Chemical Engineering Science 123 (2015) 49–56

Contents lists available at ScienceDirect

Chemical Engineering Science

journal homepage: www.elsevier.com/locate/ces

Effects of superficial gas velocity and temperature on entrainment and electrostatics in gas–solid fluidized beds

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HIGHLIGHTS

- Freely-bubbling experiments were performed in a three-dimensional fluidized bed.
- The effect of superficial gas velocity and bed temperature on entrainment and electrostatics is examined.
- Increasing superficial gas velocity will increase electrostatic charges in dense and freeboard regions of the fluidized bed.
- Increasing superficial gas velocity will increase particle entrainment.
- Increasing bed temperature will decrease electrostatic charges and temperature had negligible effect on the entrainment.

ARTICLE INFO

Article history:
Received 10 May 2014
Received in revised form
9 September 2014
Accepted 2 October 2014
Available online 28 October 2014

Keywords:
Fluidization
Electrostatics
Entrainment
Collision probe
Particle

ABSTRACT

The effects of superficial gas velocity and temperature on particle entrainment and electrostatic charges in fluidized binary mixtures of glass beads were investigated in a column of 150 mm inner diameter and 2 m height. The degree of electrification in the bed was measured by four collision ball probes at different levels. The charge density of entrained particles in the freeboard was determined by a freeboard sampler constructed as a Faraday cup. An instrumented pipe coated with Ni in the reactor exit line measured the electrical current transferred from entrained fine particles by collisions. The particle entrainment flux and electrostatic charge inside the bed and freeboard region increased with increasing superficial gas velocity. Temperature had negligible effect on the entrainment flux over the limited range studied. However, electrostatic charges decreased and the charge polarity reversed as the bed temperature increased from 20 to 75 °C.

1. Introduction

Particle entrainment is a major disadvantage of gas–solid fluidized bed reactors. The high gas velocities present in fluidized beds result in fine particles becoming entrained. Pollution control regulations and cost considerations (e.g. for catalytic reactors) require recovery of entrained particles (Briens et al., 1992). Proper design of solids recovery equipment, such as cyclones, requires accurate predictions of both solid flux and the size distribution of entrained solids.

Entrainment phenomena are still not well understood since many parameters affect the entrainment rate. Numerous empirical correlations have been proposed for predicting the flux of entrained solids. However, predictions derived from these correlations differ by many orders of magnitude (Chew et al., 2014), even when the particles, column and operating conditions are within the normal range of fluidized bed operations. Theoretical approaches based purely on hydrodynamic principles have also tended to fail badly. One possibility is that the complete failure of these approaches to consider electrostatic forces is responsible, in part or to a large extent, for the wide range of results and the huge discrepancies in predicting entrainment.

The very nature of gas–solid fluidization processes produces continuous rubbing and frequent contacts among bed particles causing generation of electrostatic charges. These charges can interfere with normal hydrodynamics of the bed resulting in particle-wall adhesion, inter-particle cohesion, electrostatic discharges, and even explosions, all of which can affect plant safety and economics (Cross, 1987). Electrostatic phenomena in gas–solid fluidization have been reported for many years (e.g. Lewis et al., 1949; Miller and Logwinuk, 1951; Osberg and Charlesworth, 1951) and need to be better understood.

High superficial gas velocities in fluidized bed reactors result in carry-over of particles. If the superficial gas velocity is increased, bed expansion increases and larger bubbles rise more quickly, resulting in larger ejection velocities of bubbles erupting at the

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http://dx.doi.org/10.1016/j.ces.2014.10.003
0009-2509/

bed surface. In addition, upwards drag on the particles in the freeboard is increased, resulting in increased carry-over of solid particles from the fluidized bed (Kato and Ito, 1972). Many researchers (e.g. Baron et al., 1990; Nakagawa et al., 1994; Ma and Kato, 1998; Choi et al., 2001) have reported that the entrainment rate increased strongly as superficial gas velocity increased, typically with entrainment proportional to U_g to the power of 3 to 4.

Several researchers (e.g. Ciborowski and Wlodarski, 1962; Tardos and Pfeffer, 1980; Fujino et al., 1985; Guardiola et al., 1996; Yao et al., 2002; Chen et al., 2003; Revel et al., 2003; Giffin and Mehrani, 2010, 2013) have also reported increases in electrostatic charge generation due to increases in fluidizing gas velocity. They explained the increase in electrostatic charge generation as being due to increases in bubble size and rise velocity. All of these studies were conducted at atmospheric pressure. Moughrabiah et al. (2009) studied the influence of superficial gas velocity on electrostatic charge generation in elevated-pressure bubbling fluidized beds of polyethylene particles and glass beads. They concluded that bed electrification increases as the superficial gas velocity increases. They explained their results by the formation of bigger bubbles and higher bubble rise velocities that enhanced particle motion in the bed.

