Studies on the Sedimentation Dynamics of Silica Particles by Dynamic Ultrasound Scattering Techniques
動的超音波散乱法によるシリカ微粒子懸濁液の運動状態解析

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1. Introduction

When micron-sized particles settle down in a liquid, the temporal velocities of particle are affected by the presence of surrounding liquid as well as other particles. This leads to velocity fluctuations of settling particles involving unique cooperative particle motion. Such a cooperative nature of the dynamics can be visualized as a blob. Recently, we have developed an ultrasound scattering technique called dynamic ultrasound scattering (DSS), which is an acoustic analog of the dynamic light scattering method. In the micrometer regime, the particle dynamics is dominated by the velocity fluctuations rather than the Brownian motion. The velocity fluctuations can be quantitatively evaluated by a time-correlation function of the temporal scattered amplitudes during sedimentation.

According to Caflisch and Luke, the velocity fluctuations of settling particles at a low- Reynolds number were given by

$$\Delta V = CV_0\sqrt{\frac{\phi L}{a}} \qquad (1)$$

where C is a constant, V_0 is the terminal velocity, ϕ is the volume fraction of the particle, L is the cell size and a is the particle radius[1]. Although this explains the increase in the observed velocity fluctuations with the particle concentration, it also implies that the velocity fluctuations diverge with the cell size. Later, a correlation length for the fluctuations was introduced to explain the unphysical divergence in eq. (1). Namely, eq. (1) holds as long as the local fluctuations are probed inside the large blob, and the velocity fluctuations are affected by the presence of blobs when the larger length scale is sampled beyond the correlation length. This suggests that the original Caflisch-Luke model holds at the very low concentration because the correlation length (or blob size) decreases with the concentration, while

the velocity fluctuations could show a weaker concentration dependence associated with the correlation length expressed as,

$$\Delta V = C\phi^{\frac{1}{3}} \qquad (2)$$

The origin of the velocity fluctuations is considered to be number fluctuations of particle in a blob[2]. This hypothesis is actually supported by some experiments. On the other hand, we have studied the velocity fluctuations of PDVB (polydivinylbenzene) microspheres, which were always reproduced by eq. (1) regardless of the size and concentration of particles[3, 4]. Later, Brenner described that screening of hydrodynamic interaction could lead to Caflisch-Luke type behavior expressed by eq. (1)[5]. However, to date, this is not systematically investigated as functions of the particle size, the volume fraction, as well as the particle Reynolds number (or particle density). In this paper, we show that the volume fraction dependence of the velocity fluctuations obtained for silica particles having larger density of particle at low volume fractions. By comparing the results obtained for the PDVB particles, it could provide a
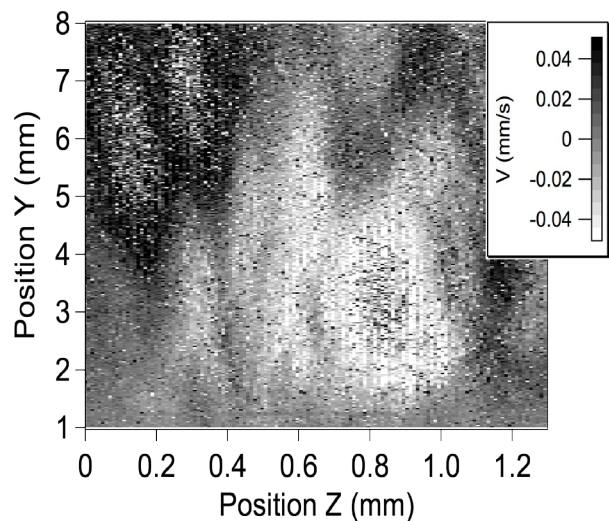

Fig. 1 Image of instantaneous velocities obtained by the phase-mode DSS technique.

better insight to understand the velocity fluctuations of settling micro-particles.

