Optimisation of microfluidic devices for extensional rheometry

Francisco J. Galindo-Rosales (galindo@fe.up.pt)
Manuel A. Alves (mmalves@fe.up.pt)
Centro de Estudos de Fenómenos de Transporte, Departamento de Engenharia Química, Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, s/n 4200-465 Porto Portugal

Mónica S. N. Oliveira (monica.oliveira@strath.ac.uk)
James Weir Fluids Lab, Department of Mechanical and Aerospace Engineering, University of Strathclyde, Glasgow G1 1XJ, UK

Abstract

The use of microfluidic devices for rheometry purposes is building up momentum, given the small sample volumes required, the reduced time-scale for measurement, and the distinctive flow characteristics resulting from miniaturisation. In extensional rheometry, miniaturisation is especially valuable due to the enhancement of viscoelastic effects and the inherent difficulties in characterising low-viscosity complex fluids in standard commercial instrumentation due to gravitational and inertial effects. We have been using a combination of numerical techniques to optimise the shape of microdevices to obtain a homogeneous flow field ideal for rheological measurements under extensional flow.

In pursuit of a microfluidic device that generates an ideal flow field for extensional rheology measurements, where we can generate a strong extensional flow with an extensive region with a nearly constant extensional rate, we have considered microfluidic contraction-expansions and stagnation point flows, such as T-channels and cross-slot devices. The numerical methodology is based on an in-house finite-volume viscoelastic flow solver, an automatic mesh generation and adaptation procedure together with the open-source CONDOR optimiser [1]. The integrated computational tool solves a minimisation problem coupled with an adequate objective function to search for a suitable shape of the flow geometry to achieve optimal performance. We have proposed an optimized shape cross-slot extensional rheometer (OSWER) based on a 2D approximation, which was shown to generate a constant, homogeneous extension rate over a wide region of the in- and out-flowing central lines [1], and here we are extending the optimisation conditions to consider aspect ratios of \(O(1)\) that are more amenable to standard soft lithography microfabrication techniques. A set of experiments have been carried out to validate the kinematics by means of micro-particle image velocimetry, and the results are found to be in close quantitative agreement with the numerical predictions, demonstrating the potential of our shape-optimization approach to design rheometric microfluidic components.


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