The effect of temperature on entrainment and electrostatics is not well understood. George and Grace (1981) studied the effect of temperature on solids entrainment fluxes in a pilot scale fluidized bed over a 300 to 445 K temperature range. They found that temperature had little effect on entrainment over this limited range. Choi et al. (1989) reported that the particle entrainment rate decreased with increasing temperature from 303 to 318 K. Other researchers (Merrick and Highley, 1974; Lee et al., 1990, 1992; Park et al., 1991) obtained similar results in fluidized bed combustors over a 293 to 1273 K temperature range. On the other hand, Romanova (1980)and Milne et al. (1993) reported that particle entrainment increased as temperature increased. Knowlton et al. (1990) investigated the effect of temperature on entrainment in a pressurized fluidized bed over a 295 to 1144 K temperature range. They found that the entrainment rate increased with both increasing gas viscosity and increasing gas density. Choi et al. (1998) found that the entrainment rate increased after an initial decrease with increasing bed temperature (up to 873 K) and concluded that the influence of temperature on entrainment rate decreased as the particle density or gas velocity increased. Some researchers (Mii et al., 1973; Yoshida et al., 1974) studied the effect of temperature (773 to 1273 K) on fluidization behaviour. They concluded that both the frequency of bubble formation and the quality of fluidization increased as temperature increased. On the other hand, Newton et al. (2001) investigated the effect of temperature on bubble behaviour in a gas–solid fluidized bed over a 295 to 358 K temperature range, finding that the bubble frequency decreased and bubbles became larger as temperature increased. Moughrabiah et al. (2009) studied the influence of temperature (up to 363 K) on the degree of electrification inside a gas–solid fluidized bed with glass beads and low-density polyethylene particles. As the bed temperature increased, the degree of bed electrification decreased. These results were attributed to smaller and slower bubbles as temperature increased.

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

2. Experimental equipment and particles

Freely bubbling fluidization experiments were performed in a modified three-dimensional elevated-pressure (up to 1000 kPa) column, constructed of stainless steel, with inner diameter 0.15 m and height 2.0 m. The column is described in detail elsewhere (Alsmari, 2014). A schematic diagram is shown in Fig. 1.

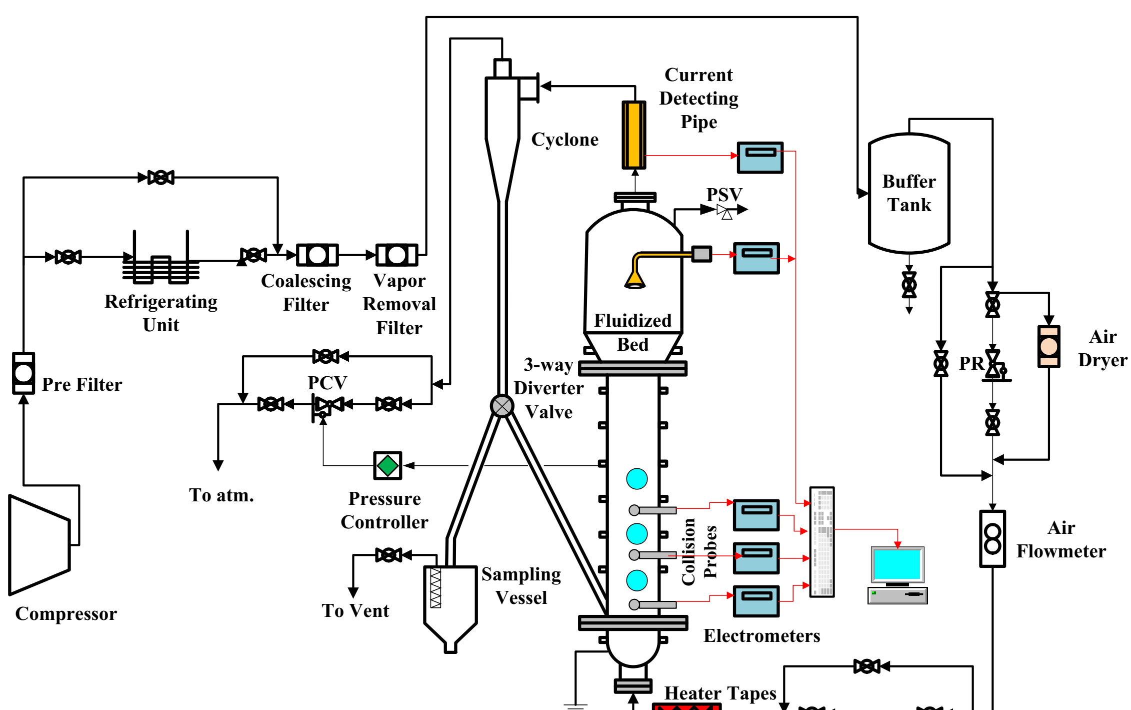

Fig. 1. Schematic of overall layout of fluidization unit. PR: pressure regulator, PVC: pressure control valve.