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Effects of particle properties on entrainment and electrostatics in gas–solid fluidized beds

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ABSTRACT

The effects of particle properties on particle entrainment and electrostatic charges in fluidized beds of binary mixtures of fines (glass beads, polyethylene or alumina) with coarse particles (glass beads or polyethylene) were investigated in a column of 150 mm inner diameter and 2 m height. The degree of electrification in the bed was measured by collision ball probes of 5.3 mm O.D. at three levels, directly connected to electrometers. The charge density of entrained particles in the freeboard was measured by a freeboard sampler acting as a Faraday cup. The magnitude of electrostatic charges inside the fluidized bed increased slightly, whereas the entrainment flux decreased, as the size of the coarse particles decreased at constant superficial gas velocity. The electrostatic charges increased and entrainment flux decreased as the coarse particle density increased. The charge magnitude inside the fluidized bed increased and the entrainment flux decreased as the fine particle density increased. The electrostatic charges and entrainment flux also increased as the fines concentration increased. The fines concentration had little or no effect on fines charge densities. Bipolar charging was observed in all experiments, with fine particles charged positively and large ones negatively.

1. Introduction

Particle entrainment is a major disadvantage of gas–solid fluidized bed reactors. High gas velocities result in fine particles becoming entrained. Pollution control regulations and cost considerations require recovery of entrained particles [5]. Proper design of solid recovery equipment, such as cyclones, requires accurate predictions of both solid flux and the size distribution of entrained solids.

Electrostatic phenomena in gas–solid fluidization have been reported for many years (e.g. [13, 19, 24]) and need to be better understood. Guardiola et al. [8] investigated the effect of particle size on bed electrification and found that as the particle size increases, electrification increased. On the other hand, Mehrani et al. [17, 18] conducted experiments in a Faraday cup fluidized bed with a binary mixture of large and fine glass beads. It was found that the fine particles carried higher charges per unit mass than the larger ones. Several researchers [2, 9, 16–18, 21, 32] have reported bipolar charging. Bipolar charging has been described as contact charging between solid particles of the same material, but different sizes. Ali et al. [2] found that for one type of particles, small particles charged negatively and large ones positively. Similar results were reported by Zhao et al. [32]. Mehrani et al. [16] performed experiments in a fluidized bed with binary mixtures of large and fine glass beads. They found that the entrained fines (30 μm mean diameter) were positively charged, whereas larger particles (566 μm mean diameter) were negatively charged. Mehrani et al. [17, 18] concluded that the charges carried by the fine particles were more likely due to charge separation. Moughrabiah et al. [21] measured the electrostatic charges on entrained fine glass beads using a collision ball probe mounted in the freeboard of a fluidized bed and found that the polarity in the freeboard was opposite to that of the dense bed of large glass beads.

Solid particles in fluidized bed industrial applications cover a very wide range of properties. Entrainment and elutriation rates are affected by these properties. It is well known that the terminal velocity for a single particle decreases as the particle diameter decreases. Therefore, greater entrainment from a fluidized bed is expected at a given gas velocity.

Kato and Ito [11] and Tasirin and Geldart [28] reported that elutriation increased as the particle size decreased in a gas–solid fluidized bed. Different results were reported by Baeyens et al. [4], Ma and Kato [14] and Nakazato et al. [23] who investigated the effect of adding fine particles on the elutriation rate. They concluded that the elutriation rate constant increased with decreasing particle size, but below a critical particle size the elutriation rate constant no longer increased. They attributed this to interparticle adhesion. Baeyens et al. [4] proposed a method for calculating the particle critical size at which adhesion forces become negligible compared with other forces. Choi et al. [6] investigated the effect of fine particles on the entrainment of coarse particles. They found that the rate of carryover of coarse particles increased with increasing proportion of fine particles in the bed. They also reported that the effect of fine particles on the elutriation rate of coarse

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particles decreased as the superficial gas velocity increased, whereas the bed particle size distribution had little effect on the elutriation of fine particles.

The effect of coarse particle density on entrainment from a gas–solid fluidized bed was evaluated by Nakazato et al. [23], who found that entrainment of fine and coarse particles decreased as the coarse particle density increased. Kato and Li [12] reported that the elutriation rate constant for Geldart group C particles in a fluidized bed of fine-coarse particle mixtures decreased with increasing mean diameter of the coarse particles in the bed for a constant superficial gas velocity. Briens et al. [5] measured the entrainment flux from a bed of polyethylene particles and found that the entrainment flux increased after neutralizing the bed charges, indicating that particle charges affected the entrainment flux.

The aim of this study is to investigate the influence of coarse and fine particle properties on both particle entrainment and electrostatic charges to gain a better understanding of the interactions between particle properties, electrostatic phenomena and particle entrainment in gas–solid fluidized beds.

2. Experimental equipment and particles

Freely bubbling fluidization experiments were performed in a three-dimensional column capable of withstanding pressure up to 1000 kPa, constructed of stainless steel, with inner diameter 0.15 m and height 2.0 m. The column is described in detail elsewhere [1]. A schematic diagram is shown in Fig. 1.

