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Editorial

Special Issue on Multiphase Flows in Microfluidics: Fundamentals and Applications

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1. Introduction

Microfluidics, a cutting-edge field involving various applications in advanced materials, new energy, single-cell/single-molecule studies, human health, biomedicine, and so forth, has advanced rapidly in the last two decades. Among the applications of microfluidics, multiphase flow is the fundamental element in various microfluidic subjects, such as those concerning emulsions, droplets, bubbles, micromixers/reactors, and microswimmers/robots. For example, microfluidic technology changes the motion of particles through varying the channel area of the diversion form, particle inertia, hydrophilicity, gravity characteristics, deterministic lateral displacement, viscoelastic separation, and zeta potential [1]. Controlling particle motion, the radial position, and the spacing between particles make them easier to capture, focus on, select, and separate, e.g., through cell separation and capture, bacterial selection, and DNA separation and focusing, to meet the needs of studies and fields such as biomedicine.

On the other hand, microfluidics (adding nanoparticles to the fluid) has been widely used to enhance heat transfer [2]. The impact of particle size, concentration, shape, and distribution on enhanced heat transfer has always been a research focus. When the particle size, concentration, and shape are fixed, the optimal distribution of particles can be obtained through controlled methods in order to achieve a better heat transfer effect. For instance, the magnetic particles in the fluid will form a chain-like structure under the action of a high-intensity magnetic field, which can enhance heat transfer. When the volume concentration of particles is 6.3%, the maximum enhancement value of thermal conductivity can be 300% [3]. Since multiphase flow in microfluidics is vital and common, it is necessary to research it.

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2. Foundation and Application of Multiphase Flow in Microfluidics

In light of the above, this Special Issue aims to collect the latest original research and reviews on the fundamentals and applications of any functional multiphase flow in microfluidics. There were 24 papers submitted to this Special Issue, and 15 papers were accepted. They address numerous topics, mainly on the motion characteristics of particles with different scales and shapes.

The particles of multiphase flow in microfluidics are usually of a nanometer scale. Multiple papers in this Special Issue involve fundamentals and applications of nanofluids or nanoparticles in fluids. Li et al. [4] reviewed the heat transfer enhancement of nanofluids with non-spherical nanoparticles by dividing the particles into three categories according to the dimension of geometric particle structure. They evaluated the shape effect of particles on the thermal conductivity and convective heat transfer based on the measured data, and pointed out that no perfect model for predicting the thermal conductivity and convective heat transfer of nanofluids with non-spherical nanoparticles had been reported. Tu et al. [5] studied the effect of background particles on the nucleation of nanoparticles by solving the Reynolds-averaged Navier–Stokes equation with the Taylor-series expansion method of moments. They found that the nucleation of nanoparticles was inhibited with increasing background particle concentration by considering the effect of binary homogeneous nucleation, Brownian coagulation, condensation, and thermophoresis of nanoparticles. Lin et al. [6] numerically simulated the nanoparticle settlement and pressure drop in a gas-solid two-phase flow in a pipe by solving the momentum equation of the two-fluid model. They found that the pressure drop increased with increasing inlet velocity, particle volume concentration, and mass, but with decreasing particle diameter, and derived an expression of the settlement index and pressure drop as functions of inlet velocity, particle volume concentration, mass, and particle diameter based on the numerical data. Wang et al. [7] studied the collision rate of nanoparticle aggregations and aggregated structure with different particle volume fractions using the Langevin dynamics method, and showed that the self-preserving size distribution of particles broadened with increasing particle volume fraction; the radius of gyration was smaller with the same cluster size, i.e., the particle agglomerations were in a tighter coagulation when the particle volume fraction was higher. Yang et al. [8] explored experimentally the effects of tracer fluid flow velocity and porous medium permeability on the dispersion phenomenon using natural and sand-filled cores, respectively, and found that a higher volumetric flow rate and lower permeability caused a delay in the tracer breakthrough time and an increase in the dispersion coefficient; the combination of high velocity and low permeability yielded a large dispersion coefficient.

