Rheology and microstructure of two-phase granular fluids: applications to the bridging problem

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Starting from basic thermodynamic principles, we derive equations for a two-phase fluid. The first phase is the micropolar (granular or “solid”) fluid and the second phase is the viscous Newtonian fluid. The phases differ in velocities, densities and viscosities. The first granular phase is described with the use of notion of the Cosserat continuum. To illustrate the model, we study how rotation of particles impacts their lateral migration in pipe and channel flows. Particularly, we address the “tubular pinch effect” of Ségre and Silberberg.

As is emphasized in couple stress theories, the Cauchy stress tensor of the granular phase is not symmetric. It is due to the fact that not only symmetric part of the rate of strain tensor contributes to the stress state but the skew symmetric part does it also. The weight of contributions is expressed in terms of symmetric and skew-symmetric viscosities. The symmetric viscosity coincides with the usual shear viscosity. As for the skew-symmetric viscosity, we suggest that it can be derived from the Krieger–Dougherty law by studding flows in concentric-cylinder Couette geometry. On this way, we prove that it is due to gyration effect that the suspension apparent viscosity increases with the particle volume fraction.

Keeping in mind applications to the bridging problem, we study also the case when the solid phase enjoys the yields stress rheology. For the steady flows in the Hele-Show cell, we find correlations between flow rates of the phases and the pressure gradient. We prove that the fluid phase flows at any the pressure gradient and we find no flow conditions (in terms of the Bingham number) for the solid phase.

To test the model, we have performed calculations in a 2-D sedimentation problem neglecting particle rotations. It turned out that the sedimentation front is orthogonal to the gravitation field at any tank inclination. The comparison with experiments is performed.

The model derived can be extended for the non-spherical particles. We studied one-phase granular anisotropic fluid flow for rod-shaped particles. Anisotropic rheology manifests itself through the fact that the stress tensor depends not only the rate of strain tensor but on the micro-inertia tensor as well. Calculations reveal that no steady flow occurs between two planes under the constant pressure gradient. Accelerations alternate with decelerations, with the flux pulsation depending on the rod length. The regions of the same particle orientation are built up and evaluate.

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