231j Dns of Dense Suspensions: Instabilities in Liquid-Fluidized Beds
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Dense fluidized beds exhibit a rich variety of complex, inhomogeneous flow structures, ranging from one-dimensional traveling waves to bubble-like voids. Although Eulerian two-phase flow models (with phenomenological closures for the effective stresses and the fluid-particle interaction force) capture the experimentally observed structures in a qualitatively correct manner, quantitative predictions remain elusive [1].

Developing closure relations for the effective stresses is a notably difficult problem: The effective stress in the particle phase consists of several contributions: the streaming stress associated with the fluctuating motion of the individual particles, contact stress arising through direct interaction between particles, and a hydrodynamic component resulting from particle-particle interaction through the interstitial fluid. Closures should also take into account the effects of compaction and dilation of the particle phase (in a granular kinetic theory context such closure enters via the solid's bulk viscosity); their validation requires systems that evolve spatial inhomogeneities. Recently Guazelli and co-workers [2,3] accurately and reproducibly measured the onset of one and two-dimensional instabilities in liquid-fluidized beds. Their data are particularly valuable, as they are made up of regions where the particle assemblies undergo dilation and regions where they compact. As compaction and dilation of particle assemblies are ubiquitous in granular and fluid-particle flows, it is important to test and validate closure models through clean model problems where both compaction and dilation occur.

We present direct simulations with interface resolution of fluidized solid-liquid suspensions. The cases we study numerically were derived from the experimental work reported in [2] and [3]. The flow of interstitial fluid is solved by the lattice-Boltzmann method (LBM). The monodisperse, spherical particles move under the influence of gravity, hydrodynamic forces stemming from the LBM, subgrid-scale lubrication forces, and hard-sphere collisions. We first show that the experimentally observed planar waves in narrow beds are well represented by the simulations. The wave speed and shape appear to be largely insensitive to the parameters involved in the hard-sphere collisions (in our collision model these are the restitution coefficient and the friction coefficient). Stress levels are sensitive to the collision parameters: compared to smooth, elastic collisions, non-ideal, frictional collisions lead to a higher collisional pressure.

Subsequently we use the detailed information contained in the simulation results to assess two-fluid model closures, with a focus on particle drag, and the role of compaction and dilation of the particle phase. We show that the solids volume fraction dependency of the drag can be well represented by a Richardson and Zaki type of correlation. We note (in accordance with [4]) that the fluctuating motion of the particles influences the average particle drag.

Collisions are largely responsible for the particle phase stress in these flows at high particle volume fractions. In the void-part of the wave, fluid and particle streaming stress are significant and of similar magnitude. At comparable solids volume fractions, the compaction zone of the wave has much higher normal stresses than the dilation zone. We argue that this difference can be represented by means of a solids phase bulk viscosity, being a function of the solids volume fraction.

Wider fluidized beds develop more complicated structures [3]. We numerically confirm the scenario for the onset of a bubble-like void in a flat fluidized bed as measured by Duru and Guazelli [3] (see Figure 1): A planar wave buckles and at its crest forms a void. In Figure 2 we qualitatively compare the particle velocities as measured and simulated.

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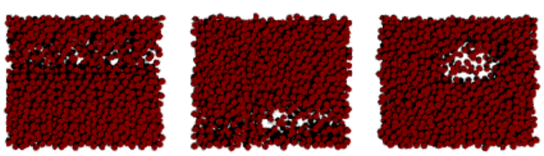

Figure 1. Three subsequent snapshots of the particle assembly forming a void. Gravity is in the downward direction, fluid is forced in the upward direction.

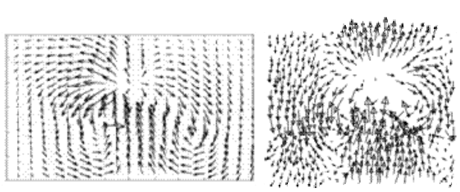

Figure 2. Particle velocities in the vicinity of the void. Left: experimental picture reprinted from [3]; right: simulation result.

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