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Modeling and simulation of thermocapillary flows using lattice Boltzmann method. (English)

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Summary: To understand how thermocapillary forces manipulate droplet motion in microfluidic channels, we develop a lattice Boltzmann (LB) multiphase model to simulate thermocapillary flows. The complex hydrodynamic interactions are described by an improved color-fluid LB model, in which the interfacial tension forces and the Marangoni stresses are modeled in a consistent manner using the concept of a continuum surface force. An additional convection – diffusion equation is solved in the LB framework to obtain the temperature field, which is coupled to the interfacial tension through an equation of state. A stress-free boundary condition is also introduced to treat outflow boundary, which can conserve the total mass of an incompressible system, thus improving the numerical stability for creeping flows.

The model is firstly validated against the analytical solutions for the thermocapillary driven convection in two superimposed fluids at negligibly small Reynolds and Marangoni numbers. It is then used to simulate thermocapillary migration of three-dimensional deformable droplet at various Marangoni numbers, and its accuracy is once again verified against the theoretical prediction in the limit of zero Marangoni number. Finally, we numerically investigate how the localized heating from a laser can block the microfluidic droplet motion through the induced thermocapillary forces. The droplet motion can be completely blocked provided that the intensity of laser exceeds a threshold value, below which the droplet motion successively undergoes four stages: constant velocity, deceleration, acceleration, and constant velocity. When the droplet motion is completely blocked, four steady vortices are clearly visible, and the droplet is fully filled by two internal vortices. The external vortices diminish when the intensity of laser increases.

MSC:

76M28	Particle methods and lattice-gas methods
76D45	Capillarity (surface tension) for incompressible viscous fluids
80A20	Heat and mass transfer, heat flow (MSC2010)

Keywords:

microfluidics; lattice Boltzmann model; thermocapillary; Marangoni stresses; droplet manipulation

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