Finite Element Simulation of Viscoelastic Fluid Flow Through 4:1 Contraction

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This study describes a detailed comparison of high-resolution least squares finite element simulations of stationary, two-dimensional flow against mid-section experimental results reported by Quinzani *et al.* [1] for a 3.97:1 contraction and with numerical results in the literature. The steady state flow simulations consider both the single-mode exponential PTT model and the single-mode Giesekus model for the concentrated polymer solution used in the experiment. Of particular interest here are the high resolution comparisons of phenomenological flow results in the contraction and the recirculation regions as well as the behavior of a least squares mixed finite element scheme for this class of flows. We also examine the behavior as the corner singularity is approached and compare our computed profiles to both experimental results and the results of other simulations. Our 2D high resolution numerical results [2] are on graded meshes with elements of degree p=5 and show that: (1) The exponential PTT model, the linear PTT model and the Giesekus model all have close quantitative agreement of stress and velocity solutions at low Deborah number *De*, but there are discrepancies near and in the contraction region as *De* is increased; (2) the numerical predictions of both the shear stress and the first normal stress difference from the exponential PTT model are closer to the experimental results than those from the linear PTT model and the Giesekus model; (3) the exponential PTT model predicts higher values of both shear thinning and extension thinning of the fluid in the downstream region of the contraction domain compared to the results from the Giesekus model. Thus, the exponential PTT model simulation gives lower values of both the shear stress and the normal stress difference than the Giesekus model in this region; (4) compared with the exponential PTT model, the linear PTT model and the Giesekus model overpredict elasticity effects in the flow where the fluid is subjected to high extension rate; (5) numerical results differ from experimental results in the region between the centerline and the recirculation zone as the reentrant corner is approached from the upstream flow direction and identify a need for additional experimental studies; (6) while the numerical simulation of both the exponential PTT and the Giesekus models predict vortex growth with increase in *De*, the experimental measurements suggest vortex shrinkage as *De* increases; (7) results near the re-entrant corner confirm that the shear stress and the first normal stress difference have a local radial singularity of the form r^{-s} where s declines with increasing shear thinning as *De* number increases.

References

[1] L.M. Quinzani, R. C. Armstrong, and R. A. Brown, Birefringence and laser-Doppler velocimetry (LDV) studies of viscoelastic flow through a planar contraction, J. Non-Newtonian. Fluid Mech., 52 (1994) 1-36.
[2] H.V. Nayak and G.F. Carey, Benchmark simulation for viscoelastic 4:1 contraction flow problem, submitted to J. Non-Newtonian Fluid Mech. (2003)