Microfluidic bifurcating networks for power-law fluids

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Bifurcating networks are widely found in nature and are often responsible for controlling fluids that exhibit complex rheological behaviour. Examples are the vascular branching network that drives blood throughout the human body, the oxygen respiratory system in the human lungs and the bifurcating formations of xylem responsible for the distribution of water and other nutrients in plants and trees. Here, we take advantage of the biomimetic principles obtained by studying these natural systems to design fluid distribution networks for use in lab-on-a-chip devices. The novel biomimetic design rule we have recently proposed allows us to generate bifurcating microfluidic networks of rectangular cross-section for use with power-law and Newtonian fluids [1]. The design is based on Murray's law, which was originally derived for blood flow in the vascular system, using the principle of minimum work. Murray [2] considered Newtonian fluid flows to predict the optimum ratio between the diameters of the parent and daughter vessels in networks with circular cross-section to obtain a uniform wall-shear stress along the network. In our study, we have extended the relationship to consider the flow of power-law fluids in planar geometries (i.e. geometries of rectangular cross-section with constant depth) typical of lab-on-a-chip applications. Furthermore, the design rule has been generalised to consider a range of shear-stress distributions via a branching parameter, offering the ability to precisely control the shear-stress distribution and predict the flow resistance along the bifurcating network.

This novel design rule has been validated numerically by means of computational fluid dynamics simulations performed using a finite-volume code under creeping flow conditions for various branching parameters and power-law fluids, ranging from shear-thinning to shear-thickening. Furthermore, we have studied experimentally the flow of a Newtonian and various shear-thinning fluids in the proposed micro-networks fabricated in PDMS by soft-lithography. A set of experiments have been carried out including pressure drop measurements and micro-particle image velocimetry to validate the kinematics along the networks. The limits of operation in terms of Reynolds number have been assessed and the results demonstrate the potential of our design for use in practical conditions.

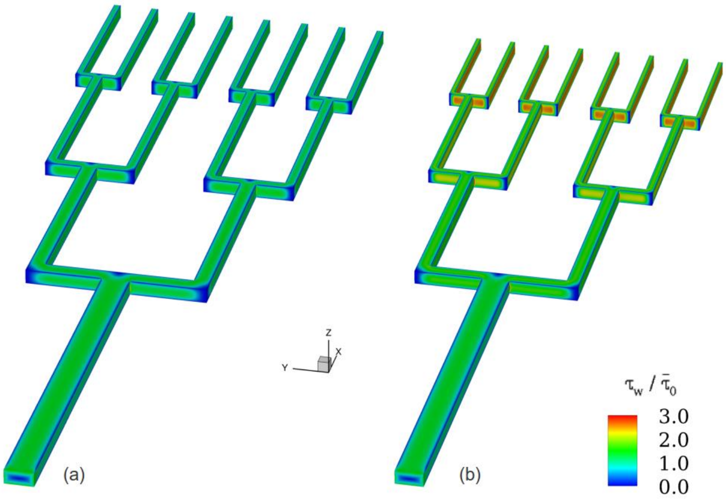

Figure 1: Contour plots of the normalised wall shear-stresses along the bifurcating networks designed for a shear-thinning fluid for a) X = 1 (uniform wall shear-stress distribution along the network) and for b) X = 1.25 (increasing wall shear-stress distribution along the network).

References

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[2] C.D. Murray, *The physiological principle of minimum work: I.The vascular system and the cost of blood volume.* Proc Natl Acad Sci USA **12**, 207–214 (1926).