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Impact of solid sizes on flow structure and particle motions in bubbling fluidization

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ABSTRACT

Knowledge of solid motions and flow structures in fluidized beds is of significant importance to a number of industrial processes, such as combustion, gasification of solid fuels, drying of particulate materials, oxidation or reduction of ores, and catalytic and thermal cracking. Many parameters, such as pressure drop, bed geometry, solid size and density, can affect the solid flow structure in a fluidized bed. In this study, experiments were designed to investigate the impact of solid size. Through PEPT studies, we found that the solid flow structure and the bubble pattern in a fluidized bed with an inner diameter of 150 mm vary significantly with solid particle size. Three flow structures have been found. For glass beads with a large size (>700 μm), a single large circulation cell is observed within the whole bed, and particles move upwards at one side of the bed to the splash zone, and then return to the bed bottom along the opposite side of the bed. When the particle size is in the range 250–450 μm, particles move upwards across the whole area of the bed at relatively uniform velocity in a layer 30 mm deep immediately above the air distributor. Above this layer, solids move inwards and travel upwards in the centre of the bed to the splash zone, and then return to the bottom of the bed in an outer annulus. When the particle size is in the range 80–200 μm, the fluidized bed can be divided into three sections. In the bottom section, solids travel upwards in the outer annulus, and move down in the bed centre. In the top section, solids travel upwards at the centre of the bed to the splash zone and then return to the intermediate height of the bed via the outer annulus. In the intermediate section of the bed (60–100 mm above the distributor), the annular upward solid flow from the bottom section encounters the annular downward flow from the top section. The two solid flows merge and change direction towards the bed centre where the particles are mixed and redistributed to the circulation cells in the upper and lower sections. The bubbling pattern also varies with the particle size. The bubble size and their rising velocity decrease with decreasing of the particle size.

1. Introduction

Bubbling fluidized beds are widely used in a number of industrial processes as an effective mean for providing good mixing and contact of the gas and solid phases, as well as good heat transfer. Applications include coal combustion, chemical, petrochemical and metallurgical processes [1–3]. This attractive feature is achieved by solid circulation within the bed, in which particles are driven by the voids, or bubbles, and transported around the bed. A different circulation pattern will give different heat/mass transfer rate and different mixing efficiency [4,5]. Numerous factors within a fluidization system can significantly affect the microscopic and macroscopic flow behaviour, such as interactions between suspended and packed particles, suspended particles and column wall, gas and particles, and gas and column wall [6–9]. The relative importance of these interactions further depends on the operating conditions, ratios of particle sizes to the column diameter, configuration of the flow system, solid properties, etc.; therefore making fundamental theoretical analysis of the hydrodynamics difficult and in some cases almost impossible [10,11]. For example, to predict solid motions and flow structures using discrete element models, the collision and friction between particles are dominated by many factors, such as: density, elasticity, surface roughness and shape of solids, static electricity, moisture, as well as the local solid concentration. Even though significant progress has been made, many uncertainties still remain, i.e. how does each of the above factors affect the solid and gas motion? How to evaluate the predicted flow patterns based on an empirical approach [12–14]?

Several experimental methods have been used to explore the mechanisms underlying the flow patterns based on optical measurements, such as particle image velocimetry [15–18], fiber probes [19], and laser doppler anemometry (LDA) [20,21]. However, the concentration of solids even in the freeboard of a bubbling fluidized bed is so high that the information obtained from these techniques can be only used to understand the hydrodynamics in the region adjacent to the

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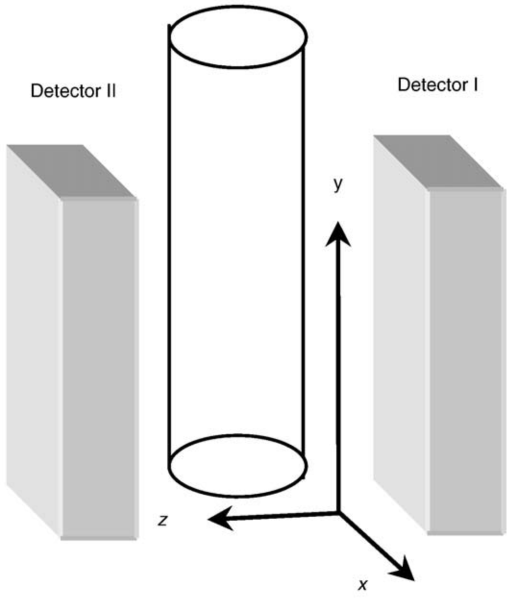

Fig. 1. Schematic diagram of the experimental setup and the spatial coordinates of plots.

