69i Accumulation of Particles at an Advancing Meniscus: Meniscus Effects in a Tube in the Presence of Gravity

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It is well known that when a suspension of particles is drawn through an empty tube in the absence of gravity, the suspended particles accumulate behind the advancing meniscus. This accumulation is a natural consequence of the non-uniform concentration distribution produced by the shear distribution in the tube. Since the fluid streamlines at the center have higher velocities than the fluid streamlines near the walls, there is a net convection of particles towards the meniscus, resulting in a steady accumulation of particles at the meniscus. A plot of the length of packed meniscus layer (L_m) versus the total length of suspension drawn into the tube (L_t) is a simple measure of the particle distribution far from the meniscus. The *x*-intercept of this plot gives the induction length required for the inception of the meniscus packing, while the asymptotic slope represents a meniscus growth rate that is directly related to the difference between the flow and area average concentrations. The induction length after which the continuous accumulation of particles is observed at the meniscus scales as R^3/a^2 in the absence of gravitational effects, where R is the radius of the tube and a is the particle radius. In this paper, we explore the effect of gravity on the meniscus behavior. Specifically, we determine the induction length, meniscus growth rate and the cross-section-averaged axial concentration profile (determined by a simple settling technique) as a function of gravity.

The Shields parameter $\psi = u\mu_0 / R^2\Delta\rho g$ measures the competing effects of gravity and viscous resuspension in this problem. Here u is the average velocity of the suspension through the tube, μ_0 is the viscosity of the suspending fluid and $\Delta\rho$ is the density difference between the particles and the suspending fluid. For large values of ψ, when viscous resuspension dominates gravitational settling, accumulation is observed at the meniscus as more particles occupy the faster streamlines near the center of the tube. The growth rate and induction length asymptote to the corresponding values for a neutrally buoyant suspension. The concentration averaged over the cross section first decreases to an asymptotic value due to particle migration towards the center of the tube and then rises sharply to maximum packing as the packed meniscus layer is reached. For small values of ψ, when gravity dominates viscous resuspension, depletion is observed at the interface, i.e. a particle-free fluid layer grows at the interface as the suspension is drawn into the tube. This is because most particles settle into the low velocity region at the bottom of the tube, leading to a net flux of particles away from the interface. The induction length can be shown to scale as $\psi R^3/a^2$; i.e. it decreases as ψ decreases. The growth rate (defined as the negative of the slope of the plot of L_m v/s L_t , where L_m now is the length of the particle free meniscus layer) increases as ψ decreases. The cross-section averaged concentration increases to an asymptotic value due to particle migration to the bottom of the channel and then drops gradually to zero as the empty meniscus layer is reached. A plot of the growth rate versus the Shields parameter gives, as the *x*-intercept, a critical shields parameter, which represents a crossover from the depletion regime to accumulation regime. The cross-section averaged concentration profiles near this critical value are nearly constant at the concentration at which the suspension is supplied to the tube. The behavior of the induction length with the Shields parameter is more interesting, especially near the critical Shields parameter. As the Shields parameter is decreased from infinity to the critical value on the accumulation side of the graph (i.e. as the effect of the gravity is increased), the induction length decreases, and then switches to a large value on the depletion side of the graph, merging into the $\psi R^3/a^2$ asymptote as ψ is further decreased. Simulations based on the constitutive equations of Zarraga et al. [*J. Rheol.*, **44** (2), 185-220, 2000] were performed to determine the induction length and the asymptotic growth rate (from the flow and area average concentrations) as functions of ψ, and the trends were found to be in satisfactory agreement with the experimental results.