Solid Particle Interaction Dynamics at Critical Stokes Number in Isotropic Turbulence

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ABSTRACT

Particle-laden turbulent flows occur commonly in both natural and industrial environments. Prediction of tidal currents, lung airways and liquid-fuelled combustion are just a few examples where understanding of the particulate phase dynamics is of interest. The present work is of significance to the nuclear industry, where the formation and build-up of corrosion and wear products on reactor fuel-pins represents a performance and safety issue, and where particle agglomeration can hinder efforts to efficiently process nuclear waste. Elucidation of the dynamics of particle-particle collisions and subsequent agglomeration would be invaluable in understanding the formation and characteristics of the depositing particulate structures in both cases.

Two spherical particle-particle interaction is studied in forced isotropic turbulence in a periodic box at Reynolds numbers, based on the Taylor microscale, Re_λ = 29 and 197 using direct numerical simulation and the immersed boundary method. The Reynolds numbers chosen represent average values found in the bulk and viscous regions of shear Reynolds number $Re_\tau = 180$ and $Re_\tau = 590$ channel flows. Inter-particle interaction is described using DLVO theory, based on the balance between electrostatic repulsion and van der Waals attraction forces, enabling the study of particle interaction statistics. Critical Stokes number, i.e. Kolmogorov Stokes number, $St_K = 1$ particles are considered given the importance of such particles in two-way coupling between the particles and the fluid flow, with a cross-over between dissipative and productive coupling observed for particles of this size [1]. Isotropic turbulence was generated in periodic boxes of size $-\pi$ to π based on the work of Lundgren [2] and Rosales and Meneveau [3]. The forcing required to generate isotropic turbulence in the boxes was linearly proportional to the velocity field, with the proportionality constant given by $A = \epsilon/3u_{rms}^2$, where ϵ is the turbulence energy dissipation rate and u_{rms} is the root-mean-square of the velocity field fluctuations, with periodic initial conditions taken as $u = \cos(y) + \sin(z)$, $v = \sin(x) + \cos(z)$ and $w = \cos(x) + \sin(y)$, where u, v and w are the velocities in the x, y and z directions. Spherical particles were represented using the immersed boundary method as polyhedra with 320 triangular faces. The parameters associated with DLVO theory were chosen to be representative of calcite, a simulant frequently considered in relation to nuclear waste management operations.

Results of the simulations are used to consider particle interactions, including particle agglomeration. For each particle pair considered, statistics were gathered over 40 instances of one typical interaction set-up, with random injection locations within the isotropic turbulence. These were run for a sufficient number of time units to give enough time for the system to exhibit different interaction dynamics, i.e. either particle near-misses, particle collision and bouncing, and particle agglomeration. Information (probability density functions) on the relative distance and relative velocity between the particles, and their angular momentum, is used to study the particle dynamics, and the likelihood of particle agglomeration. Overall, the results indicate that particles in regions of high turbulence are less likely to agglomerate since their motion is dominated by the viscous and pressure forces on the particles, whereas at lower levels of turbulence, forces transverse to streamwise motion allow pairs of particles travelling together to undergo agglomeration. Additionally, the results for the critical Stokes number particles will be compared with similar predictions for particles with different Stokes numbers.

REFERENCE

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