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Axial and radial development of solids holdup in a high flux/density gas–solids circulating fluidized bed

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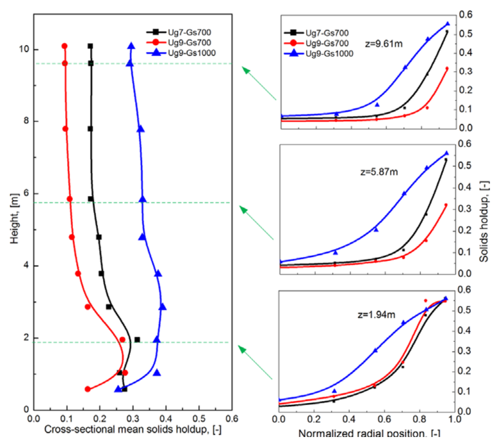
HIGHLIGHTS

- Experiments at high solids flux of 1000 kg/m^2 s.
- Homogenous axial profile of solids holdup with solids holdup up to 0.32.
- Different radial profiles of solids holdup under high density conditions compared to low solids flux conditions.
- Better gas–solids contacting under high density conditions in CFBs.

GRAPHICAL ABSTRACT

Characteristics of flow structure under extremely high flux/density in a CFB riser.



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ABSTRACT

Detailed distributions of solids holdup in an extremely high density circulating fluidized bed riser with FCC particles are mapped by an optical fiber probe. The solids circulation rate reaches as high as 1000 kg/m^2 s which has never been achieved before in an academic setting. When solids flux approaches 800 kg/m^2 s, the axial flow structure becomes uniform and the cross-sectional mean solids holdup reaches 0.22 throughout the entire riser; the same reaching 0.32 at 1000 kg/m^2 s. Compared to a typical core-annulus structure, the radial distributions of the solids holdup becomes much less uniform with a shrinking core and transits to a monotonic increasing profile towards the wall. Speed of flow development differs at various radial positions with almost instant development in the center even at the highest solids flux of 1000 kg/m^2 s and then becoming slower towards the wall. Fluctuations in high density circulating fluidized beds are significantly greater than those in low density ones, leading to more vigorous interactions between gas and solids phases. As a result, better gas–solids contacting and mixing, plus the uniform axial profiles of solids holdup, provide better reactor performance for the high solids flux/density risers than low flux/density ones.

1. Introduction

Circulating fluidized beds (CFBs) have been successfully used in industrial operations such as Fischer–Tropsch synthesis, partial

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oxidation, fluid-catalytic cracking (FCC), and combustion (Reh, 1999; Zhu and Cheng, 2005). While a CFB combustor as a gas–solid reactor operates under low gas velocity and solids flux using larger Group B particles (> 150 μm), the FCC is a gas phase catalytic process which requires significantly higher solids flux with higher gas velocity and employs smaller Group A particles. As one of the most successful and critical processes for conversion of high molecular-weight heavy oil stocks into lighter hydrocarbon products, the FCC process utilizes a riser reactor, where solids flux normally ranges from 400 kg/m^2 s to 1200 kg/m^2 s and gas velocity from 6 m/s to 28 m/s, increasing with the riser's height (Zhu and Bi, 1995). Good knowledge of flow structures in CFB systems is critical for reactor design, modeling and even for the industrial operation. Bi and Zhu (1993) had classified CFBs into high flux and/or high density ($G_s \geq 200$ kg/m^2 s, $\varepsilon_s \geq 0.1$) circulating fluidized beds (HFCFB/HDCFB) and low density circulating fluidized beds (LDCFB). Despite extensive researches dedicated to gas–solids fluidized bed over the past decades, very limited work has been conducted under solids circulation rates beyond 500 kg/m^2 s (Azzi et al., 1991; Martin et al., 1992; Contractor and In Avidan, 1994; and Knowlton, 1995).

