APPLICATION OF LATTICE BOLTZMANN METHOD TO THE MICRO– AND NANOSCALE BIOLOGICAL FLUID SYSTEMS

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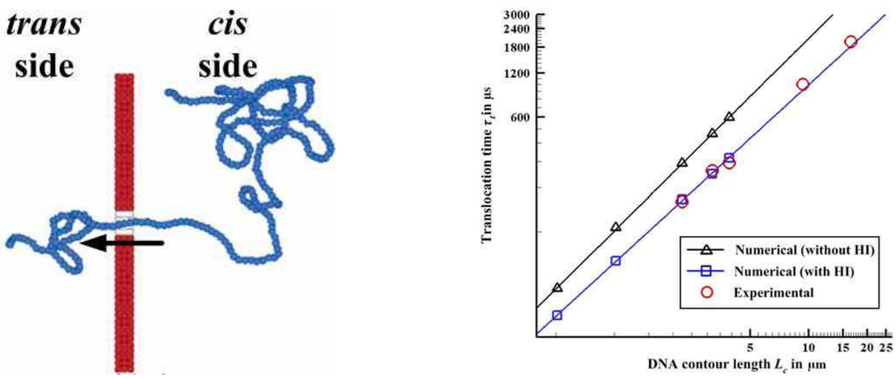
ABSTRACT

Understanding the fluid dynamics in the micro– and nanoscale devices is very essential in designing and developing micro– and nanofluidic devices for various industrial applications. The lattice Boltzmann method (LBM) has emerged as a powerful computational tool for solving fluid flow problems in micro– and nanofluidics applications because of its advantages in dealing with complex geometry. In this work, we apply LBM to simulate the following three biological flow problems at micro– and nanoscale. 1) Translocation process of a biopolymer through a synthetic nano–pore driven by an external electric field with explicit hydrodynamic interactions, 2) motion of a microscopic artificial biological swimmer, and 3) fluid flow generated inside a micro channel by an array of beating elastic cilia.

SIMULATION RESULTS

Translocation of a biopolymer through a nano–pore



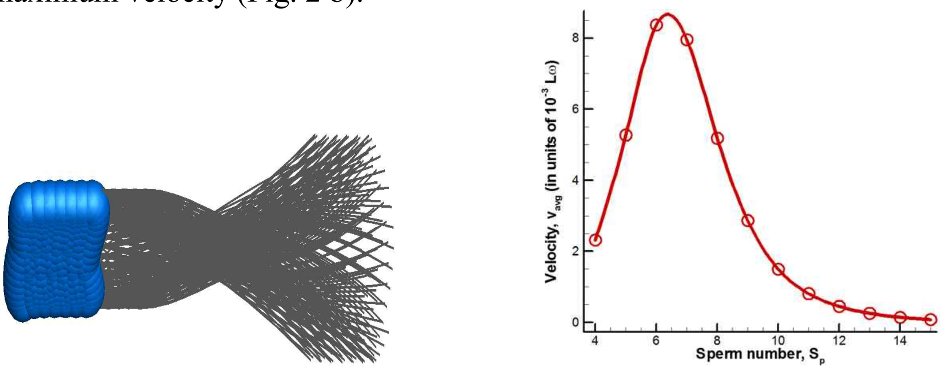
(a) (b)

Figure 1. (a) Configuration of a polymer chain in the middle of the translocation process (arrow indicates translocation direction), and (b) variation of translocation time with polymer length.

Motion of a polymer is simulated with 3–D Langevin dynamics technique by modeling the polymer as a worm–like chain of identical beads (Fig. 1a) while the hydrodynamic interactions (HI) between the polymer and fluid are incorporated by LBM. A theoretical formula is used to calculate the net electrophoretic force acting on the part of the polymer residing inside the pore. We performed simulations with and without HI effect and found that the simulation results of translocation time and velocity are in good quantitative agreement with the corresponding experimental ones when the HI effect is considered explicitly using LBM (Fig. 1b).

Propelling motion of a microscopic biological swimmer

The microscopic swimmer consists of an artificial filament [3] composed of super–paramagnetic beads connected by elastic linkers, and a load particle is attached to the one of the filament's ends (Fig. 2a). An externally oscillating magnetic field is used to actuate the filament. LBM combined with smoothed profile method is used to treat the HI caused by the load particle. We found that there is an optimum sperm number, S_p, at which the filament swims with maximum velocity (Fig. 2 b).



(a) **(b)**

Figure 2. (a) Snaps shots of the filament motion when Sp=8, and (b) variation of swimming speed of the filament with sperm number.

Fluid flow generated by cilia beating

We apply a cyclic force to the extreme tip of each cilium to actuate it. The base of the cilium is attached to the bottom surface of the micro channel. We found that there is a maximum value for the flow rate of the surrounding fluid at an optimum sperm number.

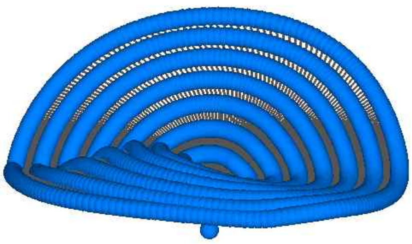


Figure 3. Trajectories of material points on a cilium beating periodically at Sp=4.3.

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