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JETTING AND BREAKUP OF WEAKLY VISCOELASTIC LIQUIDS

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Understanding the instability and breakup of polymeric jets is important for a wide variety of applications including inkjet printing, and spraying of fertilizers and paint. Such fluids are typically only weakly viscoelastic and the jetting/breakup process involves a delicate interplay of capillary, viscous, inertial and elastic stresses.

In this study, we investigate the growth and evolution of surface-tension-driven instabilities on an axisymmetric viscoelastic jet using nonlinear theory for a range of different constitutive equations. The initial growth of disturbances can be predicted using linear instability analysis for small perturbations. A viscoelastic jet is initially more unstable when compared to a Newtonian fluid of the same viscosity and inertia. As the radius of local necks in the jet constrict further, elastic stresses grow and become comparable to the capillary pressure, leading to formation of a uniform thread connecting two primary drops. This 'beads-on-a-string' structure can be captured by the Oldroyd-B model, and the radius of the thin cylindrical ligament connecting the beads necks down exponentially in time. The finite time breakup of the jet observed experimentally can be captured using the nonlinear Giesekus model. Figure 1 shows a good agreement between the temporal evolution of 2.2% HEUR1 and numerical results based on the Giesekus model.

We show that by understanding the physical processes that control each phase of the temporal evolution in the jet profile it is possible to extract transient extensional viscosity information even for very low viscosity and weakly-elastic liquids. This is especially useful since filament-stretching rheometers can typically only be used to measure the extensional viscosity of moderately viscous non-Newtonian fluids, at least in 1g. Gravitational sagging is a limiting factor in filament-stretching devices for low-viscosity polymeric liquids[1]. Similarly the capillary breakup elongational

rheometry (CABER) technique faces challenges for low-viscosity elastic polymer solutions; the Ohnesorge number needs to be large enough to be able to distinguish the effect of viscosity on the local necking and breakup of the filament[2].

Schümmer and Tebel[3] proposed that a free jet extensional rheometer may be useful for measuring the tensile properties of weakly elastic polymer solutions. However achieving a quantitative understanding of their experimental measurements was limited by the large experimental parameter space involved. We use our numerical simulations to explore the range over which a free jet can effectively be used to measure extensional viscosity of the liquid. We show that this is limited by three independent factors: 1) calculation of the tensile stress difference in the thread connecting drops must be directly connected to the evolution in the local jet radius; i.e. an "elasto-capillary balance" must be established; 2) the range of diameters over which an elasto-capillary regime is established must be experimentally-resolvable; 3) the formation of secondary droplets along the thread must be discouraged. In the present work, we show how the imposed perturbation frequency and amplitude can influence these criteria and determine the optimal range of excitations for using the self-thinning dynamics of fluid jet breakup as a means of performing extensional rheometry.

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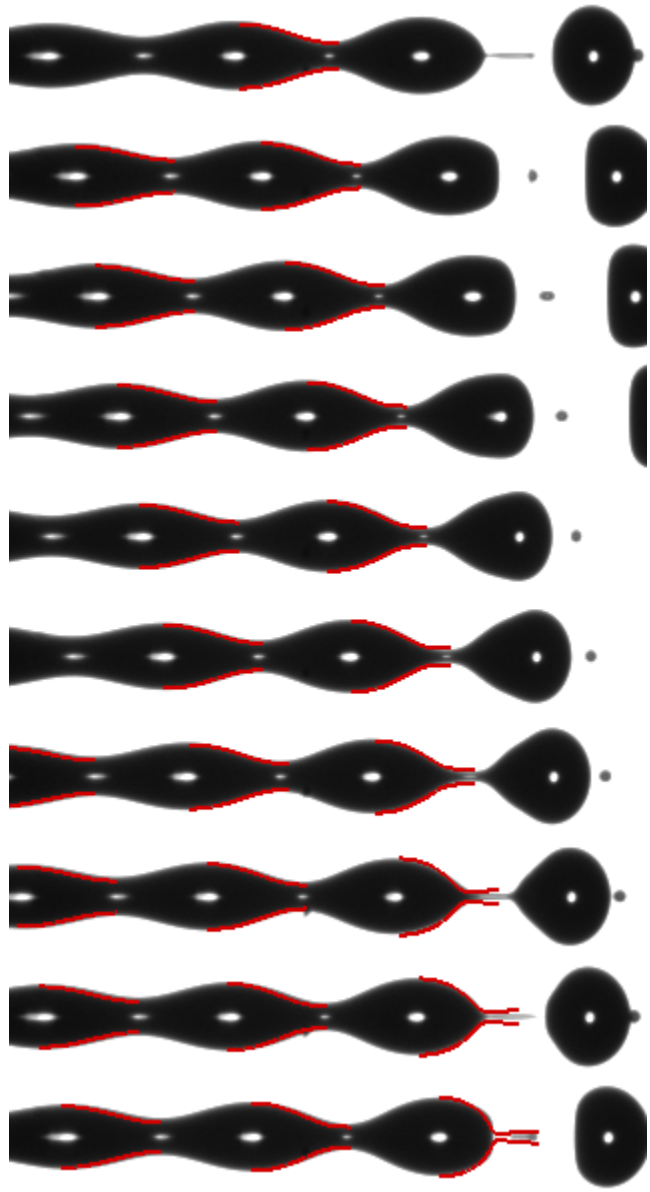

Figure 1. The temporal evolution of 2.2% HEUR1 is experimentally obtained and compared with the numerical results of the Giesekus constitutive equation (red profiles). The forcing frequency is 5.40 kHz, Ohnesorge number ~ 0.04, Deborah ~ 0.8, dimensionless wave number~0.74, mobility factor ~ 0.0001, the ratio of the solvent viscosity to the polymer viscousity ~ 0.25. Each image is separated by 24μs ~ 0.19 times Rayleigh time scale.