Particle-resolved simulations of solid-liquid suspensions – erosion & entrainment

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Erosion of granular beds by a shear flow of liquid over its surface has many natural and engineered manifestations such as sediment transport by rivers, flow in slurry pipelines, dredging applications, and solids suspension in mixing tanks. The extent to which solids are entrained by the flow is a result of a competition between hydrodynamic stress and net gravity. The dimensionless Shields number ($\theta = \dfrac{\sigma}{g(\rho_s - \rho)d}$ with σ the shear stress above the bed, and d the particle size) embodies this competition and a critical Shields number demarcates between static and mobilized solids in the (top layers of the) granular bed.

Next to having practical relevance, simulations of erosion processes are interesting for fundamental and numerical reasons. The suspension flow closely above the bed is very inhomogeneous with a solids loading that can change from random close packing to dilute over a distance of only a few particle diameters. This poses challenges to continuum-based and point-particle-based numerical approaches; e.g. not much is known about the drag force in the presence of a strong solids volume fraction gradient; not every method can deal with suspensions having such wide range of solids volume fractions. Resolved particle simulations should be able to overcome the challenges but at the same time face issues. In addition to their stiff computational demand, they relate to interactions between the particles when their surfaces are very close to or actually in (dry) contact. Then these 'direct' simulations need to revert to modelling (lubrication forces for near-contact and friction and restitution coefficients upon contact).

In this contribution we present three types of erosion-related flow systems that we have approached through resolved-particle simulations. (1) Erosion of a granular bed by a laminar simple shear flow; (2) erosion of a granular bed by a mildly turbulent ($\mathrm{Re}_\tau = 180$) channel flow; (3) erosion of a solids bottom layer by the (again mildly turbulent) flow driven by an impeller in a mixing tank. Impressions of these flow systems are given in the figure.

The laminar results show encouraging agreement with experimental data from the literature and do so for quite a wide range of model parameters related to particles near contact (lubrication and collision parameters), i.e. the results are not that sensitive to the details of the near-contact models. The laminar results inspired the turbulent channel flow simulations. They exhibit interesting features (such as turbulent structures penetrating the top layer of the granular bed) but it is hard to mimic such channels experimentally. For that reason we devised the stirred tank simulations. The miniature stirred tank systems are fairly easy to physically build and visualize in the lab and we plan to do so (not done yet). Visualization of the start-up, dynamic steady state, and shut-down of the suspension process, and comparison between numerical and experimental results would provide a means to critically assess the level of realism of resolved-particle simulations under challenging, inhomogeneous conditions. It also would allow us to study the sensitivity of non-ideal conditions (non-sphericity of particles, size distributions, surface roughness) on the overall suspension behaviour.

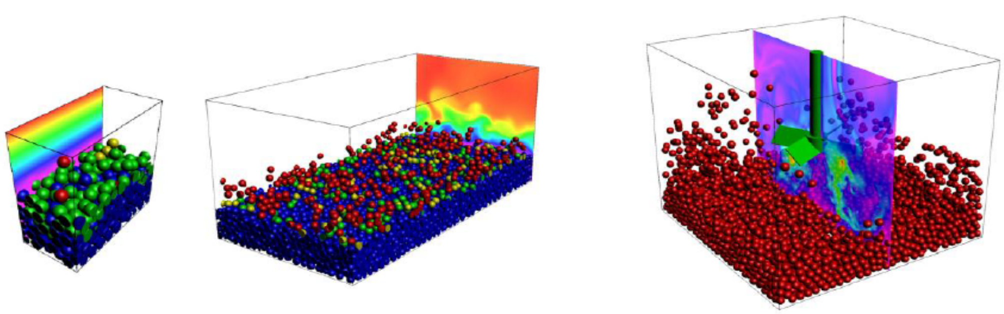

Figure. Impressions of the three flow systems. Left: granular bed under a laminar shear flow; middle: granular bed under turbulent channel flow; right: solids get partially suspended in a mixing tank. The contour planes show velocity magnitude. In the left and middle panel spheres are colored by their velocity