Abstract of ASME-JSME-KSME Joint Fluids Engineering Conference 2011
AJK2011-FED
July 24-29, 2011, Hamamatsu, Shizuoka, JAPAN

AJK2011-PL002

SOLID-LIQUID TWO-PHASE FLOWS IN MICROFLUIDICS

Jung Yul Yoo
School of Mechanical and Aerospace Engineering, Seoul National University
Former Associate Dean of Academic Affairs, Seoul National University
Former Secretary General, Korea Research Foundation
Former President, Korean Society of Mechanical Engineers
Vice President, National Academy of Engineering of Korea
Seoul 151-744, Republic of Korea

ABSTRACT

Since the concept of a microfluidic system was first introduced in the late 1970's, miniaturized devices have been progressively developed in line with the advances of microfluidics and MEMS technology. Microfluidics has been one of the core technologies in the development of integrated microsystems. Microelectromechanical system (MEMS) combined with microfluidics has been of great interest for researchers in the field of biology, chemistry, physics and engineering, which provides an ability to perform laboratory operation on a small scale using integrated microfuidic devices or lab-on-a-chip. Main advantages of miniaturized systems include small volume, ease-of-use, point-of-care diagnostics, fast reaction of a sample, and so forth. In the early stage of microfluidics research, more attention was paid to the transport of single-phase flows. However, many practical microfluidic applications are necessarily associated with two-phase flows.

In particular, BioMEMS-based devices often transport particulate samples, *i.e.*, blood cells, bacteria, DNAs, and spherical particles of sizes up to 10 μm in a microchannel with a characteristic length scale on the order of hundred microns for small but finite Reynolds number operations. This circumstance implicates solid-liquid two-phase flows, because small length-scale effect produces a high shear rate in microchannels. Under such flow conditions, particles will not necessarily follow fluid streamlines, but lateral migration is frequently observed. That is, a particle migrates across the fluid streamlines due to the motion of the particle itself relative to the fluid. The research goal regarding this phenomenon is mainly to provide an understanding of particle behavior for passive and/or active manipulation of microscale particles ranging from micro-beads even to DNA, in views of various functions such as separation, focusing, self-assembly, microflow cytometry, etc.

Thus, in the present article we focus on the lateral migration of particles in microscale flows. In fact, this is a prominent phenomenon of solid-liquid two-phase flows, which has been widely investigated in macroscale flows since the observation of Segré & Silberberg (1961) who reported that the neutrally-buoyant particles accumulate at about $r/R = 0.6$, where r is the radial position and R is the radius of the tube. This accumulation of particles is called "tubular pinch effect," and occurs unless a particle

size is so small that its relative motion with respect to the fluid is negligible. Their work triggered a series of experimental and theoretical studies on particle migration in tube flow, in channel flow, and in Couette flow laden with neutrally-buoyant particles and non-neutrally buoyant particles. In particular, Ho and Leal (1974) showed that this phenomenon originates from the velocity profile curvature of a shear flow due to the wall effect, and predicted that the equilibrium position (r/R) agrees with the experiments of Segré and Silberberg, by calculating the force acting on a sphere in two-dimensional (2D) channel flow at low Reynolds number on the basis of a regular perturbation method. More detailed explanation of the migration principle was given by Feng et al. (1994). Di Carlo et al. (2009) gave a critical review on inertial microfluidics, focusing on secondary flows in curved channels and inertial migration of particles. Xuan et al. (2010) has given an extensive review on the recent developments in both sheath flow and sheathless focusing approaches in microfluidic devices.

The objective of the present article is to give a broad review of the studies on solid-liquid two-phase flows in microfluidics, paying attention to inertial migration of micron-sized particles. As for the measurement techniques, classical laser-Doppler velocimetry, electrical impedance method, fluorescent microscopy, laser scanning confocal microscopy, and digital holographic technique are remarked briefly. Studies on flow characteristics are reviewed in the light of lateral migration and on the basis of 2D or 3D observation. Studies on applications of microfluidic devices involving solid-liquid two-phase flow phenomena are reviewed by classifying them into microcapillary-based and chip-based devices and by considering their primary functions such as focusing, concentration, separation and extraction. Microfluidic devices that are simply structured (say mountable on a single chip), highly reliable and precisely controllable will be the ultimate goal of future works on solid-liquid two-phase flows in microfluidics, which have been and will be used extensively in many areas such as environment, biology, medicine, pharmacy, agriculture, etc. Continued advancements in experimental techniques reviewed in the present article can be made in the direction of more quantitative studies, utilizing further the geometric effects of the microchannels, such as the restriction effect and curvature effect, and collaborating with numerical simulation methods, such as lattice Boltzman model and lattice spring model.

REFERENCES

D. Di Carlo, (CRITICAL REVIEW) Inertial Microfluidics, Lab Chip 9 (2009) 3038-3046.

J. Feng, H.H. Hu, D.D. Joseph, Direct simulation of initial value problems for the motion of solid bodies in a Newtonian fluid. Part 2. Couette and Poiseuille flows, J. Fluid Mech. 277 (1994) 271–301.

B.P. Ho, L.G. Leal, Inertial migration of rigid spheres in two-dimensional unidirectional flows, J. Fluid Mech. 65 (1974) 365–400.

G. Segré, A. Silberberg, Radial particle displacements in Poiseuille flow of suspensions, Nature 189 (1961) 209–210.

X. Xuan, J. Zhu, C. Church, (REVIEW) Particle focusing in microfluidic devices, Microfluid Nanofluid 9 (2010) 1-16.