SCALAR TRANSPORT IN LIQUID FLUIDIZATION

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Next to their rich hydrodynamics [1], sedimenting and fluidized solid-liquid suspensions have many practical applications in industrial processes, e.g. wastewater treatment, crystallization, and leaching, (extraction of minerals from a solids phase). These applications require insight not only in the fluidization dynamics but also in the transport of scalars (chemical agents, heat) in the liquid phase of the suspension, and the exchange of these scalars between solids and liquid. Such transport processes are, obviously, intimately linked to the hydrodynamics of the fluidized suspension.

We perform direct numerical simulations of hydrodynamics and scalar transport in fluidized beds consisting of a Newtonian liquid and spherical solid particles. The simulations are resolved beyond the size of the particles which means that the grid on which the liquid flow is solved is finer than the particle size and that we explicitly impose no-slip conditions on the surfaces of the solid spheres. Hydrodynamic forces and torques on the spheres that result from the flow simulation are used to update particle velocities (translational and rotational) and positions and thus provide updated no-slip boundaries for the liquid. This all creates an intimate and realistic coupling between liquid and solid dynamics. The numerical procedure is based on the lattice-Boltzmann method supplemented with immersed boundaries.

The scalars in the simulations are one-way coupled to the flow dynamics: the scalar concentrations respond to the liquid velocity field, the liquid flow field is not influenced by the scalars. Scalar convection-diffusion equations are solved by means of a finite volume method. Two specific scalar boundary conditions have been considered: (1) passive particles, i.e. particles that do not directly take part in the scalar transport process (in mathematical terms it means ∂c/∂n=0 at solid surfaces); (2) active particles with – as a canonical case – a fixed scalar concentration at the solid surfaces and thus transfer of scalar from solid to liquid (or vice versa). Given the usually high Schmidt numbers in liquids (Sc=O(1,000)), specifically the active particle cases require very high resolution due to the thin scalar boundary layers near the solid surfaces. For this we have devised a Coupled Overlapping Domain method [2] where fine spherical grids around each particle communicate with a coarser background grid.

Impressions of scalar spreading at a solids volume fraction of 0.4. Upper row: three instances of scalar that initially was confined to a horizontal slab halfway the domain; bottom row: same for an initially vertical scalar slab. For visibility, the spheres in front of the contours plane are not shown. Note the logarithmic colour scale.
For passive particles, the research focuses on scalar dispersion as a result of the liquid flow fluctuations brought about by the largely erratic particle motion [3]. This dispersion is highly anisotropic with streamwise scalar spreading being one order of magnitude stronger than lateral spreading. This can be qualitatively witnessed in Figure 1. Scalar dispersion coefficients appear to be correlated to particle self-diffusion [3].

Simulations with active particles [2] (see Figure 2 for an impression) have been used to relate overall Sherwood numbers (dimensionless mass transfer coefficients) with Reynolds numbers, Schmidt numbers, and solids volume fractions. An interesting finding was a reduction in mass transfer rates in fluidized beds as compared to beds of fixed particles. This is caused by hydrodynamic screening effects in fluidized systems.

REFERENCES