Turbulence attenuation by finite-size spherical particles

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When we add finite-size solid particles to turbulence, its kinetic energy K' can be drastically attenuated. This issue has been intensively investigated, but the condition for the attenuation and accurate estimate of its rate Ar are still unknown.

The present study aims at revealing the physical mechanism of turbulence attenuation due to solid particles. To this end, we conduct DNS (by the combination of the finite difference method and an immersed boundary method) of particle-laden turbulence in a periodic cube and turbulent channel flow.

Our DNS[1] of particle-laden periodic turbulence show that sufficiently large velocity difference between particles and fluid is necessary for the attenuation. More precisely, when the velocity difference is large enough for vortices to be created around the particles, the turbulence attenuation rate $Ar = (K'_0 - K')/K'_0$, where K'_0 denotes the turbulent kinetic energy of single-phase flow, is proportional to the energy dissipation rate ϵ_p in the wakes around particles (see figure 3 in Ref. 2).

This result implies that the largeness of the Stokes number St which is defined as the velocity relaxation time of particles normalized by the turnover time of the largest eddies, is the condition for the turbulence attenuation. Evidence is given in Fig. 1, where we show vorticity magnitude around particles with two different St with a common diameter. Panel (a) shows that small-St particles follow the flow and no vortices are created around them, in which case turbulence is hardly attenuated. In contrast, panel (b) shows that large-St particles cannot follow flow and vortices are generated around them. In this case, because of the energy dissipation ϵ_p due to these vortices of the particle size, turbulence is drastically attenuated (K'/K'_0 is as small as 0.5 even though the volume fraction Λ is very small, $\Lambda = 8.2 \times 10^{-3}$).

We also show that we can apply the similar idea for particle-laden turbulent channel flow, where vortices around large-St particles directly dissipate the energy, which would be transferred from mean-shear flow to near-wall turbulent structures, resulting in the turbulence attenuation.

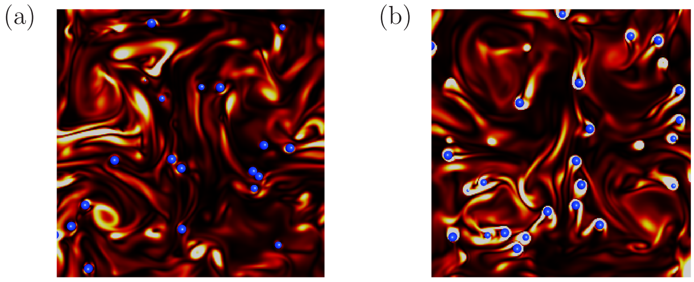

Figure 1: Vorticity magnitude (brighter regions denote larger vorticity) and particles (blue objects) on a cross-section of periodic turbulence. Particle diameter is common (about 0.17 times the integral length) but the Stokes number is different: (a) $St = 0.51$ and (b) 130.

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[1] Oka and Goto, *J. Fluid Mech.* **949**, A45 (2022).