Dynamic Wetting Failure in Surfactant Solutions

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The influence of insoluble surfactants on dynamic wetting failure during displacement of Newtonian fluids in a rectangular channel is studied in this work. A hydrodynamic model for steady Stokes flows of dilute surfactant solutions is developed and evaluated using three approaches: (i) a one-dimensional (1D) lubrication-type approach, (ii) a novel hybrid of a 1D description of the receding phase and a 2D description of the advancing phase, and (iii) an asymptotic theory of Cox [J. Fluid Mech. 168, 195-220 (1986)]. Steady-state solution families in the form of macroscopic contact angles as a function of the capillary number are determined and limit points are identified. When air is the receding fluid, Marangoni stresses are found to increase the receding-phase pressure gradients near the contact line by thinning the air film without significantly changing the capillary-pressure gradients there. As a consequence, the limit points shift to lower capillary numbers and the onset of wetting failure is promoted. The model predictions are then used to interpret decades-old experimental observations concerning the influence of surfactants on air entrainment [Chem. Eng. Sci. 31, 901-911 (1976)]. In addition to being a computationally efficient alternative for the rectangular geometries considered here, the hybrid modeling approach developed this paper could also be applied to more complicated geometries where a thin air layer is present near a contact line.

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