Powder Technology 339 (2018) 930–938

Contents lists available at ScienceDirect

Powder Technology

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

The exit impact on segregation of binary particles in the CFB system

Yi Zhang, Man Zhang, Xuan Yao, Junfu Lyu, Hairui Yang *

Key Laboratory for Thermal Science and Power Engineering of Ministry Education, State Key Laboratory of Power Systems, Department of Energy and Power Engineering, Tsinghua University, Beijing 100084, China

ARTICLE INFO

Article history:
Received 11 February 2018
Received in revised form 9 July 2018
Accepted 27 August 2018
Available online 28 August 2018

Keywords:
CFB
Binary particles
Segregation
Exit impact

ABSTRACT

Segregation exists extensively in the circulating fluidized bed (CFB) system, with solid particles of different sizes and densities. This paper studied the segregation of binary particles in a CFB system. Experimental results showed that segregation in the riser became weaker with increasing fluidizing gas velocity, u_g, and solid circulating rate, G_s. In the case of high u_g (6.0 m/s) and high G_s, segregation almost disappeared and the binary particles in the whole system became complete mixing. The average jetsam mass fraction along the riser height showed different relations with the initial jetsam mass fraction in the literature. In order to explain the discrepancy in the literature, this paper indicated the exit geometry influenced the segregation in the whole CFB loop, i.e. not only in the riser, but also in the external loop. For the abrupt exit, the internal refluxing of solids always existed in the sharp bend for the inertial separation of particles, and more coarse particles rebounded at the riser exit than the fine particles. Thus more coarse particles stayed in the riser than in the standpipe.

1. Introduction

Fluidization technology has been widely used in gas-solid reaction, including coal combustion, chemical looping combustion, gasification and so on [1–4], owing to its excellent heat and mass transfer properties, high fuel flexibility and large scale operability. Circulating fluidized bed (CFB) boilers, especially, are commonly applied in solid fuel combustion combining limestone injection into the furnace for desulphurization. Therefore, the bed materials of a CFB boiler consist of various kinds of particles, such as solid fuel, ash and limestone, which have different sizes and densities. The smaller or lighter solid particles, called flotsam, are more easily to be entrained upward by fluidizing gas, while the bigger or heavier ones, called jetsam, show more potential to settle downward to the bottom of the bed. This common process in fluidized beds is referred to as solid segregation, and the process against the solid segregation is called solid mixing [5–7]. Particularly, solid segregation and mixing exist extensively and maintain dynamic equilibrium in the CFB system.

Influencing factors on the solid segregation and mixing in fluidized bed, including solid particle size, solid density, fluidizing gas velocity, bed height, test rig column shape and so on, were studied in the literature through experiments and simulations [8–16]. To obtain more detailed information about the segregation, different CFD models, like TFM [11,13], DEM [10], and MFM [16], were developed to study the segregation. However, most of these studies were carried out in the risers and the superficial gas velocity was lower than the particle terminal velocity, so most studies were in bubbling beds. While, a CFB system contains the riser and the external loop, including the cyclone, standpipe and loop seal, and the superficial gas velocity is 2–10 times of the particle terminal velocity. Therefore, the segregation may be affected by the circulation, high gas velocity and the loop structure in the CFB system, further affecting the design and performance of the CFB system.

Up to now, detailed experimental investigations of segregation in the CFB system are still limited [17,18], and exist some contradictory findings. Nakagawa and Bai [19,20], Bodelin [21], Hirschberg and Werther [22], Bareschino [23] studied the effect of operating conditions on binary particles segregation and mixing in the riser. When solid circulating rate, G_s, was constant, the mixing became more intensive with the increasing of fluidizing gas velocity, u_g. However, the influence of G_s was in controversy. Nakagawa & Bai [19,20] and Mitali [17] found that the increasing of G_s would improve the solid mixing, while Bodelin [21] and Bareschino [23] found the opposite effect in the similar experiments. Chew et al. [24] studied the segregation phenomenon of Group B particles not only in binary mixtures but also in continuous PSD, and found some different trends between binary mixtures and continuous PSD. A monotonic increase in segregation for the binary mixtures with increasing solid load, while a non-monotonic trend for continuous PSD. The radial segregation is the weakest in bottom bed for the binary mixtures, while the opposite trend is found for the continuous PSD.

Referring to the jetsam distribution along the riser height, the relations between the initial mixing fraction of jetsam, x_{c0}, and the average mass fraction of jetsam, x_c, along the riser height, especially near the riser exit, were totally different. In the study of Nakagawa & Bai [19], both of the average solid size and the jetsam mass fraction decreased along the riser height. At the riser exit, x_c was lower than x_{c0}, shown

* Corresponding author.
E-mail address: yhr@mail.tsinghua.edu.cn (H. Yang).

https://doi.org/10.1016/j.powtec.2018.08.070
0032-5910/

in Fig. 1(a), i.e. the flotsam had larger mass fraction than the initial mass fraction at the exit zone. However, in the studies of Werther [22] and Mitali [17], the average jetsam mass fraction, x_c, was always larger than the initial jetsam mass fraction, x_{c0}, at any height. Moreover, in the study of Mitali [17], with the initial mixing jetsam fraction of $x_{c0} = 20\%$, the average mass fraction of jetsam in the riser was $x_c = 30\%$ in the complete mixing state, shown in Fig. 1(b). According to the mass balance in the whole CFB system, even in the case of complete mixing in the riser, the mass fraction of jetsam in the riser was larger than that in the standpipe, which meant that much more jetsam remained in the riser and more flotsam were entrained into the standpipe.

The potential reason for the above discrepancy may be the structure differences, like the loop seal and exit geometry. The smooth exit and abrupt exit have different constraints to the gas solid flow and may cause the different mass and pressure balance in the whole loop [25], and the exit effect is more obvious in laboratory CFB system with riser diameter lower than 200 mm [26].

