Modeling of Electroosmotic Phenomenon for Transport in Micro/nano-fluidic Devices

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Micro/nano-fluidic devices become increasingly important in medical, pharmaceutical and defense applications, for example in drug delivery, DNA analysis and sequencing, and biological/chemical agent detection sensors on microchips. The main advantages of these emerging micro/nano-fluidic technologies are their low-cost, lightweight, small-size and fast response. The technological demands on micro/nano-fluidic systems require a better understanding of the micro-scale ion/thermal/fluidic transport phenomena, which differ from their larger-scale counterparts mainly due to the size and the surface force effects. Electroosmotic phenomenon is one of the most dominant effects in the micro/nano scale liquid flows in which an ionized liquid move with respect to a stationary charged surface under the action of an external electric field. Motivated by the potential of transporting fluid using electroosmotic action, a comprehensive numerical and theoretical study is performed on this phenomenon.

A spectral element algorithm is developed to analyze the Navier-Stokes equations under the action of inertia, viscous, pressure, and electrokinetic forces in arbitrary micro-geometries. This algorithm mainly addresses the challenges of integrating ion-transport effects in the classical Navier-Stokes equations for electrokinetic phenomena with special efforts on the resolution of EDL in micro-fluidic devices. Numerical simulation results for combined electroosmotic/pressure driven flows in various micro-geometries, such as straight channel, cross-flow junction, Y-split junction and T-junction are also obtained. Flow control in the Stokes flow regime is shown to have linear dependence on the magnitude of the externally applied electric field. Electroosmotic action is also applied in step channel and groove channel geometries by proper selection of surface materials and electric field directions to eliminate flow separation.

Finally, we validated numerical simulation results against experimental measurements obtained from micron scale particle image velocimetry (μPIV) for grooved micro-channels and cross channel junctions. Comparisons of numerical and experimental results indicate very good agreements between them. Numerical solutions of electric potential and field distributions in these micro-geometries are also presented. Both numerical and experimental results show strong dependence of electric field lines on flows.