PREDICTING SEGREGATION OF BIMODAL SUSPENSION UNDER WALL-BOUNDED HIGH SHEAR-RATE FLOWS

Byoungjin Chun, Hyun Wook Jung*
Dept. of Chemical and Biological Eng., Korea Univ., Seoul 02841, Korea
* E-mail: hwjung@grtrkr.korea.ac.kr

Presented at the 20th International Coating Science and Technology Symposium
Minneapolis, MN, USA, September 20-23, 2020,

Introduction

Functional liquids used in coating industries are often particulate suspensions to make the coating products with demanded characteristics such as wear resistance, optical properties, and thermal and electrical conductivities. Evenly distributed particles in the coating films are mostly desirable, however, it is not always achievable even though well-dispersed raw materials are supplied. In slot coating processes, for instance, the inhomogeneity of flow field can be encountered inside the narrow slit channel as well as the coating bead region under high shear-rate flows, where the Reynolds number based on particle size is easily up to *O*(0.1). Furthermore, industrial particulate materials (i.e., inks, slurries, and pastes) are inherently mixtures of various types of particulates including ceramic, metallic, and polymeric particles, leading to an additional difficulty to control the uniformity of products.

In our previous work [1], the migration behavior of bidisperse suspensions under a pressure-driven flow (P-flow) through a slit channel was investigated, using lattice Boltzmann method (LBM) and diffusive flux model. The particle distributions were found to be significantly changed by hydrodynamic interactions between two types of spherical particles (large(L) and small(S)). Under the P-flow, the whole (L+S) particles are gradually crowded to the lower shear-rate region (so-called shear-induced migration (SIM)), and simultaneously the size segregation is noticeably progressed that the large particles locate more in the middle and the small particles are relatively near channel walls. We have extended this study into an investigation of bidisperse suspensions under a simple shear flow (i.e., a plane Couette flow, C-flow) at finite Reynolds numbers. Under this C-flow, since the imposed shear field is homogeneous everywhere, there is no significant change in the particle distribution due to the SIM. Instead, the presence of finite inertia causes suspended particles to move away from the wall (so-called wall-lift or inertial migration) [2-4]. In the case of a mixture of particles of different sizes, the segregation can occur between L and S particles due to the size dependence of the wall-lift velocity, which can be mitigated by shear-induced diffusion.

Simulation Method

We have numerically studied the segregation phenomena of concentrated bimodal spherical particles suspended in a Newtonian simple shear flow, employing the LBM. The method fully considers the hydrodynamic interactions between particles in the limit of small but finite inertia. As schematically depicted in Fig.1, spherical particles of two different radii (a_L and a_S) are neutrally buoyant and non-Brownian. The *x* axis represents the flow direction, and the flow is bounded by the two plates along the *y* axis with the channel height *H*, moving in opposite directions with $u_w/2$, respectively. Accordingly, the *z* axis corresponds to the vorticity direction. A periodic boundary condition is applied in both *x* and *z* directions with each length of L_x and L_z. Inside the calculation domain, volume fraction of ϕ_S^0 of small spheres, and volume fraction ϕ_L^0 of large spheres are suspended in a Newtonian fluid with viscosity η. The flow driven by moving walls is described by following hydrodynamic equations,

$$\nabla\cdot\mathbf{u}=0, \text{ and } \rho\left(\frac{\partial\mathbf{u}}{\partial t}+\mathbf{u}\cdot\nabla\mathbf{u}\right)=-\nabla p+\eta\left(\nabla\mathbf{u}+(\nabla\mathbf{u})^{\mathrm{T}}\right)$$

where ρ, $\mathbf{u}$, and p are the density, the velocity, and the pressure of a suspending fluid, respectively.

Simulation Results and Conclusion

Throughout this study, the channel height was set to 80δ, where δ is the length unit of LBM. Concentrated suspension is assumed; most of the simulations are performed for the total solid volume fraction ($\phi^0=\phi_L^0+\phi_S^0$) of 0.2. We considered mainly the simplified condition that the concentration of large particles is sufficiently low and thus the L-L interaction is negligibly small compared to L-S and S-S interactions. The Reynolds number based on particle size is defined as $\mathrm{Re}_m=\rho\dot{\gamma}a_m^2/\eta$, where m is either L or S, and the imposed shear rate is $\dot{\gamma}=u_w/H$. As depicted in Fig.2(a-d), it is predicted that the following combined effects affect the temporal size segregation (Fig. 2(c)); the wall lift induces the size segregation and the shear-induced diffusion mitigates the segregation (Fig. 2(d)). Total particles are crowded in the middle, however, quite opposite to our expectations, larger particles are more crowded near walls and small particles are in the middle when the Reynolds number becomes O(0.1).

References

[1] B. Chun, J. S. Park, H. W. Jung, and Y.-Y. Won, *J. Rheol.* 63(3):437, 2019.
[2] P. G. T. Saffman, *J. Fluid Mech.*, 22(2): 385, 1965.
[3] P. Cherukat and J. B. McLaughlin, *J. Fluid Mech.*, 263:1, 1994.
[4] J. Magnaudet, S. Takagi, and D. Legendre., *J. Fluid Mech.*, 476:115, 2003.

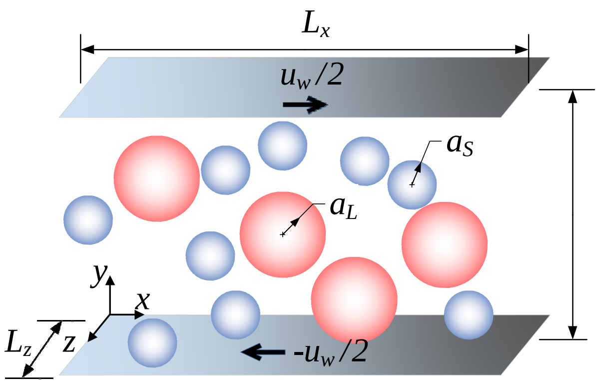

Figure 1. A schematic illustration of a periodic box for simulating bidisperse suspension under a simple shear flow. The red spheres represent large and blue ones are small particles. Two oppositely moving solid walls are placed *y*=0 and *y*=*H*.

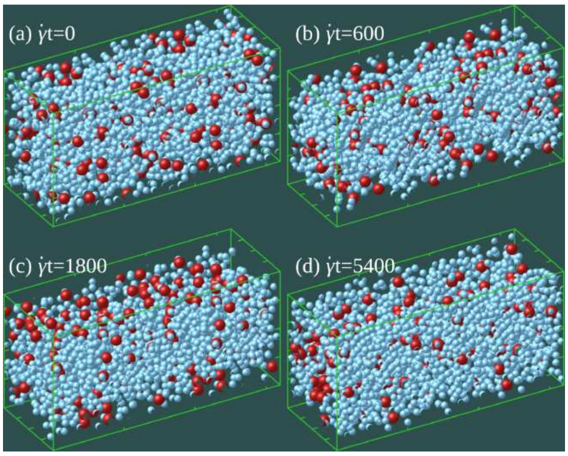

Figure 2. Snapshot images of particle distribution in time, where time is represented by strain ($\dot{\gamma}t$). The size ratio (a_L/a_S) set to be 1.6. $\phi_L^0=0.05$, $\phi_S^0=0.15$, Re_L=0.5, and Re_S=0.2. (a) Initial distribution, (b) and (c) are temporal distributions, and (d) steady-state distribution.