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A stochastic description of wall sources in a turbulent field. Part 3: Effect of gravitational settling on the concentration profiles

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Abstract

A stochastic method, which uses a modified Langevin equation to represent the fluid turbulence seen by the particles, is used to determine the fully-developed concentration profiles that exist for the turbulent flow of a dilute suspension of spheres in a horizontal channel. Particles with a wide range of inertial time constants and settling velocities are studied. The validity of using the Boussinesq approximation to represent turbulent mixing is explored.

Keywords: Disperse flow; Concentration profiles; Particle deposition; Turbulent mixing; Stochastic analysis; Langevin equation

1. Introduction

In horizontal flows of a suspension, gravity can greatly increase the rate of deposition over what would be observed in a vertical system (Mito and Hanratty, 2004a). This paper presents the results

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of computer experiments which examine this phenomenon by determining concentration profiles. We show that distortions of the profiles are accompanied by increases in the deposition rate, but that large increases can also be experienced without changes in the symmetry of the concentration profile.

The work is motivated by our interest in gas–liquid flows, so the analysis is restricted to systems with large ratios of the densities of the particles to the densities of the fluid and for which particle interactions are not considered. An idealized representation of the disperse flow that exists in the core of an annular pattern is considered. Gas and spherical solid particles flow in a horizontal channel. Particles injected at the bottom and top walls eventually deposit. By adjusting the relative rates of admission of particles at the two walls, a fully-developed condition can be realized for which the net flux of particles in a direction perpendicular to the wall is zero at all locations in the channel. The two walls are considered to consist of arrays of point sources, so the theoretical problem is to calculate the behavior of a wall source.

The Lagrangian analysis of the trajectories of particles in a turbulent field has been advanced by carrying out studies in a direct numerical simulation of the carrier fluid. This type calculation is not feasible if one wants to study a large range of variables and large Reynolds numbers. The approach taken in this paper is to represent the fluid turbulence seen by the particles with a Langevin equation.

Concentration profiles of dispersed particles in horizontal pipes and channels have been studied with a Lagrangian approach by several investigators for cases in which deposition was not occurring. Sommerfeld and Zivkovic (1992) and Lun and Liu (1997) used $k-\varepsilon$ models to represent the mean fluid velocity field. Fluctuations seen by particles were sampled from an uncorrelated Gaussian distribution for randomly chosen eddy lifetimes (or interaction times), which results in an exponentially decaying autocorrelation function for the velocity fluctuations. (A discussion of eddy interaction models has been given by Graham (1996)). Oesterle and Petitjean (1993) used uncorrelated Gaussian random variables and experimental measurements to take account of the influence of fluid turbulence. Sommerfeld (2003) used a Langevin equation (Sommerfeld et al., 1993) to represent the fluid velocity fluctuations seen by particles. Zhang and Ahmadi (2000) carried out studies of deposition in a DNS of channel flow.

The chief contribution of the present paper is that it presents results over a very wide range of experimental conditions. The numerical approach is similar to what was used by Sommerfeld (2003) in that a Langevin equation is used. Despite the importance of the problem very few experimental investigations of concentration profiles in horizontal annular flow have been made. These include studies by Williams et al. (1996), Paras and Karaberas (1991) and some early works that are summarized by McCoy and Hanratty (1977).

A review of previous studies in this laboratory in which the Langevin equation is used to calculate particle dispersion is in order: Mito and Hanratty (2002) explored the use of a modified Langevin equation to describe the turbulent dispersion of fluid particles from point sources located at different locations in a channel. Good agreement with experiments in a DNS at $Re_\tau = 150$ and $Re_\tau = 300$ was realized. This method was also employed to describe wall sources of thermal markers. Fully-developed temperature profiles were calculated by picturing heated or cooled walls as consisting of arrays of sources or sinks. Again, excellent agreement was obtained with Eulerian calculations done in a DNS (Mito and Hanratty, 2003a). Iliopoulos et al. (2003) showed that the dispersion of solid particles from a point source in turbulent channel flow