Three-dimensional Surfactant-covered Flows of Thin Liquid Films on Rotating Cylinders

Weihua Li and Satish Kumar

Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, MN 55455, USA

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Extended Abstract

The coating of discrete objects is an important but poorly understood step in the manufacturing of a broad variety of products. An important model problem is the flow of a thin liquid film on a rotating cylinder, where instabilities can arise and compromise coating uniformity. In this work, we use lubrication theory and flow visualization experiments to study the influence of surfactant on these flows. Two coupled evolution equations describing the variation of film thickness and concentration of insoluble surfactant as a function of time, the angular coordinate, and the axial coordinate are solved numerically. The results show that surface-tension forces arising from both axial and angular variations in the angular curvature drive flows in the axial direction that tend to smooth out free-surface perturbations and lead to a stable speed window in which axial perturbations do not grow. The presence of surfactant leads to Marangoni stresses that can cause the stable speed window to disappear by driving flow that opposes the stabilizing flow. In addition, Marangoni stresses tend to reduce the spacing between droplets that form at low rotation rates, and reduce the growth rate of rings that form at high rotation rates. Flow visualization experiments yield observations that are qualitatively consistent with predictions from linear stability analysis and the simulation results. The visualizations also indicate that surfactants tend to suppress dripping, slow the development of free-surface perturbations, and reduce the shifting and merging of rings and droplets, allowing more time for solidifying coatings in practical applications.