Interaction between Particles and Homogeneous Turbulence: Particle Settling and Turbulence Modification Measurements

Shenqyang (Steven) Shy
Department of Mechanical Engineering, National Central University, TAIWAN
(E-mial: sshy@ncu.edu.tw; Fax: 886-3-427-6157)

This presentation shows quantitative measurements of interactions between small solid particles and homogeneous turbulence in both water and air media obtained by high-speed digital particle image velocimetry and accelerometry together with the wavelet transform analysis. Three different experimental apparatuses were applied, namely (1) vibrating-grids turbulence using a pair of vertically oscillated grids in a water tank, (2) fan-stirred turbulence in a cruciform air vessel using a pair of counter-rotating fans and perforated plates at each end of the large horizontal cylindrical vessel, and (3) Taylor-Couette featureless turbulence using two concentric, counter-rotating inner and outer cylinders. All three apparatuses are capable of generating a sizable region of stationary homogeneous isotropic or featureless turbulence to interact with small heavy descending particles from their top. Focus is on the effect of the Stokes number, *St*, a time ratio of particle response to the Kolmogorov scale of turbulence, to particle settling rates and turbulence modification. It is found that the particle settling velocity (V_s) is much greater than the terminal velocity (V_t) in still fluid for all three different experiments. Specifically, the value of (V_s - V_t) reaches a maximum of 0.13 u' when $St \approx 1$ and $V_t/u' \approx 0.5$ at $Re_\lambda = 120$ and $Re_p < 1$, in good agreement with previous numerical results, where u' is the energy-weighted rms turbulent intensity and Re_λ and Re_p are the Reynolds number based on the Taylor microscale (λ) and the mean diameter of particles, respectively. Non-uniform particle concentration fields are observed and most significant when $St \approx 1.0$, at which the particle clusters accumulate preferentially around the outer perimeter of small intense banana-like vortical structures. These clucters can turn and stretch banana-like vortical structures toward the gravitational direction and thus significantly increase the mean settling rate especially when $St = 1$. From spatiotemporal analyses of the flatness factor, we found that the characteristic length and time scales of these preferential particle clusters are related to the spacing between the adjacent intense vorticity structures of the order λ and the time passage of these clustering structures of the order of the Kolmogorov time scale (τ_k), respectively. This explains why the settling rate is on its maximum when $St \approx 1$, because the particle motion is in phase with fluid turbulence where the relative slip velocities are smallest.

By comparing the average frequency spectra between laden (heavy particle) and

unladen (neutral particle) turbulent flows over the measuring field at a fixed $Re_\lambda = 120$, turbulence augmentation is found for most frequencies in the gravitational direction especially for $St \geq 1$. In the transverse direction, augmentation occurs only at higher frequencies beyond the Taylor microscale for all values of *St* studied varying from 0.36 to 1.9. It is concluded that the increasing amount of energy spectra (turbulence augmentation) due to the presence of heavy particles is greatest at τ_k^{-1} when $St \approx 1.0$. Furthermore, the slip velocities between fluid turbulence and heavy particles can stimulate the laden turbulent flow to become more intermittent in the dissipation range. A simple energy balance model for turbulence modification is given to explain these results and area for further study identified.