AN EFFICIENT ALGORITHM FOR SIMULATING MICRO-COLLOIDAL DEVICES

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Inspired by the experiments conducted by Terray et al.[1], we have performed 3D numerical simulations of the micro-devices accordingly. We use the Spectral Element Method to solve for the flow field, and the Force-Coupling Method (FCM) to represent the interaction between the particles and the carrier fluid via the force monopole and dipole terms in the equation of fluid motion (1). Therefore, we can efficiently work with fluid phase only, see [2] for details. Any external force and torque contributions, either specified or computed via a penalty method, are added into $\mathbf{F}$ and G_{ij} to achieve the desired motion.

$$\rho\frac{D\mathbf{u}}{Dt} = -\nabla p + \mu\nabla^2\mathbf{u} + \mathbf{F}\Delta(\sigma_m, \mathbf{x} - \mathbf{Y}(t)) + G_{ij}\frac{\partial\Delta(\sigma_d, \mathbf{x} - \mathbf{Y}(t))}{\partial x_j} \tag{1}$$

In the example of micro-peristaltic pump, a set of time-periodic forces perpendicular to the bulk streamwise direction is added into particles. The external force for the micro-gear pump is varying in both values and directions. No other force is applied, and periodic boundary conditions are applied at the ends of the microchannels; therefore net pumping effects are created. Figure 1 (left) shows the 2D traveling wave motion towards the left at three moments, with arrows representing the direction of bulk fluid motion. Figure 1 (right) shows the 2D gear pump configuration. The small arrows at the particles' centers denote the instantaneous rotating direction, while the overall bulk fluid flux is from the left to the right. The third example - the micro-mixer, has an ellipsoid particle powered by a torque to create rotation.

References

[1] A. Terray, J. Oakley, and D.W. Marr, "Microfluidic Control Using Colloidal Devices," *Science*, v. 296, p. 1841-1844, 2002.

[2] D. Liu, M. Maxey, and G.E. Karniadakis, "A Fast Method for Particulate Microflows," *Journal of Microelectromechanical Systems*, v. 11, No. 6, p. 691-702, 2002.

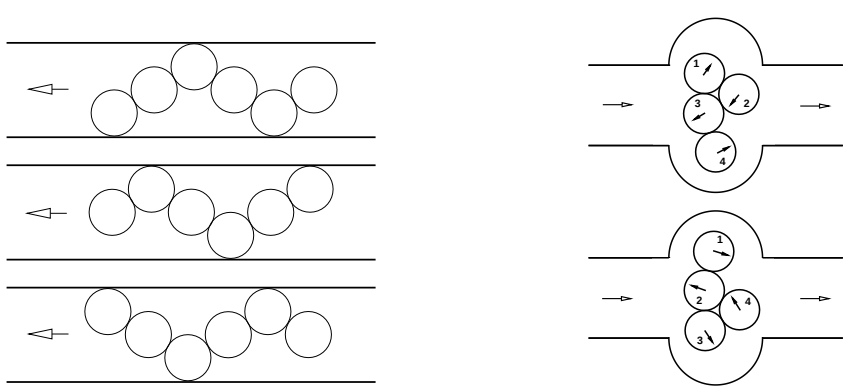

Figure 1: (a) Peristaltic pump showing traveling wave motion at t=0,1,2 with a period $T = 4$; (b) Gear pump showing two counter-rotating pairs of particles in a lobed microchannel.