Chemical Engineering Science 66 (2011) 5064–5076

Contents lists available at ScienceDirect

Chemical Engineering Science

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

Effects of particle properties on flow structure in a 2-D circulating fluidized bed: Solids concentration distribution and flow development

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A R T I C L E I N F O

Article history:
Received 14 January 2011
Received in revised form
17 June 2011
Accepted 28 June 2011
Available online 23 July 2011

Keywords:
Fluidization
Hydrodynamics
2-D CFB
Solids concentration
Particle properties
Optical fiber probe

A B S T R A C T

The effects of particle properties (particle density, size and sphericity) on solids concentration in a 2-D riser were comprehensively investigated by measuring the axial and lateral solids concentration with an optical fiber probe. In this study, solids concentration of different types of particles shows that heavier particles have higher solids concentration laterally and axially than lighter particles; larger particles result in more compact solids distribution and such size effect is more evident at the riser bottom; more spherical particles lead to higher solids concentration. Various forces acting on particles and the change in the slip velocity between gas and particles were used to explain the effects of particle properties on solids distribution.

1. Introduction

Circulating fluidized bed (CFB) reactors have been used for a wide range of industrial applications over the past 50 years. Hydrodynamics of gas–solid two-phase flow in CFB systems often affect the mass transfer, heat transfer, gas and solids mixing as well as the chemical reaction. The axial and radial solids distributions representing the flowing structure in a CFB reflect the characteristics of hydrodynamics. This has led to a significant number of scientific studies focusing on the solids distribution in risers of different sizes and shapes and under a variety of operating conditions. Previous studies have shown the profiles of axial and radial solids holdup/voidage (Bai et al., 1992; Arena et al., 1991; Dry, 1986; Li and Kwauk, 1980; Horio et al., 1988; Yan and Zhu, 2004), characteristics of gas and particle velocities (Horio et al., 1988; Yang et al., 1984; Zhang, 1990; Monceaux et al., 1986a; Parssinen and Zhu, 2001; Huang and Zhu, 2001), differential pressure profiles (Schlichthaerle and Werther, 1999; Bi and Grace, 1995), as well as gas–solids mixing (Mostoufi and Chaouki, 2001). It has been found that operating conditions (Bai et al., 1992), inlet and outlet structures (Xia and Tung, 1989; Jin et al., 1988), riser geometry (Yan and Zhu, 2004) and some other factors all impact on the axial and radial solids distributions.

However, very few studies have been carried out with regard to the effects of particle properties on the flow in a riser systematically and comprehensively, hindering the progress on the design and the operation of the industrial CFB reactors (Mastellone and Arena, 1999).The experiments conducted by Bai et al. (1992) showed axial voidage profiles of particles with different size and density by employing pressure gradient transducers. The results indicated that the difference in voidage distribution between different particle sizes becomes smaller with higher gas flow rate and lower solids circulation rate, and that heavier particles had a lower voidage in the bottom section and a higher voidage in the top of the riser. Mastellone and Arena (1999) applied pressure transducers to measure axial solids voidage profiles, and used an isokinetic sampling probe to measure radial profiles of upward and downward solids mass fluxes. They concluded that particle size had no significant effect on the axial solids distribution along the riser, but that radially, the coarser particles gave flat profiles without solids flowing downwards on the wall while smaller particles presented a relatively wider "annulus". Qi et al. (2008) investigated the axial and radial solids distributions of fluid catalytic cracking (FCC) catalyst particles and sand particles, and also compared the uniformity of the radial distributions in acceleration zone and developed section for the two types of particles. They indicated that the effects of particle diameter and density on the axial and radial distributions of solids concentration in the acceleration zone differ from those in the fully developed section. Although some researchers have studied the flow structure in CFB risers with different particles and gave some conclusions about the effect of particle properties on the flow behaviors. However, as reviewed above, no in-depth or comprehensive experiments have been systematically carried out. For example, there were no radial profiles of solids distribution presented by Bai et al. (1992), since the pressure gradient transducer was restricted to measuring the

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0009-2509/$ - see front matter
doi:10.1016/j.ces.2011.06.057

cross-sectional average of solids holdup. So was the isokinetic sampling probe used by Mastellone and Arena (1999), which was able to measure local solids flux, but not the solids holdup or particle velocity. Qi et al. (2008) presented axial and radial solids distributions for both FCC catalyst particles and sand particles. In their study, tests were conducted in different risers with different types of distributors and the emphasis of the study was to determine the effect of a nozzle gas distributor.