In this paper, segregation of binary particles in the CFB system, especially the jetsam mass fraction distribution between the riser and the standpipe, was studied by experiments. The influence of fluidizing gas velocity, u_g, and solid circulating rate, G_s, on segregation were investigated. In addition, the impact of the exit geometry on the jetsam distribution in the CFB system was studied to explain the discrepancy in the literature.

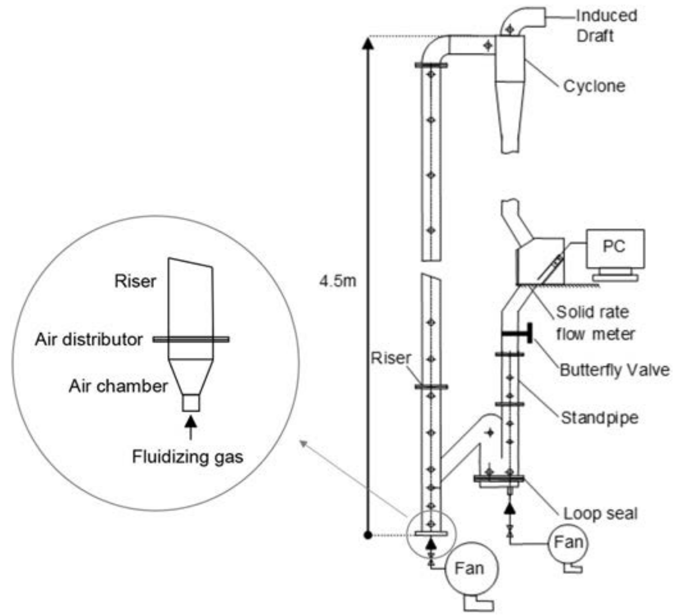


Fig. 2. Schematic diagram of the experimental test rig.

2. Experimental

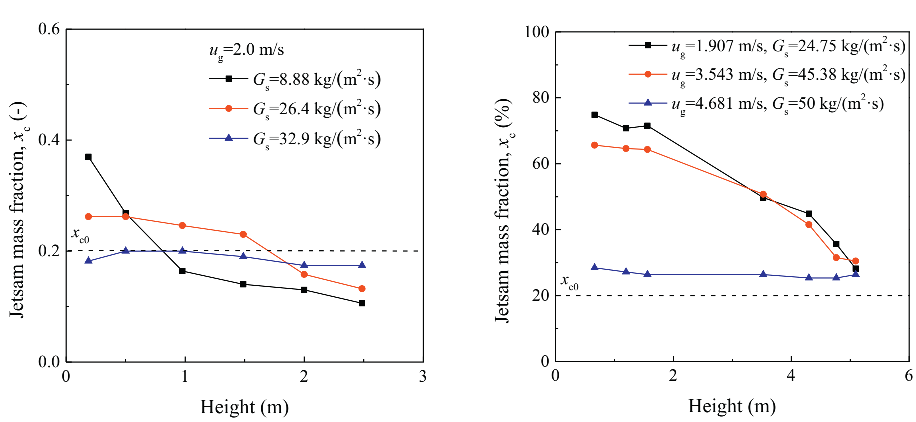
Experiments were conducted in a cold CFB test rig, shown in Fig. 2. The system was consisted of a distributor, a riser, a cyclone, a standpipe and a loop seal. The riser had a cross-section area of 0.1 × 0.1 m^2 and a height of 4.5 m. A pyramid air chamber was applied to guarantee the uniform air distribution. Moreover, two layers of sieves (mesh size 100 μm) were used as the air distributor not only to distribute the air but also to prevent the particles falling into the air chamber. The high-efficiency cyclone was used to reduce particle loss. The standpipe had a height of 3.0 m and an inner diameter of 0.08 m and was connected to the riser with a loop seal. 19 pressure taps were installed at different heights along the solid circulating loop to measure the pressure drop online. There were 5 sample taps (4 on the riser, 0.1 m, 1.3 m, 2.1 m, and 3.95 m in riser height direction, 1 on the standpipe) in the system for collecting solid samples by a sucking probe, whose schematic diagram was shown in Fig. 3.

Three exit geometries, i.e. C-shape, T-shape and L-shape, shown in Fig. 4, were used in our experiments to study the exit impact on segregation. T-shape exit had the fixed project height of 0.15 m. The filler was used to fill the cavity in the upper zone of the T-shape, so the T-shape could change to the L-shape in our experiments.

Fluidizing gas rate and loop seal aeration rate were individually measured by gas flow meters. Two methods were used to measure G_s in the standpipe. One was based on the time accounting for the circulating solid accumulating to a certain height in the standpipe after a sudden close of a butterfly valve installed in the standpipe. The other method used a self-designed online G_s measuring device placed under the cyclone. In the test, G_s was calculated based on the standpipe area. More details on the experiment test rig can be found in the previous study [27].

All experiments were carried out at ambient temperature and atmospheric pressure. The bed materials were quartz sands, whose physical properties were listed in Table 1. The particle size distribution of two kinds of quartz sands were shown in Fig. 5, and the quartz sands belonged to Geldart Group B particles. The coarse sands were regarded as the jetsam, accounting for 40% (x_{c0}) of the initial bed material, and the fine particles were flotsam, accounting for the other 60%.

During the test, a probe was inserted into the centerline of the riser from the sample tap to suck the particles out. Solid samples were withdrawn by non-isokinetic sampling for two considerations. On one hand,



(a) Nakagawa & Bai (x_{c0}=0.2) [19] (b) Mitali (x_{c0}=20%) [17]

Fig. 1. Jetsam mass fraction along the riser height in the literature.