Chemical Engineering Science 114 (2014) 9–20

Contents lists available at ScienceDirect

Chemical Engineering Science

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

Detailed measurements of particle velocity and solids flux in a high density circulating fluidized bed riser

Chengxiu Wang [a,b], Jesse Zhu [a,b,*], Chunyi Li [a], Shahzad Barghi [b]

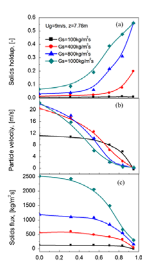
[a] State Key Laboratory of Heavy Oil Processing, China University of Petroleum, Qingdao 266555, China
[b] Department of Chemical & Biochemical Engineering, University of Western Ontario, London, ON, Canada N6A 5B9

HIGHLIGHTS

- Experiments under high solids circulation rates (G_s up to 1000 kg/m^2 s).
- Uniform axial profile of particle velocity (V_p) under extremely high G_s.
- Shapes of Radial profiles of V_p and local solids flux varying with G_s.
- Stronger correlations of V_p against solids holdup under low G_s.

GRAPHICAL ABSTRACT

Typical radial profiles of (a) solids holdup, (b) particle velocity, and (c) solids flux under various operating conditions.



ARTICLE INFO

Article history:
Received 28 January 2014
Received in revised form
30 March 2014
Accepted 4 April 2014
Available online 12 April 2014

Keywords:
Circulating fluidized bed
Riser
High flux
High density
Particle velocity
Solids flux

ABSTRACT

A comprehensive study of particle velocity and solids flux is conducted in a high density circulating fluidized bed with extremely high solids circulation rate up to 1000 kg/m^2 s, for the first time in the lab-scale settings. Results show that the axial distribution of particle velocity becomes more uniform in such extremely high solids flux conditions than cases with lower solids flux. Radial profiles of particle velocity and solids flux become increasingly steep with increasing solids circulation rate. No net downward flow near the wall is detected, which is considered an important advantage of the high density riser leading to reduced solids backmixing. Correlations of particle velocity against solids holdup are stronger for low density conditions than for high density cases, suggesting that gas–particle interaction dominates in low density risers, while particle–particle interaction plays a key role for the motion of particles in the extremely high density ones.

1. Introduction

Circulating fluidized bed (CFB) as a representative particle discharge system is utilized in chemical, metallurgical, as well as energy and environmental industries. It offers advantages with respect to effective mass and heat transfer, high solids/gas throughput, flexible gas–solids flow rate control and so forth (van Der Hoef and Van Sint Annaland, 2004; Zhu and Cheng, 2005). The performance of CFB systems deeply depends on the hydrodynamics. The major hydrodynamic features of gas–solids CFB risers have been described with axial dense/dilute transition solids flow and a core–annulus structure in radial direction (Li and Kwauk, 1980; Bai et al., 1992; Nieuwland and Meijer, 1996; Smolders and Baeyens, 2001; Li, 2010). This kind of heterogeneous flow structure and the dilute solids holdup (usually less than 0.10) hampers the CFB system's application to processes, which require high solids/gas ratio and high heat exchanges (Zhu and Bi, 1995; Grace et al., 1999; Du et al., 2003; Zhu and Zhu, 2008). The overall efficiency of a riser could be improved when a uniform distribution of the solids particles was achieved.

* Corresponding author at: State Key Laboratory of Heavy Oil Processing, China University of Petroleum, Qingdao 266555, China Tel.: +1 519 661 3807; fax: +1 519 850 2441.
E-mail address: jzhu@uwo.ca (J. Zhu).

http://dx.doi.org/10.1016/j.ces.2014.04.004
0009-2509/

Issangya et al. (1997, 1999, 2000) presented that axial homogenous flow with no downward flow near the wall could be achieved under high gas velocity and high solids circulation rate. Liu et al. (1999) thereafter pointed out that gas backmixing became lower using the same high density operating conditions. Zhu and Zhu (2008) proposed a novel circulating-turbulent fluidized bed (C-TFB) operated with low gas velocity and high solids flux, resulting in a high-density flow with solids holdup of up to 0.25 through the entire C-TFB with a nearly uniform axial solids flow and negligible downflow given rise to a good gas–solids contact.

Solids holdup, particle velocity and solids flux are three key parameters of hydrodynamics in gas–solids systems, determining the mass and energy distribution and reaction efficiency, which are the basis for modeling, optimization, and design of commercial-scale CFB systems. While there are a large number of papers reporting on the hydrodynamics, only a few of them are dealing with the high solids flux/density conditions, especially on particle velocities and/or solids flux (Wei et al., 1998; Pärssinen and Zhu, 2001; Qi et al., 2012a, 2012b). To the best of our knowledge, very few researches have been directed toward particle velocity and solids flux, especially to the latter one, over a high solids flux of 500 kg/m^2 s due to the limitations of experimental settings or measurement techniques. A better understanding of particle velocity and solids flux distribution has a vast impact on practical use of the high solids flux/density circulating fluidized beds, which is also highly important to enhance industrial reactor performance. To obtain more information on solids holdup, particle velocity and solids flux in a high density riser, a multipurpose optical fiber probe, which can take the measurements of those parameters simultaneously, is used in this research. A systematic research program in the CFB riser is conducted to determine axial and radial profiles of particle velocity and solids flux, as well as solids holdups. The nature of the axial and radial profiles with regards to the first two parameters is investigated in the current study, while the solids holdup is studied separately (Wang et al., 2014). Relationships between solids holdup and particle velocity are also evaluated to compare the difference between low density and high density CFB risers.

