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Shear-induced Migration of Brownian Suspension in a Pressure-driven Microchannel Flow

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Abstract

Experimental study was conducted to characterize shear-induced lateral migration of 1.0-㎛-diameter Brownian particles flowing through a rectangular microchannel which can be used to deliver small amount of liquids, drugs, biological agents and particles in microfluidic devices. Measurements were obtained by using a mercury lamp with a light of 532-nm wavelength, an inverted epi-fluorescence microscope, and a cooled CCD camera to record particle images. Peclet number was used as a parameter to assess the lateral distribution of the particles at a fixed volume fraction of 0.1%. It was shown that as Pe increased, particles were moved toward the centerline of the channel, which is in good agreement with previous studies.

Key Words : Lateral migration (횡방향 이동), Brownian particle (브라운 입자), Microchannel (마이크로채널)

1. Introduction

Microfluidic devices based on micro-electromechanical systems (MEMS) are being adopted in diverse engineering applications, such as micro valve, micro pump and, in particular, lab-on-a-chip which currently draws a lot of attention in bioengineering area. As is well known, most microfluidic devices may deliver particles less than several micrometers in size, such as microorganisms, drugs, even a DNA, which are dominated by the Brownian motion. By analyzing motions or distributions of particles moving through the microchannel, one can separate, sort, count and even manipulate particles. This can be done by exerting either external force, such as gravitational, electrical, thermal force, or no external force such as shear-induced force on particles. Masumi et al. (2004) showed that particles of different sizes can be separated continuously in a microchannel by only inducing shear force which causes a particle to migrate across the streamline of the flow field. Moreover, it was pointed out that particles through a microchannel can be counted more accurately by controlling lateral concentration of the particles in micro total analysis system (Fuller et al., 2001).

In macro scale, the particle migration of a non-Brownian and neutrally buoyant particle was studied by Segre and Silberberg (1962) in a pipe with 5.5-mm radius. They observed that a rigid particle in a Poiseuille flow migrated to an equilibrium position located at r/a = 0.6, which was termed the *tubular pinch effect*. Also, it was reported that the magnitude of the maximum concentration increased as either r/a or volume fraction ϕ increased (Lyon and Leal, 1998).

However, in micro scale, few studies have been carried out. It was reported that red blood cells (RBC) clearly exhibit the *tubular pinch effect* at high shear rate, but it disappears at low shear rate in a microchannel of 100-㎛ height (Wim et al., 1994). Recently, Frank et al. (2003) performed an investigation by varying ϕ and Pe, and reported that shear-induced Brownian particles migrate toward the center of the channel (50 ㎛ × 500 ㎛). They studied three cases of volume fractions, 0.05, 0.22 and 0.34%. However, volume fraction of particles is often less than 0.1% for microfluidic devices. Therefore, it will be interesting to see what happens to the concentration distribution of Brownian particles at such low volume fraction.

In the present paper, we study shear-induced migration of Brownian particles in a microchannel for different Pe at a fixed volume fraction of 0.1%. To obtain particle images, epi-fluorescence microscope equipped with a cooled CCD camera and a mercury lamp were used. The concentration of particles can be calculated from a normalized intensity of mean averaged images.

2. Experiment and results

The experimental apparatus shown in Fig. 1 consists of an epi-fluorescence optical microscope through which the green light (λ = 532 nm) is transmitted, a cooled CCD camera and a fluid feeding system. The white light generated from the mercury lamp is filtered to make a green light which passes through a NA = 0.63 40× objective lens into the microchannel. Fluorescent polymer particles (ρ =1.05 g/cm^3) whose diameters are 1.0 ㎛, absorb the green light and reflect a red light (λ = 570 nm). The remaining red light is focused by a lens

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onto a cooled 1030×1300×12 bit interline transfer CCD camera which acquires images at a rate of 20 frames per second. Microchannel was glued to a circular tube through which liquid was fed by a syringe at various flow rates.

Fig. 2 shows normalized intensity profiles for an inhomogeneous particle distribution in a microchannel of 50-㎛ gap at different Pe and ϕ = 0.1%. To yield a normalized intensity, the images were averaged over x-direction (flow direction), and then averaged over y-direction (lateral direction) to produce the mean intensity profile as a function of y. Thus, we obtain normalized intensity by dividing the image by the mean intensity of that image.

As shown in Fig. 2, for various Pe, the particle concentration is higher at the center of the channel than at the wall, which means that the particles migrate toward the center of the channel. This shows a similar trend to the study of Lyon and Leal (1998) for non-Brownian particle and by Frank et al. (2003) for

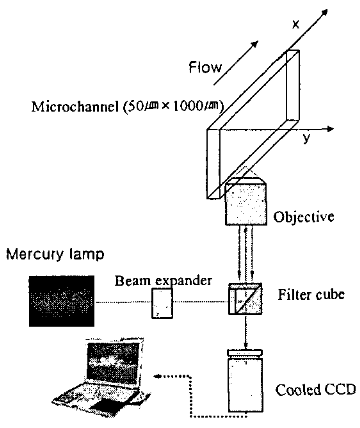

Fig 1. Schematic of the experimental system. A mercury lamp is used to illuminate 1.0-㎛ fluorescence particles through an epi-fluorescence inverted microscope. A cooled CCD camera is used to record the particle images.

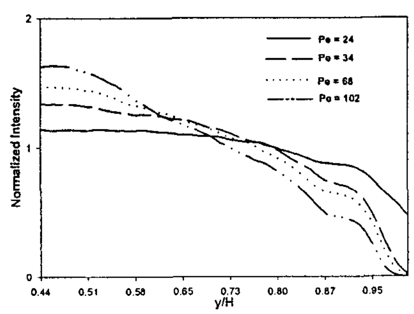

Fig 2. Lateral distribution of Brownian particles in a microchannel. As Pe number is increased, a normalized intensity increases at the center of the channel, which means that the particles migrate toward channel axis.

Brownian particle. This effect becomes more prominent with increasing $\mathrm{Pe} = 6\pi\eta_0\dot{\gamma}a^3/kT$. From this definition of Pe, it is noted that a the radius of particle diameter plays a very important role in particle migration. Moreover, particles migrate due to shear-induced particle interaction scaled by ϕ^2 (Frank et al., 2003). Also, driving forces of the migration have been identified as the wall repulsion due to the lubrication, the lift due to particle rotation in the case of the Poiseuille flow and the lift caused by the velocity profile curvature (Feng et al., 1994).

3. Conclusion

In this paper, experimental study was performed to characterize shear-induced lateral migration of Brownian particles in a microchannel. Peclet number Pe was adopted as a parameter at a fixed volume fraction of 0.1%. It was shown that as Pe increased, the particle concentration is higher at the center of the channel than at the wall, which is a similar trend to other results.

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