Leveling of Thin Films of Colloidal Suspensions

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Liquids used in coating processes are often colloidal suspensions, and the resulting products are integral to numerous technologies such as abrasion-resistant coatings, displays, and solar cells. In most coating applications, a thin film of uniform thickness is desired but may be difficult to achieve if irregularities in the coated liquid film do not level before the film solidifies. Often, there exists a finite time between the stage where liquid is applied to a substrate and downstream processes such as curing and drying. It is therefore crucial to understand the factors that influence the leveling of thin liquid films.

We analyze a model for leveling of thin films of colloidal suspensions. The suspension is described as a continuum, with a convection-diffusion equation governing the concentration of colloidal particles. The particles are allowed to adsorb and desorb from the liquid-air interface, and influence the interfacial tension, viscosity, and diffusivity of the suspension. The lubrication approximation is applied to simplify the convection-diffusion equation along with the mass and momentum conservation equations.

Linear stability analysis of the simplified equations reveals a number of different physical mechanisms that control leveling. Notably, there exist parameter regimes where increasing the Marangoni number (ratio of surface-tension-gradient forces to viscous forces) causes (i) slower leveling initially, but faster leveling at longer times, and (ii) slower leveling at both short and long times. Nonlinear simulations show that the linear analysis describes well even the leveling of large-amplitude disturbances, and that the presence of a concentration-dependent viscosity and bulk diffusivity speed up leveling. The results of this work should be useful for estimating leveling rates in coatings laden with colloidal particles, and also in coatings containing soluble surfactant.

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