

209a Coarse-Graining of Two-Fluid Models for Fluidized Gas-Particle Suspensions

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It is well known that gas-particle flows exhibit large fluctuations in velocities and local suspension density. In riser flows, these fluctuations are associated with the random motion of the individual particles (typically characterized through the granular temperature) and with the chaotic motion of particle clusters, which are repeatedly formed and broken apart. These clusters occur over a wide range of length scales and their dynamics span a broad range of time scales.

The origin of these clusters is well understood, and two-fluid model equations are able to capture their existence in a robust manner; however, to resolve the clusters at all length scales, extremely fine spatial grids are necessary [1]. Due to computing limitations, the grid size used in simulating industrial scale gas-particle flows is invariably much larger than the length scales of the finer particle clusters. Such a coarse-grid simulation will clearly not resolve the structures which exist on sub-grid length scales.

Agrawal et al. [1] established that the clustered state shows drastically different properties than a uniform field of particles, and argued that, in coarse-grid simulations where the fine details of the particle clusters are not resolved, the influence of the sub-grid structures must be accounted for through appropriate sub-grid models. They also outlined an approach for deriving ad hoc sub-grid corrections from small, well-resolved simulations with periodic boundary conditions. In their study, they employed the Wen & Yu [2] expression for the drag coefficient and the kinetic theory of granular materials to close the particle-phase stress [3].

Andrews et al. [4] derived such ad hoc sub-grid corrections (which take the form of modified constitutive relationships for the gas-particle drag and particle-phase shear and normal stresses) and incorporated them into a sub-grid model for the coarse grid simulation of flow in risers. The resulting sub-grid model gave drastically different results than the kinetic theory model simulated at the same grid resolution. The simulation including the sub-grid model reproduced a number of qualitative features of the macroscopic flow seen in practice, such as higher concentration of solids at the walls and at the bottom of the riser and a downflow of solids at the walls.

In the present study, the filter size dependence of sub-grid corrections is examined and steps are taken towards validating the sub-grid model approach. To this end, we coarse grain the two-fluid model equations through a filtering operation [5]. In these coarse-grained equations, the consequences of the flow structures occurring on a scale smaller than a chosen filter width appear through correlations for which closure relations should be derived or postulated. If constructed properly, the filtered equations should produce a solution with the same macroscopic features as the finely resolved kinetic theory model results; however, as the coarse-grained equations place less stringent requirements on the grid resolution than the original two-fluid model equations, they would be easier to solve.

We have extracted filtered drag coefficient and particle phase stresses as functions of the local particle volume fraction and the size of the spatial averaging window (i.e. filter width). This was done through highly resolved simulations of fluidized suspensions in a large periodic domain, followed by filtering of the results using different filter widths. These simulations were performed using the MFIX code [6]. The filtered drag coefficient decreased systematically with increasing filter width, while the filtered particle-phase stresses manifested simple linear relationships with the local particle volume fraction.

We have also sought to validate the coarse-graining approach which uses the filtered drag coefficient and particle phase stresses by comparing the results obtained in test simulations using the coarse-grained equations with those obtained by highly resolved simulations of the kinetic theory model. The test

geometry is also a large periodic domain whose dimensions are small enough to achieve converged solution of the kinetic theory model equations, yet great enough to allow meaningful simulation of the coarse-grained equations. These simulations were run at a range of grid resolutions, and two different filter widths were investigated. As expected, the coarse-grained equations yielded coarser structures than those seen in the kinetic theory simulations, and they also led to a converged solution for a much lower grid resolution. The details of these results will be described in the presentation.

References:

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