The degree of electrification in the bed was measured by three collision ball probes, identical to those employed by Moughrabiah et al. [21]. Ball probes are made of highly conductive materials and connected to electrometers to measure cumulative charges induced and transferred from surrounding media. While these probes are intrusive, they provide a simple means of monitoring the charges within fluidized beds. In our case, each probe consisted of a stainless steel ball, 5.3 mm in diameter, connected directly to an electrometer (Kistler model 5010B).

To determine the charge density of entrained particles in the freeboard region, a sampling device incorporating the Faraday cup principle was developed and deployed. This device was mounted in the freeboard at the center of the fluidization column and at a height of 3 m above the distributor plate. It consists of two copper inverted cones electrically insulated from each other. The freeboard sampler is described in detail elsewhere [1]. A schematic diagram appears in Fig. 2. For entrainment rate measurements, the entrained particles were diverted into a sampling vessel of 100 mm inner diameter and 254 mm height.

Tables 1 and 2 show the key properties of the coarse and fine particles tested in this study, while Table 3 gives the properties of the binary particle mixtures. The particles were chosen so that it was possible to investigate independently both the effect of fine particle properties for given coarse particles and the influence of the properties of the coarse particle for given fine particles.

3. Results and discussion

3.1. Effects of coarse particle size

To investigate the effect of coarse particle size on the entrainment and electrostatic behavior inside the fluidized bed, free-bubbling experiments were conducted in the three-dimensional elevated-pressure fluidization column, with GBL, GBM and GBS as the larger nearly mono-sized particles, and GBF as fines (binary mixtures M1, M2 and M3 in Table 3). Collision ball probes were located at three levels A, B, and C (0.15, 0.31 and 0.55 m above the distributor). The freeboard sampler was centered in the column with its bottom 3 m above the distributor. The static bed height was ~0.54 m in all cases. The relative humidity of the fluidizing air was maintained at 12 ± 2%. The temperature, pressure and superficial air velocity were maintained nearly constant at 20 ± 2 °C, 414 kPa and $U_g = 0.3$ m/s, respectively, to isolate the influence of coarse particle properties. In each experiment, the bed

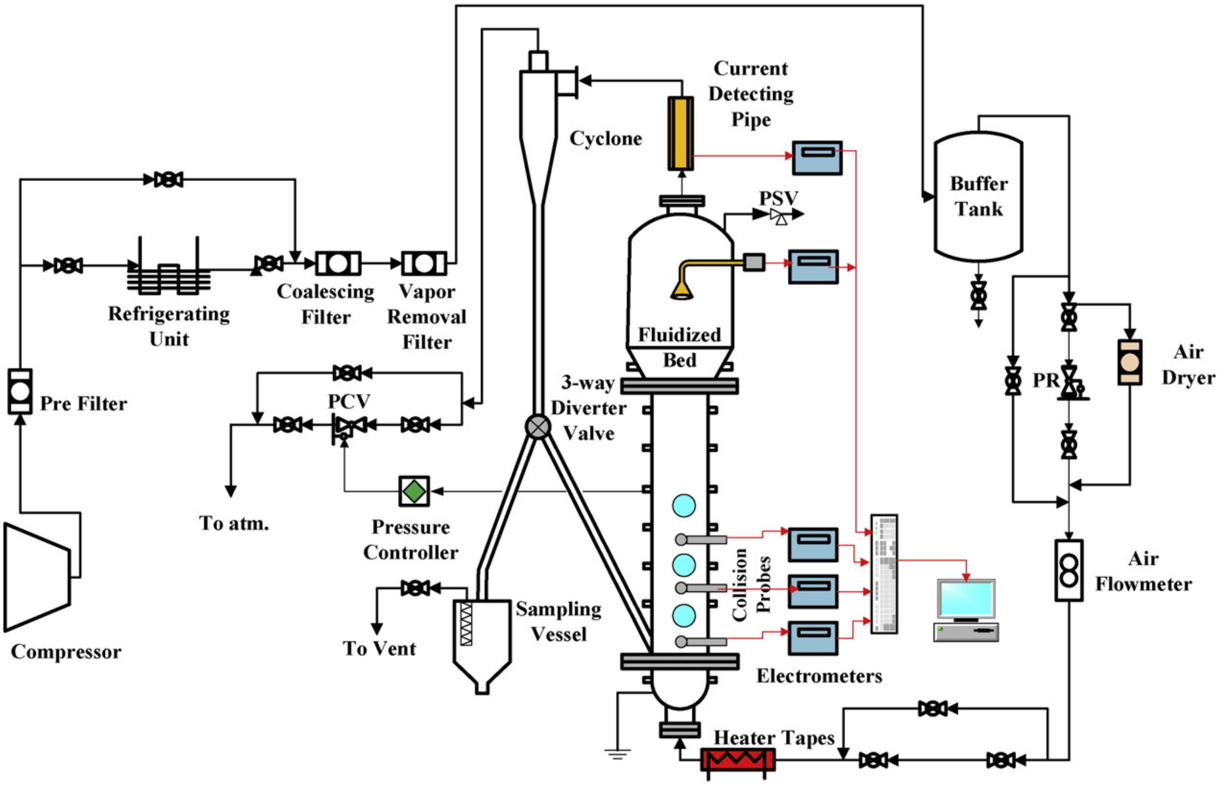

Fig. 1. Schematic of overall layout of fluidization unit. PR: pressure regulator, PCV: pressure control valve.