

## Collectivity and individuality of particle dispersion under gravity

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Collective motion of fine particles in liquid can be widely seen not only in engineering processes but also in natural phenomena such as water treatment [1], sediment transport [2], bio-convection [3] and lava convection [4]. It is well-known that the spatial variance of particle concentration brings about large-scale convection flow under gravity and sometimes it affects macroscopic motion of particles. In this study, of particular interest is whether collective or individual motion of particles reveals in liquid under the gravity field. The existence of concentration interface, which is an ambiguous interface between suspended particles and pure fluid, plays a significant role in these extreme behaviors.

Figure indicates the settling behaviors of stratified-suspended particles in a vertical Hele-Shaw cell filled with liquid [5]. In cases of small particle size with high concentration, the interfacial instability occurs at the lower concentration interface and the suspended particles behave as an immiscible fluid even though there is no distinct border with pure fluid [6]. Consequently the settling velocity is much faster than that of an isolated particle. On the other hand, in case of large particles with low concentration, the concentration interface is less distinct and the suspended particles settle individually. The transition from these collective to individual motions of suspended particles is controlled by the border resolution of concentration interface. We define the dimensionless parameter which describes the border resolution of concentration interface by the ratio of average particle distance  $d_p/\phi^{1/3}$  ( $d_p$ : particle diameter,  $\phi$ : concentration) to the dominant wavelength of the instability  $\lambda$ . As can be seen in Figure, the dimensionless parameter well describes the transition from fluid-like to particle-like behaviors. The suspended particles (and the interstitial fluid) perfectly behaves as continuum for  $d_p/\phi^{1/3}\lambda < 0.03$  and behaves individually relative to fluid for  $d_p/\phi^{1/3}\lambda > 0.2$  [5].

The similar collective motion of suspended particles has been studied on the settling of particle clouds in viscous fluid. Some researchers have suggested that the collective motion of particles in clouds can be explained by the swarm of Stokeslet [7]. They have found that the particle cloud behaves collectively when the flow generated by each particle (Stokeslet) enough screens the surrounding flow. If the above parameter is rewritten by number density of particles  $N$ , it is expressed as  $(6/\pi)^{1/3}/N^{1/3}\lambda$ . Therefore the border resolution of concentration interface express the discretization of space by Stokeslet  $1/N^{1/3}$  for a given lengthscale  $\lambda$ .

One more interesting similarity to previous study is the wavelength of instability. From the linear stability analysis of Rayleigh-Taylor instability on both miscible and immiscible interfaces of pure fluids [8], it is found that the dominant wavelength of miscible interface with no diffusion and immiscible interfaces with no interfacial tension are asymptotically close to constant value. The wavelength at concentration interface is also close to the asymptotic value [9]. From this point of view, the concentration interface can be interpreted both as the the immiscible interface with no interfacial tension and the miscible interface with no diffusion.

### References

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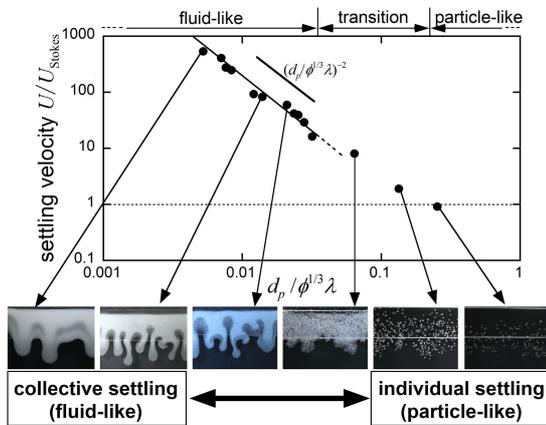


Figure 1: Collective and individual settlings of suspended particles in Hele-Shaw cell.