Particle Concentration and Stokes Number Effects in Multi-Phase Turbulent Channel Flows

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ABSTRACT

The transport of solid particles by turbulent fluid flows is common in many natural and industrial processes. A detailed understanding of the dynamics of such systems is important in determining the long-term properties of the flow, and in particular the dispersion, deposition and resuspension of particles. A knowledge of these mechanisms is vital to improving and optimising flow systems containing particulate suspensions. Previous work investigating these kinds of flows has demonstrated Stokes number-dependent particle behaviour in the near-wall region [1-3]. However, understanding of the physics of this behaviour is poor.

This work investigates the effect that particle concentration has on the dynamics of two-phase channel flows at low and high density ratios, paying close attention to particle motion in the near-wall region. The fluid phase is modelled using the direct numerical simulation code, Nek5000, at a shear Reynolds number of 180. A two-way coupled Lagrangian point-particle tracking method is used to predict the dispersed solid phase. A non-dimensional particle equation of motion is introduced using solely solid phase properties non-dimensionalised against bulk fluid length and timescales. This includes the effects of drag, lift, pressure gradient and added mass forces. A feedback force is included in the Navier-Stokes equations based on the sum of particle forces in a grid-cell to account for two-way coupling. The near-wall particle concentration is monitored to determine whether the dispersed-phase statistics have settled.

Two density ratios are studied, $\rho_P^* = 2041$ and $\rho_P^* = 2.5$, corresponding to flows in air and water, respectively. For each of these cases a high and low concentration regime is studied with volume fractions $\Theta_P = 10^{-3}$ and $\Theta_P = 10^{-4}$. Mean fluid velocities and turbulence intensity statistics are obtained and compared for each system. It is observed that for the solid-air suspension, the particles' turbulence intensities deviate greatly from that of the fluid phase, whereas for identical particles in water, the velocity fluctuations are similar of the fluid. Wall-normal particle concentration profiles are also compared and an explanation as to the extent of turbophoresis in each system is offered by considering time-averaged contributions from each force. For the high concentration regimes, the effect which two-way coupling the system has on the fluid turbulence intensities is also discussed.

Ongoing work to be included in the final paper will include an analysis of the particle-wall interaction process which will classify collision events based on deposition velocities using the free-flight model [4]. Contributions to near-wall statistics from each particle classification will then be investigated in order to elucidate the dynamics in that region.

REFERENCES

[1] Y. Li, J. B. McLaughlin, K. Kontomaris and L. Portela, "Numerical simulation of particle-laden turbulent channel flow." *Physics of Fluids*, **13**(10), 2957-2967, (2001).

[2] D. W. Rouson, J. K. Eaton, "On the preferential concentration of solid particles in turbulent channel flow." *Journal of Fluid Mechanics*, **428**, 149-169, (2001).

[3] F. Zhao, W. K. George and B. G. M. Van Wachem, "Four-way coupled simulations of small particles in turbulent channel flow: The effects of particle shape and Stokes number." *Physics of Fluids*, **27**(8), (2015).

[4] J. Young and A. Leeming. "A theory of particle deposition in turbulent pipe flow." *Journal of Fluid Mechanics*, **340,** 129-159, (1997).