Evaluation of an Elastic Instability Criterion for Viscoelastic Fluids in Planar Elongational Flow

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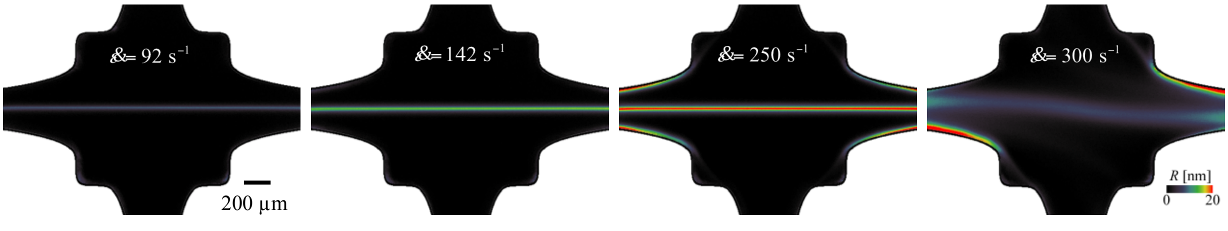
There is now a well-established dimensionless criterion (Pakdel & McKinley (1996) *PRL* **77**: 2459) for understanding the critical conditions that control the onset of elastic instabilities dominated by shearing kinematics. In the present work, we use a range of model viscoelastic test fluids to test this criterion in the context of a well-defined, extensionally-dominated flow field, in a device similar to the cross-slot geometry (Haward et al. (2012) *PRL* **109**: 128301). The results of combined micro-particle image velocimetry (μ-PIV) and flow-induced birefringence (FIB) experiments performed over a wide range of Weissenberg numbers (Wi = λ&, where λ is the fluid relaxation time and & is the elongation rate), reveal a much richer sequence of instabilities than has previously been reported. As the Weissenberg number is increased beyond Wi > 0.5, FIB measurements show the development of a highly localized birefringent strand aligned along the outflowing stagnation-point streamline, indicating the expected local orientation of polymer molecules. For these low values of Wi, μ-PIV measurements show a pseudo-Newtonian flow field with a centrally-located stagnation point and hyperbolic streamlines. However, for $0.5 < \mathrm{Wi} < 2$, the stagnation point becomes laterally displaced from its central location towards one or the other exit channels of the flow geometry, and with further increases in Wi begins to oscillate erratically between the exit channels . Interestingly, the birefringent strand maintains localization and uniformity throughout this range of Wi. Finally, beyond another fluid-dependent critical Wi, the flow breaks symmetry globally and spatio-temporal fluctuations are apparent in both the μ-PIV and the FIB measurements. Prior to the onset of the first flow instability, the flow field is well-described by an ideal hyperbolic stream function and the FIB measurements can be used to quantify the spatial distribution of stresses, allowing spatial evaluation of the dimensionless instability criterion. We find "lobe-like" contours in the value of the criterion, with peaks occurring near to (but not at) the central stagnation point. The critical values of this criterion at onset of elastic instability compare well with values reported for torsional, shearing-dominated flows.



Flow-induced birefringence measured in the planar elongational flow device with a 0.07 wt% solution of high molecular weight polystyrene at the indicated extensional rates, &. The color scale represents the retardation in units of nm. The right-most image at &= 300 s^{-1} illustrates the appearance of the symmetry-breaking flow instability.