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Surface Tension Effects in Oscillatory Squeeze Flow Rheometry

JOSEPH BARAKAT, University of California, Santa Barbara, ZACHARY HINTON, NICOLAS ALVAREZ, Drexel University, TRAVIS WALKER, South Dakota School of Mines and Technology — We report experiments, numerical simulations, and analytical models of the time-dependent force exerted by low- and high-viscosity fluids undergoing oscillatory squeezing between two parallel plates in a commercial extensional rheometer. At high oscillation frequencies and high fluid viscosities, the force is driven primarily by viscous shear stresses according to standard predictions of lubrication theory. We show that surface tension modifies the force response at low frequencies and viscosities, resulting in an "apparent elasticity" akin to a Kelvin-Voigt solid. The latter response is highly sensitive to the film aspect ratio and strain amplitude of oscillation. Using a combination of semi-analytical theory and finite element simulations, we are able to reproduce the force response seen in experiments over six decades in the modified capillary number (ratio of oscillatory viscous stresses to surface-tension stresses). The overall impact of this work is twofold. First, surface-tension effects oftentimes emerge as an unwanted artifact in linear and nonlinear viscoelastic measurements of bulk material properties. Our analysis precisely isolates and quantifies this undesired contribution and, therefore, may be used to properly interpret measurements of low-viscosity fluids at low frequencies. Second, the agreement between our experimental measurements and models suggest the use of oscillatory squeezing as a method of measuring the surface tension or, more generally, the dynamic surface properties of liquids.

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