Scaling laws for turbulent channel transport of neutrally-buoyant finite-size particles

Dense turbulent suspensions appear in a wide range of environmental and industrial contexts. In many cases the particles have a finite-size, i.e., a size comparable to or larger than the smallest scales of the turbulent flow. In these cases turbulence — in itself one of the most challenging problems in classical physics — is greatly modified due to the presence of the particles, which interact both with each other and with the suspending fluid. To obtain insight on the physics of these complex flows we performed direct numerical simulations of turbulent plane-channel transport of neutrally-buoyant spherical particles. The Navier-Stokes equations governing the incompressible Newtonian suspending fluid are solved with a standard finite-volume pressure-correction scheme. The Newton-Euler equations that govern the particle motion are coupled to the Navier-Stokes equations through an immersed-boundary method, which enforces the local fluid velocity to be equal to the local particle velocity. Lubrication corrections for small inter-particle and particle-wall gaps are introduced to compensate lack of spatial grid resolution and a soft-sphere collision model is used to compute contact forces/torques. We varied the flow governing parameters parameters from dilute to dense cases, from large to relatively small particles and for a wide range of Reynolds numbers. Our results show that a near-wall layer of particles cause the suspension to deviate from the continuum limit in which its dynamics is well described by an effective suspension viscosity. By exploiting the momentum balance we derived scaling laws for the mean velocity profile of the suspension flow, together with an equation able to predict the overall drag as function of the flow governing parameters. We validated our predictions for a reasonably wide range of the governing parameters.