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CFD SIMULATION OF FLUID-PARTICLE AND PARTICLE-PARTICLE INTERACTION IN PACKED AND FLUIDISED BEDS

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ABSTRACT

Solid-liquid fluidized beds are used widely in industry for hydrometallurgical, catalytic cracking, ion exchange, adsorption, crystallisation, sedimentation, and particle classification. In each of these operations, size and density distribution of particles is present and influence bed expansion, particle segregation and overall motion of both liquid and particles. It is these properties that govern heat and mass transfer and reaction rates and determine bed volume and residence time requirements.

This study investigates experimentally and computationally a number of phenomena underlying the behaviour of fixed and fluidised beds. Both instantaneous and time-average velocity measurements have bee performed in a refractive index matched bed to obtain local energy dissipation rates. A commercially available CFD code (FLUENT) was used to simulate bed composition, liquid flow rate and end effects on fluid-particle drag, bed expansion, segregation and intermixing. Finally, direct numerical simulation was developed to resolve detailed flow structures around individual and interacting particles. Each of these aspects of the research is more full described below:

EXPERIMENTAL MEASUREMENTS

PIV experiments were performed using an index-matched (RI=1.47) borosilicate glass turpentine/ tetrahydronaphthalene solution fluidised bed in the creeping, transition and turbulent regimes ($0.3<Re<720$). Radial and axial average and instantaneous velocities were measured over the entire range of Reynolds number and from this information both axial and radial turbulent intensities and stress components were determined. The flat radial profiles of the average velocity and turbulent intensities highlighted the homogenous nature of the solid-liquid fluidized bed.

FLUENT CFD SIMULATION

FLUENT 6.2 was used to simulate mono-sized packed and fluidised beds having high (>20) D/d_p ratio and in the creeping, transition and the turbulent flow regimes. Using the drag law of Joshi (1983) and Pandit and Joshi (1998), the computed index (n) was in excellent agreement with the published values of Richardson and Zaki (1954).

Simulations were also carried out at low D/d_p ratios (3, 5, and 10) to explore the influence of wall effects on the fluid-particle drag across fixed beds. Computationally, the particles were fixed artificially in a regular configuration but not in mutual contact. As expected, it was found that wall influence on the fluid-particle drag coefficient was reduced with increasing D/d_p ratio, such that at $D/d_p=10$ the deviation from the Ergun equation was only 13.2 percent. The effect of particle concentration on the drag coefficient for both fixed and expanded beds was also investigated. It was found that the drag coefficient, increased with increasing particle concentration. For instance, at a Re of 1000 the drag coefficient increased by 2.5 and 8 times as the particle concentration went from 0.217 to 0.365, to 0.577, respectively. For the fluidised beds, the simulations were able to capture the channelling effects through high voidage regions near the wall.

The FLUENT analysis was extended to binary particle size systems to explore the behaviour of segregation and intermixing. Binary mixtures with ratio of terminal settling velocity range 1.2-3.2 and Reynolds number from 0.33 to 2080 were investigated. The computational model was in good agreement with experimental observations and predicted the layer inversion phenomena due to different size and density as well as the critical velocity at which the complete mixing of the two particle species occurred.

DIRECT NUMERICAL SIMULATION (DNS)

A DNS code was developed to model the fluid flow around a freely falling sphere. Briefly, the code is a non-Lagrange multiplier based fictitious-domain method as described by Veeramani et al. (2007). Simulations were performed in the range $1<Re<210$, with excellent agreement with published experimental values for the separation angle (θ) and the normalized wake length (L/d_P). For $Re<200$, it was found the wake generated by the freely falling sphere was identical to that of a fixed sphere. At $Re=210$, a double threaded wake was observed, resembling the experimental observations of Magarvey and MacLatchy (1961). Computationally, the instability in the wake gave rise to a lift force resulting in the rotation and lateral migration of the sphere. Under these conditions the lift coefficient for the freely falling sphere was 1.8 times greater than that for the fixed sphere.

The DNS modelling was extended to multi-particle (9, 27, 100, 180 and 245) systems to examine the influence of hindrance on the wake dynamics, settling velocity and drag coefficient of individual spherical particles. A moving reference frame was used at the center of mass of each sphere along the flow direction so that the finely resolved grid region was retained for each instant in time. It was found that the time averaged settling velocity of an individual particle decreased with an increase in the number of particles surrounding it, and resulted in a decrease in the swarm velocity. For the simulation involving 245 particles the predicted bed voidage was in good agreement with the Richardson and Zaki (1954) correlation.

Finally, the drag coefficient and suspension viscosity computed for the DNS simulations have been compared with published experimental results (e.g. de Kruif et al., 1985; Gibilaro et al., 2007) and models (e.g. Einstein,1906; Frankel and Acrivos; 1967). At low solids concentration, the suspension viscosity models were similar and in good agreement with the DNS simulations. At solids concentrations above about 10 percent there was wide variation between the models, with the DNS simulations matching closely the work of Frankel and Acrivos (1967). The DNS modelling has shown that suspension behaviour can be correctly predicted without introducing the notion of suspension viscosity once the force interactions between particles has been properly resolved.

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