209c Consistency of Fully Developed and Periodic Simulations in Gas/Solids Flow in a Riser

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Gas/solids flow simulations over a periodic domain are useful for determining the sensitivity of model parameters because the calculations take only a few hours to complete instead of the weeks required to simulate a full riser. Many numerical gas/solids flow studies published in the literature have assumed the definition of fully developed flow in a riser to be synonymous with using periodic boundaries. We show that this is not a reasonable assumption in gas/solids flows; certain fully developed solutions cannot be obtained by simulations over a periodic domain.

The calculations are performed with a transient gas-solids flow model that uses kinetic theory to describe the solids stresses. The simulations are conducted with inlet-outlet boundary conditions (fully-developed simulation) and with periodic boundary conditions (periodic simulation). We assume that a fully developed region exists in a full riser if the radial profiles of the time-averaged solids axial velocity and volume fraction remain constant, and the time-averaged solids radial velocity is negligible. These results are then compared with those obtained in a system with periodic boundaries with identical gas and solids fluxes. We simulated two gas/solids flow regimes in a 10-cm diameter riser using glass beads of 2400 kg/m3 and 120 microns in diameter: a low gas velocity (7 m/s) case (solids mass flux = 135 kg/m2s) and a high gas velocity (18 m/s) case (solids mass flux = 1150 kg/m2s).

In both the gas velocity cases the periodic simulation predicts the well-known core-annular flow behavior consistent with experimental observation (solids concentration is high near the wall and low at the center). Similarly the solids velocity profiles in both velocity cases have a maximum at the center in agreement with experimental observation. As shown by Benyahia et al. (2004) a core-annular behavior can be obtained in periodic simulations by using kinetic theory and a dissipative boundary condition for granular energy. But, in sharp contrast with experimental data, the periodic simulation for both low and high gas velocities shows the maximum solids flux to be near the wall. Experiments show that the maximum solids flux is near the wall at high gas velocities, but is at the center for low gas velocities [S.B. Reddy Karri and T.M. Knowlton, 1999. A Comparison of Annulus Solids Flow Direction and Radial Solids Mass Flux Profiles at Low and High Mass Fluxes in a Riser, Proceedings of the 6th International Conference on Circulating Fluidized Beds, J. Werther, editor, Page 71.]. This trend is correctly reproduced by the fully-developed simulations for the case of high gas velocity. So the periodic simulation for low gas velocity does not match the fully-developed simulation or experimental observations.

In all cases, the mechanism responsible for core-annular flow was clusters that formed within the domain and moved toward the walls of the riser. In the low gas velocity case, clusters at the walls moved downward. The downward motion of the clusters caused irreconcilable difference between the periodic simulation and fully-developed simulation. In the periodic simulation the clusters continue to move downward, whereas in the fully-developed simulation the clusters move toward the center when they meet the inlet boundary and get recirculated. The recirculation causes the solids concentration at the center of the riser in the fully-developed simulation to be higher than that in the periodic simulation. Hence the solids mass flux at the center can become high and even achieve a maximum value in fully developed simulations. This is not possible in a periodic (or 1-D) simulation. Furthermore, this essentially 2-D effect cannot be achieved by adjusting model parameters in the periodic simulation.

At high gas velocity, the clusters at the walls move upwards and no recirculation occurs. Hence, the results of fully-developed simulation and periodic simulation are similar and consistent with experimental trend at high gas velocities.