Microfluidics with non-Newtonian fluids

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The non-linear rheological properties of non-Newtonian fluids often impart unexpected behavior to flow systems. When those fluid properties, such as viscoelasticity, are combined with the small scales of microfluidics, the non-linearities that are inversely proportional to the device characteristic length scale, are strongly enhanced and may come to dominate the flow dynamics.

In this presentation we show several examples of viscoelastic fluid flow instabilities under creeping flow conditions, which we investigated experimentally as well as numerically. These are preceded by a presentation of the governing equations, relevant dimensionless numbers as well as by a brief description of the experimental techniques and numerical methods used. Regarding the latter we refer to the High-Weissenberg Number Problem and possible remedies.

In looking at the examples and results we concentrate on flows containing a non-negligible extensional flow contribution and here it will be important to distinguish between flows with and without important shear effects. First, we discuss the flow of polymer solutions through the cross-slot geometry, where a sequence of viscoelastic flow transitions depends on the Reynolds ($Re$) and Weissenberg ($Wi$) numbers. Then, we look at a single hyperbolic contraction with various fluids as a prerequisite to understand also the flow behavior in serial systems of triangular and hyperbolic elements. These systems behave as fluidic diodes, because of the role played by extensional viscosity, which is particularly enhanced on the hyperbolic-based geometry leading to higher flow diodicities. In another interesting application the flow of polymer solutions through a series of symmetric and asymmetric micro-contractions/expansions emulate flow through porous media.

Finally, we present results of numerical simulations on the benchmark two-dimensional 4:1 sudden contraction at negligible $Re$ and increasing $Wi$ followed by experimental data on a planar 3D contraction/expansion based on the 2D geometry. The flow is steady at low $Wi$, then it becomes time dependent and increasingly complex eventually showing a frequency doubling mechanism and a chaotic-like behavior with back-shedding of vorticity as $Wi$ increases. The behavior observed numerically and experimentally is qualitatively similar, although the various transitions take place at different values of $Wi$.

The presentation ends with an outline of future directions of research.

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