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Axial solids flow structure in a high density gas–solids circulating fluidized bed downer

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ABSTRACT

Axial flow behaviors are investigated with an optical fiber probe using FCC particles at extremely high solids circulation rates up to 700 kg/m^{2}s and superficial gas velocity ranging from 3–7 m/s in a laboratory-scale downer system. Results show that axial distributions of particle velocity and solids holdup are significantly affected by the operating conditions. Superficial gas velocity is the predominance for particle velocity distribution while solids circulation rate plays a key role in solids holdup distribution. Development of solids flow can be accelerated by increasing superficial gas velocity and/or decreasing solids circulation rate. High solids holdup, higher than 0.06, can be achieved in the entire downer with relatively uniform axial profiles at solids circulation rate of 700 kg/m^{2}s indicating a preferential flow with reduced backmixing in the downer.

1. Introduction

Two phase gas–solids circulating fluidized bed (CFB) reactors have found very important applications in the field of chemical, petrochemical, environmental and energy industries [1,2]. CFB reactors can mainly be operated in two modes: concurrent upflow CFB (riser) wherein the gas and solids flow upward and concurrent downflow CFB (downer) which involves downflow of both gas and solids [2,3]. In riser reactors, particles flow upwards due to the lift caused by the ascending gas. As the gas velocity is lower near the wall than in the central region of the reactor [3], the particle will move more slowly near the wall than in the center, resulting in a slower moving area with a higher solids holdup near the wall and a low-resistance path for ascending gas in the center. Hence, the gas mainly flows through the center, whereas more particles are mainly located near the walls. The resulting flow pattern is called core-annulus. Furthermore, the upward flow of solids and gas in riser reactors oppose gravity, resulting in a solids flow that is significantly slower than the much higher gas flow. This results in backmixing of the solids and the occurrence of undesirable secondary reactions in industrial operations such as overcracking in FCC process [4,5]. In contrast to riser reactors, downflow reactors do not display large differences in velocity and solids holdup between the center and the wall of the reactor. Furthermore, as the particles do not oppose gravity, the particle is more evenly distributed across the entire reactor. The difference in velocity between the gas flow and the solids flow in these reactors is smaller than in riser reactors so that backmixing is largely avoided. Consequently, the effective contact time of the solids and the gas in a downflow reactor is less than in a riser reactor [2,6,7].

In the past two decades, downer has drawn much attention [1,3, 7–19]. Wei and Zhu [20] systematically studied the axial solids mixing behavior and compared the similarities and differences between the downer and the riser. Zhang et al. [11,12] comprehensively investigated the hydrodynamics in a 100 mm downer of 9.3 m high using FCC particles. Ma and Zhu [9] measured the heat transfer inside the same downer. Luo et al. [14] conducted some experiments on the characteristics of mass transfer with the adsorption of CO_2 tracer by activated charcoal particles. Recently, Li et al. [21] used a hot model reaction (ozone decomposition) to study the performance of downer reactor.

Although many studies on the downer reactors had been carried out, only a few researches focused on the high density/flux CFB downer. In a special effort to achieve high solids holdup, Liu et al. [22] designed a special high-density downer where a 0.66 m tall funnel with 250 mm top diameter was placed at the top of a 25 mm and 5 m tall downer to pre-accelerate the particles, so that they can be fed into the downer at their terminal velocity so as to facilitate high solids flux. With this particular apparatus, an average solids holdup as high as 0.07–0.09 was achieved with solids circulation rate (G_s) over 400 kg/m^{2}s using FCC particles. They also obtained a solids holdup of 0.2 when G_s equaled 1500 kg/m^{2}s with glass beads. Chen and Li [23] reported that solids concentration reached 0.14 with the maximal solids flux of 200 kg/m^{2}s under very low superficial gas velocities (U_g = 0.8–1.2 m/s). Song

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et al. [24] presented that using coke particles, mean solids holdup of 0.165 was achieved at $G_s = 1400$ kg/m^{2}s and $U_g = 2.0$ m/s in a short downer (only 3.2 m high) operated under a batch mode. Guan et al. [25] proposed a triple-bed system including a CFB downer and the solids holdup was up to 0.03 in the fully developed region with $G_s =$ 439 kg/m^{2}s. However, most of these experiments concentrated on solids holdup mainly inferred from the axial pressure profiles under inadequate operating conditions. So far, there have still been very few attempts to study axial solids flow structure, especially particle velocity and flow development in high density/flux downer reactors. Therefore, more studies are needed on high flux CFB downer to obtain a more detailed and clearer understanding of the axial flow structures in downer reactors. For this purpose, a comprehensive study is conducted on axial solids holdup, particle velocity and flow development using an optical fiber probe in a very high flux CFB downer in this paper.

