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Particle-Resolved Numerical Simulation of Turbulent Suspension Flow Using the Lattice Boltzmann Equation

LIAN-PING WANG, University of Delaware

Particle-laden turbulent flow is of importance to many engineering applications and natural phenomena, such as aerosol and pollutant transport, interaction of cloud droplets, spay combustion, and chemical processes. In general, the dynamics of dispersed phase and that of the carrier fluid phase are closely coupled. Most previous studies utilize the point particle approach to study the effects of particles on the carrier turbulence, under the assumptions that the particle size is significantly smaller than the smallest turbulence length scale and the particle volume fraction is low. The present study focuses on the motion and hydrodynamic interactions of finite-size freely moving particles in a turbulent background flow. To simulate carrier fluid turbulence, a mesoscopic lattice Boltzmann approach is applied with the multiple relaxation-time collision model, which yields a more robust viscous flow simulation method than the single-relaxation collision model. The no-slip boundary condition on the moving surface of each particle is implemented using an interpolated bounce-back scheme. The refill problem resulting from the moving boundary is handled by a non-equilibrium correction method to reduce the unphysical force fluctuations acting on the particles. The short-range lubrication force not resolved by the simulation is represented by a physical model involving particle relative location and velocity. For the carrier fluid phase, computational results are discussed in terms of the change of energy spectrum compared with the particle-free turbulence, the time evolution of the turbulent kinetic energy and the dissipation rate. For the dispersed phase, the focus will be on the particle-pair statistics such as the relative velocity and radial distribution function as well as particle-particle collision rate. The effects of varying particle size, volume fraction, and particle-to-fluid density ratio will be examined. The results will be compared to those from the previous point-particle approach and related particle-resolved approach.