Most particles in the applications are non-spherical, and the transport and deposition of non-spherical particles are very complicated because particle rotation and orientation distribution are strongly coupled with the translation motion [9]. Some papers in this Special Issue are related to the motion characteristics of non-spherical particles. Lin et al. [10] numerically simulated the distribution and deposition of rod-like nanoparticles in a turbulent pipe flow by considering the Brownian and turbulent diffusion of nanoparticles. They showed that the penetration efficiency of particles decreased with increasing particle aspect ratio, Reynolds number, and pipe length-to-diameter ratio, and built a relationship between the penetration efficiency of particles and related synthetic parameters based on the numerical data. Kawaguchi et al. [11] studied the contribution of an elliptical particle flowing between parallel plates to the effective viscosity, focusing on the particle-wall distance and particle rotational motion, and found that the contribution of particle shape to the effective viscosity was enhanced when the particle flowed near the wall; the spatial variation of the local relative viscosity was larger than the temporal variation regardless of the aspect ratio and particle-wall distance. Wang et al. [12] numerically simulated the diffusion of non-spherical submicron particles in a converging–diverging micronozzle flow using the Euler–Lagrangian model, and showed how particle transportation with varying shape factors and densities resulted in different particle velocities, trajectories, and focusing; the particle with a larger shape factor or larger density exhibited a stronger aerodynamic focusing effect in a supersonic flow through the nozzle. Yang et al. [13] simulated the motion of rod-like particles in the turbulent contraction flow and indicated that the rod particles aligned with the streamline in the central region as the particle concentration increased, but tended to maintain the original orientation distribution in the boundary layer. Zhang et al. [14] studied the rising characteristics of shaped bubbles in near-wall static water using the volume of fluid method, and found that the wall surface and the distance between the bubble and the wall influenced the rising of the bubble; the effect of interaction between the bubbles was significantly greater than the effect of the wall surface.

There are also several papers on the motion of bi-disperse and self-driven particles, and the motion of particles in a non-Newtonian fluid. Chen et al. [15] numerically simulated the motion and distribution of bi-disperse particles in Poiseuille flow and showed that the particle spacing would increase and could not remain stable when the smaller particle was downstream; the particle spacing first increased and then decreased, and finally tended to be stable when the larger particle was downstream. Liu and Lin [16] reviewed multiphase flow with self-driven particles and focused on the interactions between self-propelled/self-rotary particles and passive particles, the aggregation, phase separation, and sedimentation of squirmers, the effect of rheological properties on its motion, and the kinematic characteristics of axisymmetric squirmers. Yang et al. [17] studied the trajectories and velocities of two side-by-side particles of different densities settling in a shear-thinning fluid with viscoelastic properties. They showed that the wake of the heavier particle could attract or rebound the light particle due to the shear-thinning or viscoelastic property of the fluid, and the sedimentation of the light particle could induce the distinguishable transverse migration of the heavy one.

There are also papers on specific engineering applications in the Special Issue. Yang et al. [18] proposed a three-phase foam (TPF) containing dispersed solid particles to improve foam stability under harsh reservoir conditions. They fabricated a novel TPF system, assessed the ability of the TPF to control steam channeling and enhance oil recovery, and observed a stronger foamability at a lower consolidation agent concentration. At the same time, there was a longer foam half-life period and solid particle settling time at a larger consolidation agent concentration. Lin et al. [19] studied the effect of velocity on particle behavior in membrane filtration. They gave the best working conditions to help suppress membrane pollution and indicated that particle deposition was weakest, resulting in better water productivity, when the inlet velocity was about 1 m/s.

3. Prospect

Although this Special Issue has been closed, more in-depth research on the multiphase flow in microfluidics is required. For example, more advanced computational fluid dynamics technology is expected to simulate micro flow and particle motion, more precise instruments and advanced experimental methods can be expected to test flow and capture particles, and more advanced manufacturing technology will improve microfluidic devices; as such, the technology of microfluidics is expected to be widely applied in more fields.

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