2. Experimental details

2.1. CFB experimental setup

A riser–downer system is employed to carry out all the experiments of a high flux downer reactor, as schematically shown in Fig. 1.

Particles from a storage tank with an inner diameter up to 457 mm are fed into the system through an inclined feeding pipe at the bottom

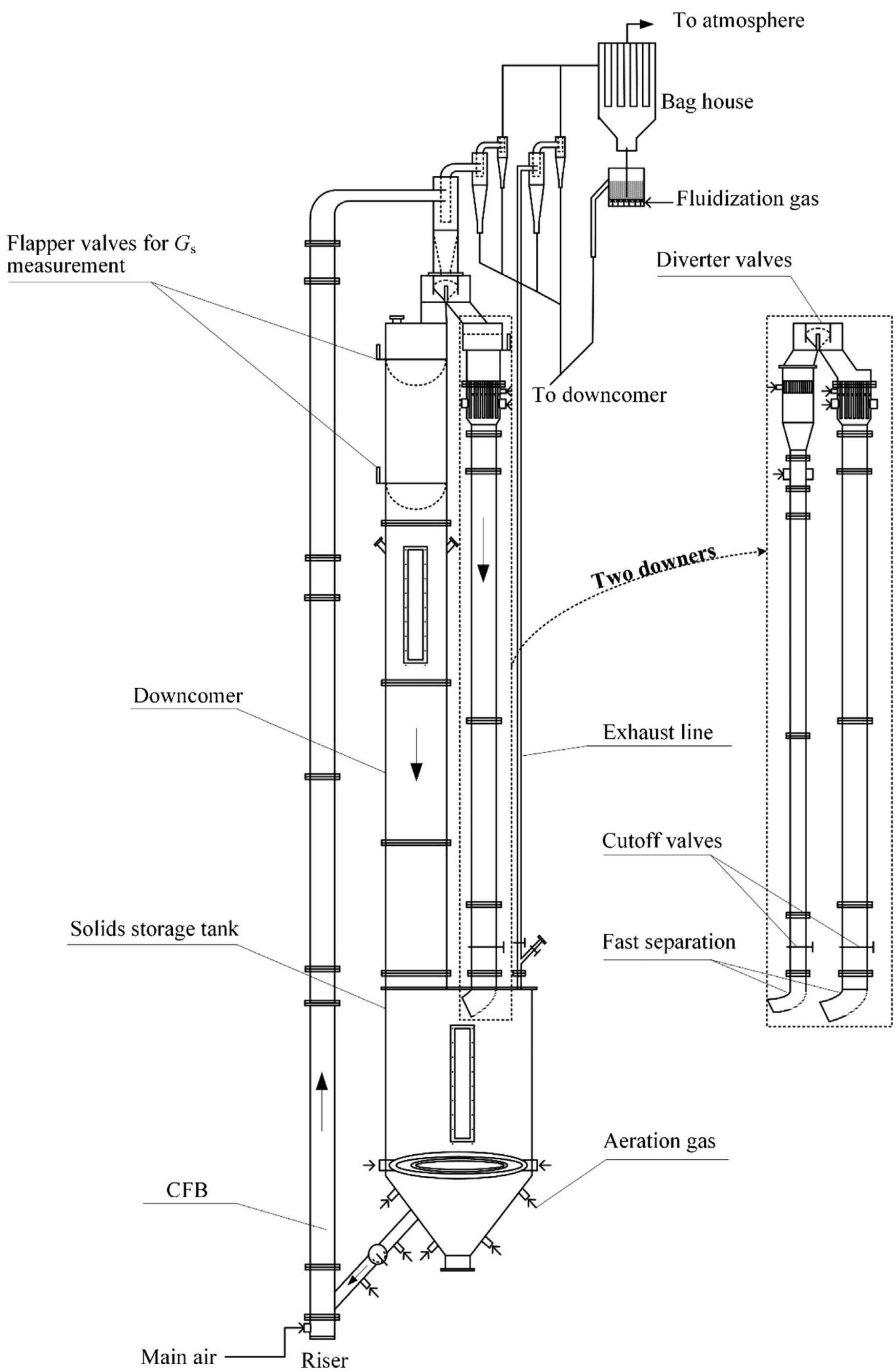

Fig. 1. Schematic diagram of the high flux circulating fluidized bed system.