Experimental Verification of Novel Non-Newtonian Rectifier Design

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Non-Newtonian fluids appear in many applications due to elastic objects such as polymers, DNA etc. This can give rise to shear-thinning behavior as well as fluid memory due to past deformations, also known as viscoelastic effects.
Before the introduction of the log-conformation formulation by Fattal and Kupferman[1], models of viscoelastic fluids in complex geometries broke down at moderate elasticity – severely limiting industrial applications. Although it is now possible to compute the flow at high elasticity, getting convergent results is complicated by the small appearing length scales as well as the transient nature of the flow. Elastic turbulence models do not exist.
The method of topology optimization addresses the issue of placement and shaping of holes for achieving certain objectives. This method has seen significant adoption within the field of structural engineering, and it has been extended to many other problems, such as the Navier-Stokes equations[2].
The project objective is to tackle the non-intuitive nature of viscoelastic fluids with the help of topology optimization. We have successfully applied the method to the problem of viscoelastic rectifiers. These device feature anisotropic flow resistance due to viscoelastic effects and they can be applied as passive valves in a micropump. We find that a change of topology from the experimentally realized devices, should yield superior performance in the regime of moderate elasticity. We thus propose a design with a contraction and an obstacle rather than asymmetric contractions (Fig. 1 and 2).
To verify the overall validity of our approach, we have produced devices with this new topology for experimental characterization. In the time of writing we however find that the design gives rise to increased blocking/clogging, which prevents reproducible results (Fig. 3).

[1] R. Fattal and R. Kupferman, "Time-dependent simulation of viscoelastic flows at high Weissenberg number…", J. of Non-Newtonian F.M. 126(1), 23-37, 2005.

[2] L.H, Olesen et al., "A high-level programming-language implementation of topology optimization...", Int. J. for Numerical Methods in Engineering 65(7), 965-1001, 2006.

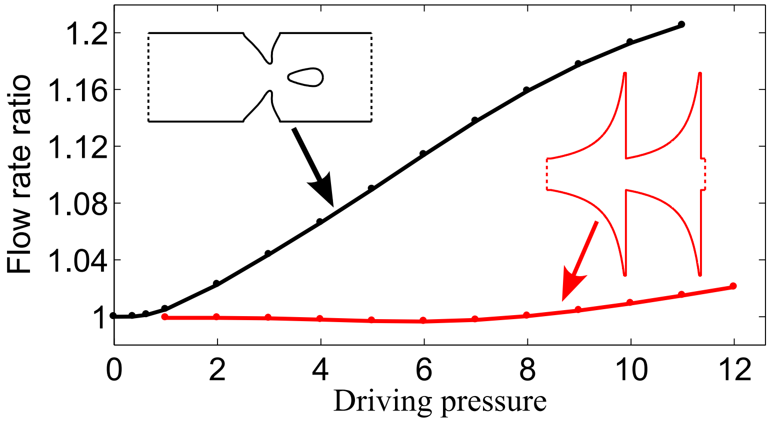

Fig. 1: The flow rate ratio (→ divided by ←) for two geometries is compared. In this regime (of moderate elasticity) the contraction-obstacle design (top left) has superior performance.

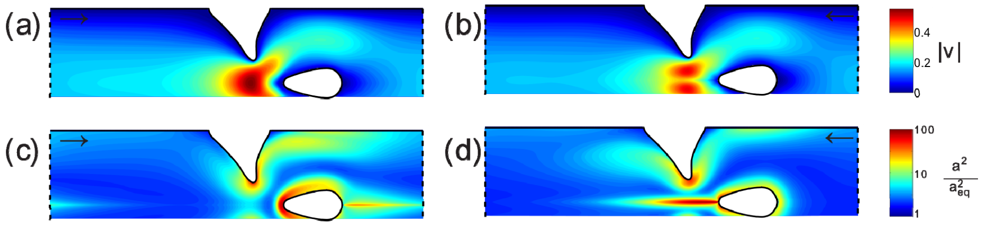

Fig. 2: A strand of elongated "polymer" appears in the obstacle wake (c-d). This gives rise to a damping, which in the case of the reverse flow configuration (←) results in a local velocity minimum in the contraction center (b). This does not happen for the other flow configuration (a).

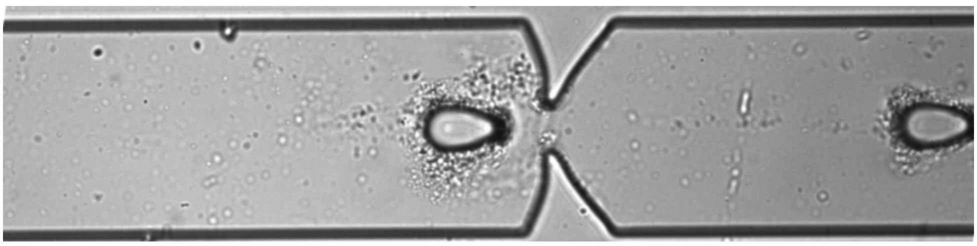

Fig. 3: A partially blocked microchannel after the flow has been from right to left. The obstacle in the center of the picture is the first of 25 and this is where the phenomenon is pronounced the most. The problem does not seem specific to the fluid, so it is probably due to PDMS residue related to the fabrication process.