Recently, studies under high solids flux (Issangya et al., 1999; Grace, 2000; Karri and Knowlton, 1999; Pärssinen and Zhu, 2001a, 2001b; and Yan and Zhu, 2004) had shown that the hydrodynamics are quite different in comparison with low flux and low density CFB risers operated with $G_s < 200$ kg/m^2 s. Issangya (1998) and Issangya et al. (1999) conducted tests in a 6 m high riser under high density conditions (U_g=4–8 m/s, G_s=200–425 kg/m^2 s) and reported that the mean solids holdup was up to 0.1–0.2 without axial variation and the particle downward flow was negligible. Later, Liu et al. (1999) studied gas dispersion in the same system used by Issangya et al. (1999) and found that gas backmixing became lower in the high density riser. More recently, Bi (2004) compared mixing behavior and illustrated that a clear transition of axial mixing appeared from LDCFB to HDCFB operating. In the study by Pärssinen and Zhu, (2001a), (2001b), a high solids flux of 550 kg/m^2 s was reached and both axial and radial solids holdup profiles became less uniform under higher solids flux. Issangya et al. (1999, 2000) also reported that radial solids holdup profiles became less uniform at higher G_s (> 300 kg/m^2 s) with lower solids holdup of less than 0.06 in the center region and 0.4–0.44 near the wall.

Understanding the fluid and particle dynamics is evidently of importance to successful modeling of CFB reactors. Flow dynamics also influences pressure drop across the riser, heat transfer (Grace, 1986a, 1986b) as well as erosion rate of surfaces (Zhu et al., 1989). Improved understanding of the flow structures in high flux/density circulating fluidized bed systems should enable better comprehension of the advantages and limitations of HDCFB

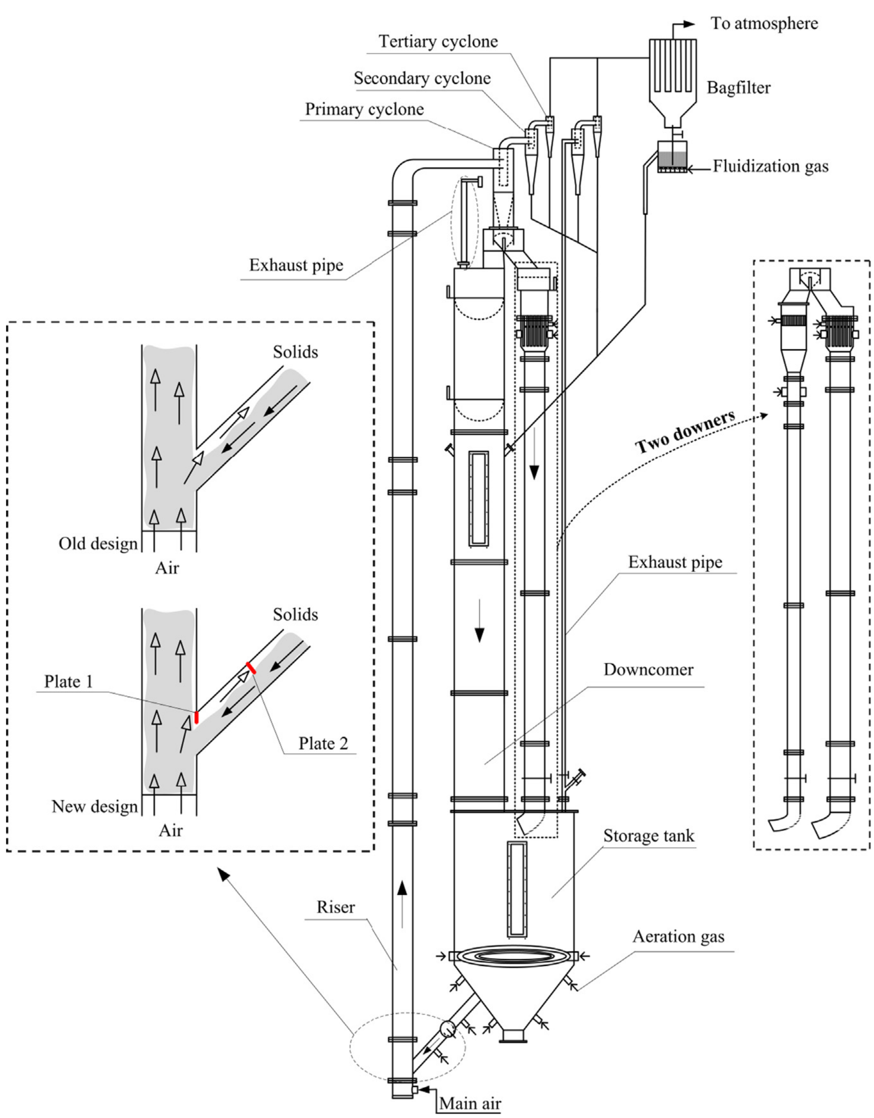

Fig. 1. Schematic diagram of the multifunctional CFB system.