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Free-surface and Inertial Phenomena in Viscous Suspensions

Suspensions, or particle-laden liquids, are quite commonly encountered. One can readily list examples from natural contexts such as blood and mud flows, along with applications such as coatings, cement, and ceramic precursors. Mechanistic understanding of suspension behavior is thus basic to a range of problems in physical science. The case of nearly hard spheres in Stokes flow has received abundant attention, and a few key results will be reviewed. This background will motivate our examination by both experiment and analysis of the much less-studied cases of 1) free surface shear flows of concentrated suspensions, and 2) inertial flows of liquid-solid suspensions at dilute to moderate concentrations. Note that these are separate topics for this discussion.

For the free-surface flow, we focus here upon coating type or "film" flows, and limit attention to suspensions of neutrally-buoyant suspensions, with particles density matched to the surrounding liquid. Our experiments and analysis of the simplest case of flow down an inclined plane illustrate that a Newtonian model of the flow is incomplete due to bulk migration of the particles, while the intense interactions between particles in this shear flow is reflected in a highly irregular surface structure. Suggestions of particle-induced instabilities arising from the experiments will be noted.

Changing topics, we note that inertial effects at the particle scale are characterized by a finite particle-scale Reynolds number, and much of what we discuss in regard to inertial effects will consider $Re_p = O(1)$, again for neutrally buoyant particles. At the particle scale, numerical study shows that this level of inertia profoundly alters the basic flow patterns around isolated bodies, with similar changes to pair interaction trajectories. Proceeding up in scale, our experiments in tube flows show that such hydrodynamic interactions between particles under dilute (1-2% solids by volume) results in the formation of "trains" consisting of well-spaced and long-lived linear structures of up to about 50 particles flowing along the wall of the tube. At the bulk scale, addition of a small fraction of solids for which $Re_p = O(1)$ results in a dramatic reduction in the tube-scale Reynolds number for the onset of intermittent turbulence – the classic Re = 2100 transition is shifted below Re =1000 for a few percent solids of 1/10 trhe tube diameter! Results for 0.2% up to 30% solids by volume will be presented. No explanation for the latter behavior has been developed.

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