2. Experiments and Results

An aqueous dispersions of silica particles was poured into a polystyrene disposal cell (10×10×40 mm) to perform velocity fluctuation measurements by DSS. A longitudinal plane wave transducer was aligned perpendicular to the sedimentation direction to extract the horizontal component of the velocity fluctuation ΔV_y. The velocity fluctuations of the silica suspensions with different diameter, 3, 7, and 10 μm, were examined as a function of the volume fraction.

Fig. 1 shows a 2D velocity profile evaluated by the phase-mode DSS technique. The image of the instantaneous velocity indicates that the silica suspensions form a unique blob structure and the particle dynamics involves cooperative motion (at least not random). Before discussing the volume fraction dependence of the velocity fluctuations, it is important to confirm the particle velocity is in the steady state. **Fig. 2** shows the time-dependence of the scattered intensity and the instantaneous velocity obtained for the silica particles with the diameter 3 μm. The particle velocity was very unstable at the beginning of the recording time because of the effect of mixing (regime I), but as
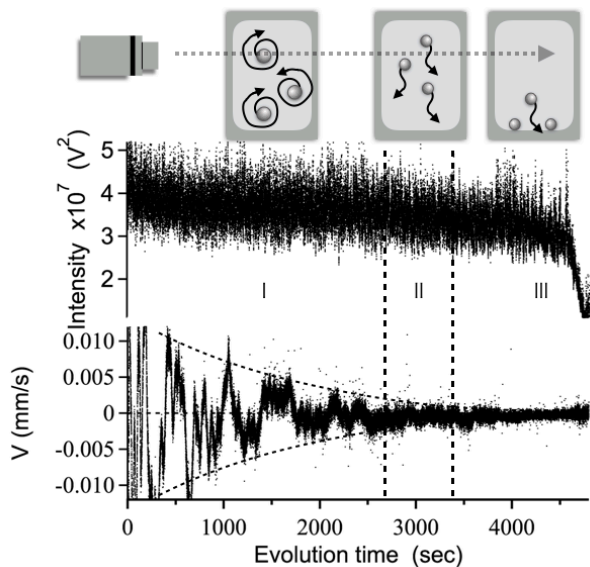

Fig. 2 The time-dependence of the scattered intensity and the instantaneous velocity obtained for the silica particles with the diameter 3 μm.

the time goes on the velocities leveled off. As shown in the graph, the region II was regarded as the steady state in which the velocity was taken as the representative value of the sample. In the

regime III, the particle almost settled down.

Fig. 3 shows the summary of the velocity fluctuations as a function of the volume fraction. While the results for 3 and 7 μm particles indicated the square-root dependences given by eq.(1) (the solid lines), a weaker dependence was found for the 10 μm of silica, which is reproduced by eq. (2) (the dashed line). The similar behavior was also found for the silica particles dispersed in methanol.
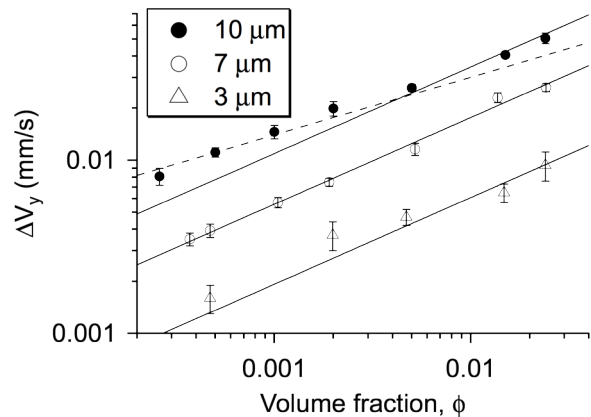

Fig. 3 The velocity fluctuations as a function of the volume fraction.

3. Conclusions

The velocity fluctuations of the settling silica suspension were investigated by dynamic ultrasound scattering techniques. While most of the data followed Caflisch-Luke model, the largest particle as well as the suspension having large density difference between particle and methanol exhibited the 1/3 dependence of the velocity fluctuation. It may be ascribed by relatively short correlation length associated with the large Reynolds number.

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