Flow of power-law fluids in microfluidic bifurcating networks designed using biomimetic principles

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The flow of a non-Newtonian power-law fluid, described by the Ostwald-de Waele relationship is investigated numerically in rectangular-shaped bifurcating networks designed using biomimetic principles. Murray's law is based on the principle of minimum work and in its original form establishes the optimum ratio between the diameters of the parent (d_0) and daughter vessels (d_1 and d_2) for circular cross-sectional networks. The relationship derived by Murray can be written as $d_0^3 = d_1^3 + d_2^3$ [1]. The theory has recently been extended to consider rectangular cross-sectional networks containing Newtonian fluids [2]. In the present work, we demonstrate numerically the ability to customise these networks for use with power-law fluids and to generate particular resistance gradients in microfluidic distribution systems.

The problem is investigated using a fully-implicit numerical code based on the finite volume method for collocated meshes [3]. We consider isothermal, laminar flow of a power-law fluid for power law indices ranging from 0.2 to 3 to study the behaviour of both shear-thinning and shear-thickening fluids. A range of geometries has been designed to generate precise resistance gradients and initially tested using creeping flow conditions (Reynolds number, $Re \rightarrow 0$), which is a reasonable approximation in microfluidics. A number of simulations using different initial channel aspect ratios and different Re were also performed to assess the flow characteristics and examine the limits of the validity of the biomimetic rule for power-law fluids under various flow conditions. Analysis of the tangential wall shear stress and flow resistance distribution shows the ability of the network design to impart the desired flow characteristics.

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