This paper discusses work performed to investigate the effects of particle properties on the axial and lateral solids distribution in a CFB riser. This study was carried out in a two dimensional (2-D) CFB riser, which was a thin rectangular riser of a CFB unit. The effects of riser geometry on the solids distribution have been discussed and the results obtained from the 2-D CFB have also been compared with the solids concentration of 3-D CFB in author's earlier study (Xu and Zhu, 2010). In this study, FCC particles, sand and three types of glass beads were used. Measurement of solids distribution was conducted with an optical fiber probe, which has proved to be an effective tool for measuring the local solids concentration and particle velocity. The influence of particle properties on axial and lateral solids distribution is discussed in this study.

2. Experimental

All experiments were carried out in a rectangular circulating fluidized bed illustrated schematically in Fig. 1. The down comer is a 38×203 mm rectangular column with a 203 mm (8 in) i.d. cylindrical storage in the top. The riser is a rectangular column with a 7.6 m height and a $19\,mm\times114\,mm$ ($0.75\,in\times4.5\,in$) cross-section. With the definition that the width of the cross section is considerably greater than the depth, which is usually in the range of 10–25 mm (Grace and Baeyens, 1986), the rectangular riser can be considered as a two-dimensional column.

The primary air at ambient temperature and pressure was supplied to the riser bottom through a perforated distributor. To avoid any misleading effects due to electrostatic forces, a small

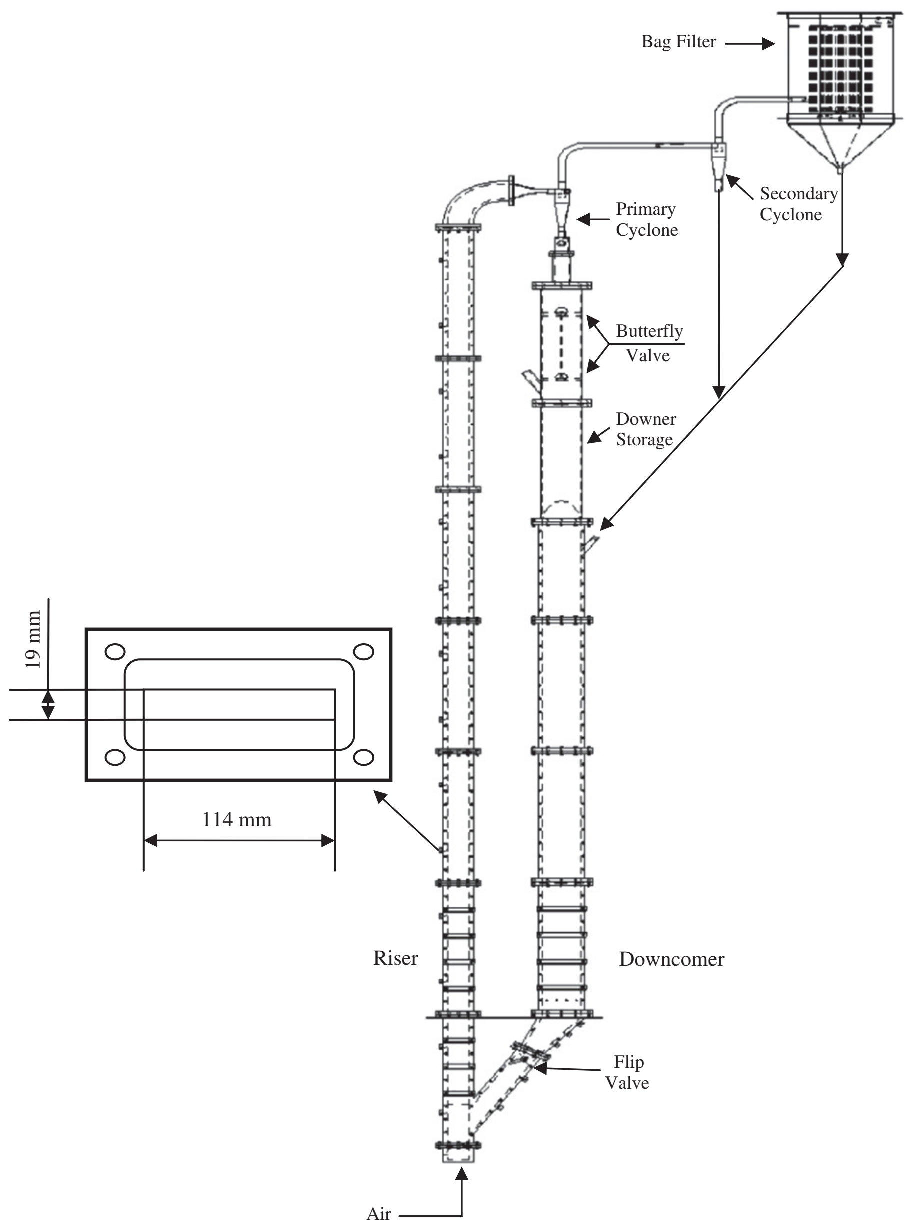

Fig. 1. 2-D circulating fluidized bed unit and schematic of riser cross section.