Geophysical Research Abstracts, Vol. 9, 00736, 2007
SRef-ID: 1607-7962/gra/EGU2007-A-00736

Coalescence of gravitationally settling particles

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We consider a system in 3D space where many small spherical particles are distributed in a range of sizes and heights (with uniform distribution in the horizontal plane), and let them move vertically with a terminal size-dependent velocity. As a larger particle overtakes a smaller one, a collision can occur during which the two particles merge and form a bigger one. This system models certain regimes of rain formation, bubbles moving up in water due to buoyancy and sedimentation of clay particles in water.

We study this system via direct numerical simulations (DNS) in which we follow the paths of all particles, detect their collisions and apply particular merging rules. The simplest model of merging (free merging) allows the two particles to merge every time their separation becomes less than the sum of their radii. Another model we use (forced locality) allows the two particles to merge only if they have comparable sizes, i.e. if their size ratio remains within specified bounds.

We also find steady state and self-similar analytical solutions to the corresponding Smoluchowski equation, and we compare these solutions with DNS. In the setup where small particles are continuously injected and large ones removed uniformly in 3D space, we obtain a constant flux Kolmogorov-Zakharov distribution, which appears to be nonlocal in the free-merging model, and therefore only relevant to the forced-locality model. We obtain unsteady solutions which describe gelation, i.e. creation of infinite particles in finite time. We find steady height-dependent solutions in which the particles are injected at some height and removed at a different height. We find that the predictions obtained based on the Smoluchowski mean-field model are in good agreement with DNS.