Evolution of suspension sedimenting in a container bounded by horizontal walls

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Concentration inhomogeneities of the particles sedimenting in the fluid under gravity force with small Reynolds numbers lead to the large-scale velocity disturbances. Caflisch & Luke [1] showed that the velocity fluctuations in a homogeneous suspension with random distribution of particle locations grow linearly with container size. The divergence of fluctuations for infinite system is due to slow decaying, like r^{-1}, of disturbance field far from a particle. Luke [2] studied the evolution of velocity fluctuations in an infinite container with periodic boundary conditions in all directions and particle density stably stratified in vertical direction. He considered the dynamics of linear perturbations followed from the solution of an unsteady continuity equation for the concentration and Stokes equations for the velocity field. As a result a finite variance in the velocity was obtained when $t > 0$ and the container size tends to infinity. The large-scale vortex structures were observed in many recent experiments. Guazzelli [3] studied the transient behavior of the structures at low particle concentration. Their lengthscale is of the order of cell size at short times, and it diminishes at later times. Whether some steady state can be attained is still an open question. Ladd [4] simulated a settling suspension using a lattice-Boltzmann model of the fluid phase. The fluid-velocity fluctuations are found to grow with the cell size in a container with periodical boundary conditions, while in a container bounded at the top and bottom by no-slip walls they saturate.

In the present work the evolution of large-scale disturbances of the particle concentration and fluid velocity in the homogeneous sedimenting suspension is studied. A rectangular container is bounded by rigid walls in vertical direction and periodic in horizontal directions. The continuum model and perturbation methods [2] are applied to obtain solution for any initial distribution of particle concentration as the functions of time and vertical coordinate. The basic flow is a zero fluid-velocity field and constant concentration profile below a sedimentation front which travels with the Stokes velocity. Solution for the linear perturbations is presented in terms of Fourier series. As the Stokes equations governing the fluid flow are linear the evolution of any initial harmonics of concentration disturbances is considered separately.

The concentration inhomogeneities and velocity fluctuations are shown to decay with time. The decay is due to decrease of particles' number because of their deposition on the bottom wall and the variation of sedimentation-front shape. An inhomogeneity with enhanced concentration translates downward faster. After some time the sedimentation front will be lower in this region than the basic-flow position while that for the inhomogeneity with reduced concentration will be higher.

The ensemble-averaged fluctuations and the correlation functions depend on the position of the viewing window. The steady values can not be attained at a fixed position. Fluctuations evaluated in the middle of the cell grow linearly with the height of a cubic container, but saturate or even decrease as the container width grows and the height is fixed. Similar behavior was obtained by simulations [4] of dense suspension in a thin container.

Figure 1 presents the results of calculation of vertical velocity fluctuations in comparison with the experimental values [3] for the particle volume content $\phi = 0.0005$. The fluctuation profile in the container with the aspect ratio $1:1:2$ at short times has the plateau in the middle part (see Fig. 1 (a)). The fluid velocity is very small in the clean fluid, $z > H - U_s t$. The maximum remains approximately in the middle of the suspension layer and decreases only slightly with time. However the fluctuations averaged over the viewing window diminish as the sedimentation front approaches its upper boundary. The qualitative agreement of the theoretical and experimental time dependences is good (Fig. 1 (*b*)).

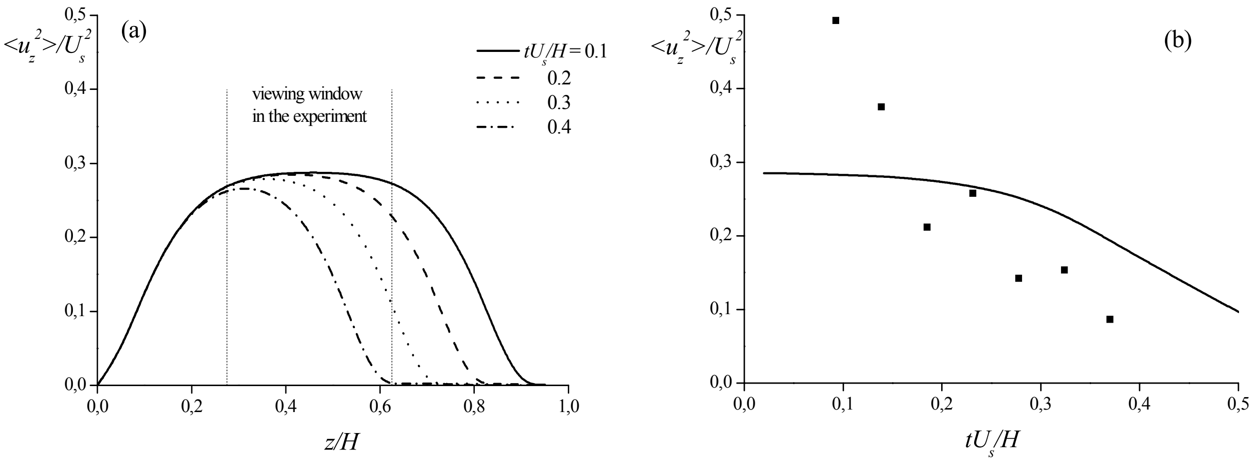

Figure 1

References

[1] R. E. Caflisch and J. H. C. Luke, "Variance in the sedimentation speed of a suspension," Phys. Fluids **28,** 759 (1985).

[2] J. H. C. Luke, "Decay of velocity fluctuations in a stably stratified suspension," Phys. Fluids **12,** 1619 (2000).

[3] E. Guazzelli, "Evolution of particle-velocity correlations in sedimentation," Phys. Fluids **13,** 1537 (2001).

[4] A. J. C. Ladd, "Effects of container walls on the velocity fluctuations of sedimenting spheres," Phys. Rev. Lett. 88 (2002).