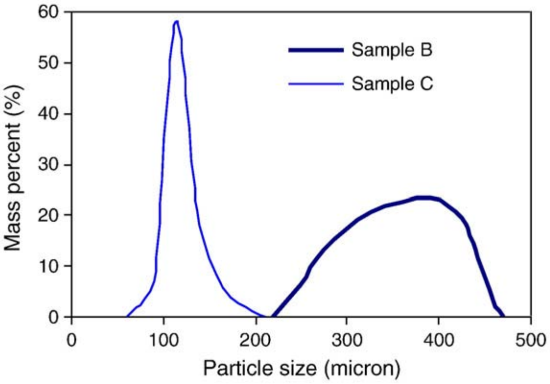

Fig. 2. Size distributions of glass beads.

wall, but the gas–solid flow inside the bed cannot be characterized [22]. If intrusive probes are used to observe the interior of the fluidized bed, the probes may alter the flow structure [23–26].

The objectives of this work were to directly measure solid motion and flow structure within glass bead fluidized beds using the non-intrusive positron emission particle tracking (PEPT) technique for investigating the impact of particle sizes on the solid/gas motion and flow structure. The information obtained can be used to illustrate the difference in the mechanism of mass and heat transfer, chemical reactions, mixing and segregation within a fluidized bed with different materials.

2. Experimental technique and materials

The experimental setup consisted of a positron emission particle tracking system and a gas–solid fluidized bed as shown in Fig. 1. The gas–solid fluidized bed was a Plexiglas cylindrical column of 152 mm I.D. and 1000 mm height. The bed was placed vertically between the two γ-ray detectors of the Birmingham positron camera which cover a

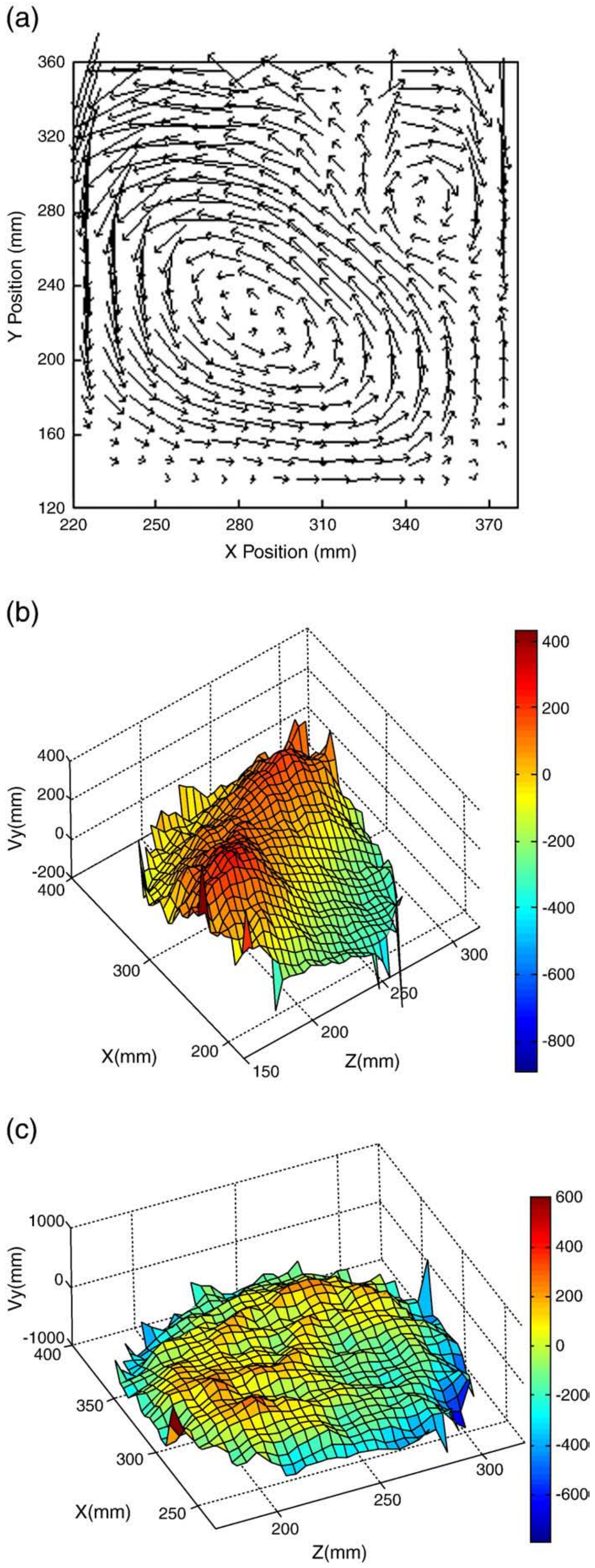

Fig. 3. Flow patterns of glass beads with a size of 800–1000 μm. ($U-U_{mf}=0.40$). (a) Time-averaged particle velocity vector map. (b) Glass bead velocity V_y within a 10 mm layer at a height of 30 mm above the air distributor. (c) Glass bead velocity V_y within a 10 mm layer at a height of 190 mm above the air distributor.