The effect of surface viscosity on droplet breakup and relaxation under extensional flow

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ABSTRACT

This study performs boundary-integral simulations to investigate the role of interfacial viscosity on the deformation and breakup of a single droplet in Stokes flow. We model the insoluble surfactant monolayer using the Boussinesq–Scriven constitutive relationship for a Newtonian interface, and simulate the droplet in uniaxial extensional flow. The deformation and breakup results are compared against recently developed small-deformation perturbation theories. The simulations find that the surface shear/dilational viscosity increases/decreases the critical capillary number beyond which the droplet becomes unstable by reducing/increasing the droplet deformation at a given capillary number compared to a clean droplet. We present the relative importance of surface shear and dilational viscosity on droplet stability based on their measured values reported in experimental studies on surfactants, lipid bilayers, and proteins. In the second half of the talk, we incorporate the effect of surfactant transport by solving the time-dependent convection-diffusion equation and consider a nonlinear equation of state (Langmuir isotherm) to correlate the interfacial tension with the changes in surfactant concentration. We explore the coupled influence of Marangoni stresses, surfactant dilution, and pressure-dependent surface viscosity on the droplet deformation and breakup. We conclude by discussing how surface viscosity alters the relaxation of an initially extended droplet in a quiescent external fluid. We note that even small amounts of surface viscosity can alter the thinning behavior towards pinch off, even when surfactant convection (i.e., surface Peclet number) is significant.

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