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Particle size segregation in debris flows: insights from simulations of immersed sheared granular flows

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During the course of a debris flow's motion, large particles, such as rocks and boulders, rise to the free-surface while the finer sand and silt-sized particles settle to the base. This inverse-grading process influences the development of coarse-grained heads and levees in debris flows that consequently enhance the flow mobility. Size segregation is well-studied in dry granular flows wherein it is found to be highly efficient and results in sharply separated layers of differently sized particles. Segregation diminishes in the presence of pore fluids (i.e. water or muddy slurry) and in some cases is no longer evident, although the mechanisms behind this inhibitive effect is poorly understood. In order to accurately capture size segregation in debris flows, and its impacts on the flow dynamics, it is important to understand how different types of pore fluids influence the segregation process. In this research, we systematically investigate the effects of various interstitial fluids, characterized by their density and viscosity, on the rate of particle size segregation through coupled granular-fluid simulations. Debris flows are simulated as sheared granular mixtures composed of spheres having two distinct particle sizes, immersed in ambient fluids. Solid and fluid interactions are modelled through drag and buoyant forces. Fluid effects are also evaluated across different shear rates, confining pressures, mean diameters, and gravity. It is found that the segregation slows down as the fluid viscosity is increased, but is unaffected by it below certain threshold values. In the low viscosity limit, segregation is affected only by the relative density between the particles and the fluid, and by flow inertial conditions. Analysis of stresses acting on a segregating particles reveals that the decrease of segregation rates with the viscosity is due to the increase of fluid drag forces which effectively weaken the contact stress gradients and velocity fluctuations responsible for driving the large particles upward. An empirical scaling formula is developed which accounts for the effects of fluid viscosity and the relative density on size segregation immersed in different fluids.