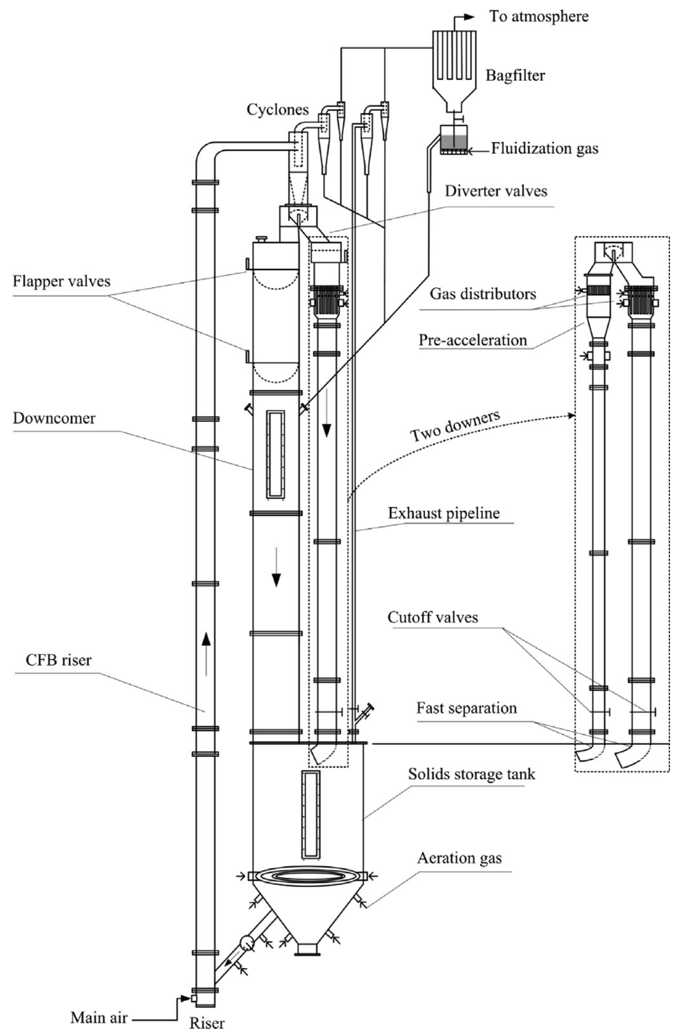


Fig. 1. Schematic diagram of the multifunctional CFB system.

2. Experimental details

2.1. CFB experimental setup

Experiments are performed in a multifunctional circulating fluidized bed system as shown in Fig. 1. It consists of three circulating fluidized beds, the left hand fluidized bed serves as a high flux/density circulating fluidized bed riser with 76 mm in diameter and 10 m in height. The right hand fluidized bed loops are two circulating fluidized beds downers (concurrent downflow circulating fluidized beds) of different diameters (76 mm i.d. and 5.8 m high and 50 mm i.d. and 4.9 m high, respectively). A downcomer with an inner diameter of 203 mm returns solids during riser operation and at its bottom there is a solids storage tank with an inner diameter of up to 457 mm which serves as a general solids storage for the entire system. Total solids inventory of FCC particles in the downcomer and storage tank could be up to 450 kg, equivalent to a solids height of up to 6.0 m given rise to high back pressure in the downcomer enabling high density operation in the CFB riser. In order to obtain higher solids flux and steadier operating conditions, other modifications had been carried out in the CFB systems (Wang et al., 2014).

The multifunctional circulating fluidized bed can be operated as a CFB riser and downer. For CFB riser operations, particles in the storage tank are carried upwards by the main air passing through the multihole distributor plate with 12% open area. At the top of the riser, particles and gas are separated by three series of cyclones (primary, secondary and tertiary cyclones) and most of the particles returns to the downcomer and further down to the storage tank and then transferred back into the riser. The remaining fine particles are trapped by the bag filter and are periodically delivered back to the downcomer.

The three CFBs are constructed using aluminum with small portions made of Plexiglas for visual observation. In order to minimize possible electrostatic charges generated during the experiments, the whole fluidized bed system is electrically grounded. The solids circulation rate can be adjusted by regulating the ball valve mounted in the solids feeding line and measured by a device with two flapper valves installed in the top section of the downcomer. Main air at the ambient temperature is supplied by a compressor capable of delivering 283 m^3/min at 690 kPa. Equilibrium FCC catalyst particles with 76 μm mean particle size and 1780 kg/m^3 particle density are used in this study. The particle size distribution is given in Table 1.

2.2. Measurements of solids holdup and particle velocity

Local solids holdup and particle velocity are measured simultaneously using a reflective-type optical fiber probe, which has been shown to be effective and accurate for measuring the local solid concentration and particle velocity in high velocity fluidized beds without significant disturbance of the overall flow structure