Modeling Instabilities During Particle Sedimentation

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Summary

The goal of this research is to develop an innovative numerical simulation capability for flow of suspensions of particles in liquids, which are relevant to several important energy-related technologies. We will incorporate effects that span time and length scales associated with molecular to macroscopic phenomena. As part of this goal, at the macroscopic scale, we need to determine how to efficiently model suspensions in situations in which the molecular-scale effects do not dominate and to determine the limits of applicability of these models. We have studied instabilities that can occur in complex geometries when the particles are not neutrally buoyant in the liquid. We have shown that, although a fairly simple constitutive model can capture qualitative behavior of a suspension, actual systems in the laboratory exhibit instabilities on a shorter timescale than the simulation result. This points out the need to better understand the physics at smaller time and length scales to develop better continuum-scale constitutive equations.

This work focuses on development of robust numerical simulation capabilities for suspensions of small solid particles in liquids, incorporating effects spanning diverse time and length scales. Batch sedimentation of noncolloidal particle suspensions is studied with nuclear magnetic resonance flow visualization and continuum-level numerical modeling of particle migration. The experimental method gives particle volume fraction as a function of time and position, which then provides validation data for the numerical model. A finite element method is used to discretize the equations of motion, including an evolution equation for the particle volume fraction and a generalized Newtonian viscosity dependent on local particle concentration. The diffusive-flux equation is based on the Phillips model [1] and includes sedimentation terms described by Zhang and Acrivos [2] and Rao et al. [3].
The model and experiments are utilized in three distinct geometries with particles that are heavier and lighter than the suspending fluid, depending on the experiment: 1) Sedimentation in a cylinder with an expansion, 2) Particle flotation in a horizontal cylinder around a horizontal rod, and 3) Flotation around a rectangular inclusion. Secondary flows appear in both the experiments and the simulations when a region of higher density fluid is above a lower density fluid. The secondary flows result in particle inhomogeneities, Rayleigh-Taylor-like instabilities, and remixing.

Figure 1 shows the first geometry.
Note in the Figure that clear liquid forms under the lips of the cylinder expansion, thus

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causing lower density liquid to be beneath the higher density suspension above the expansion. As this low density liquid escapes, remixing occurs and the uppermost interface between the suspension and the clarified liquid becomes "V" shaped. Although the recirculation in the experiments occurs, it is not visible in these still frames; however, the unique shaped interface can be seen. As in the other geometries the onset of the secondary flow is earlier in the experiment than predicted in the simulations; however, the effect in the simulations is somewhat more pronounced than in the experiments in all geometries .

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References

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3. Rao R, Mondy L, Sun A and Altobelli S. A numerical and experimental study of batch sedimentation and viscous resuspension. *International Journal for Numerical Methods in Fluids* 2002; **39**: 465-482.

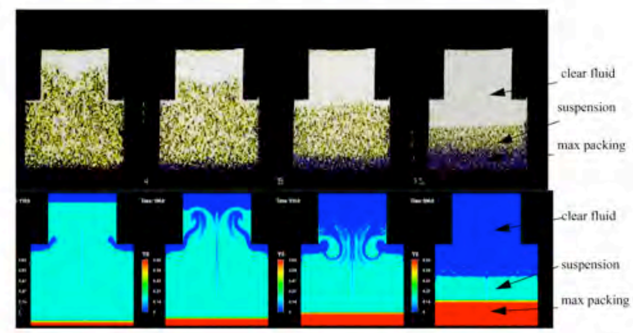

Figure 1. *Particle Settling in a Cylinder with a Contraction for 0.192 volume fraction of 0.0397cm radius PMMA particles in a glycerol and water suspending fluid. Particles are slightly heavier than fluid : a) NMR imaging at t=105.s, 175s, 315s, 560s b) Finite Element Simulations at t=110s, 190s, 310s, and 590s*

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