FY 2000 Status Report Part II: Modeling of Slurry Transport and Saltwell Pumping, reported in ORNL/TM-2000/302, Mississippi State University, Starkville, Mississippi.
- Poloski, A. P. et al., 2009. Deposition Velocities of Newtonian and Non-Newtonian Slurries in Pipelines, PNNL-17639, WTP-RPT-175, Rev-0, Pacific Northwest National Laboratory, Richland, Washington.
- Doorne, C.H. et al. 2007. Measurement of laminar, transitional and turbulent pipe flow using Stereoscopic-PIV, Experiments in Fluids, Volume 42, Issue 2, pp 259-279.

Acknowledgements

- U.S. Department of Energy, Office of Environmental Management
- DOE-FIU Science & Technology Workforce Development Program
- Dwayne McDaniel, PhD, PE
- Leonel Lagos, PhD, PMP

FIU Applied Research Center
FLORIDA INTERNATIONAL UNIVERSITY