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Impact of particle properties on gas solid flow in the whole circulating fluidized bed system

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A B S T R A C T

The effect of particle properties on gas solid flow in the whole circulating fluidized bed (CFB) system was investigated. Two Geldart-B particles with different sizes were used and the differences in pressure balance and material balance of the whole CFB system with a loop seal were described. The results show that coarse particles have a larger transport velocity U_{tr} to fall into the fast bed regime, which means accumulation in the riser is easier for the coarse particles at the same fluidization velocity U_r. The coarse particles also have a smaller solid saturation carrying rate $G_{s,max}$ and a lower height of the acceleration region in the fast fluidization regime. Considering the pressure balance of the system, a higher pressure head should be supplied by the standpipe at the aeration tap of the loop seal under the same G_s when coarse particles are used. The pressure drop through the cyclone is lower for coarse particles under the same solid concentration at the entrance of it. In the loop seal, coarse particles need more aeration gas to reach the same G_s because of its higher minimum fluidization velocity. Coarse particles show a higher pressure drop through the weir part and a lower pressure drop through the horizontal part of the loop seal. In the standpipe, coarse particles have a lower drag coefficient and need a higher gas solid slip velocity to build up the same pressure gradient, so fine particles suffer less bypassing gas into the cyclone and have higher material seal capability. However, because of the same density of the two particles, the maximum pressure gradient built up in the standpipe is similar.

1. Introduction

Circulating fluidized bed (CFB) technology has been widely used in coal-fired power generation. In a CFB boiler, known as an open system, size distribution of circulating ash is typically in a range of 100 μm–300 μm as a result of material balance [1]. Solids with different size or density show different fluidization performance in gas–solid two phase flow [2], which can be partly depicted with Archimedes number *Ar* [3]. Solids with different *Ar* numbers have different gas solid flow behaviors in each component of a CFB system, that's why segregation commonly happens in the riser while separation happens in the cyclone.

There are many researches carried out in the past thirty years about the effect of particle size distribution on the performance of CFB reactor, such as Grace et al. [4,5] and Geldart et al. [6]. Their results show that not only the mean particle size, but also the size distribution has a considerable effect on solid fluidization behavior. However, their researches mainly focused on the bubbling fluidization regime and turbulence fluidization regime. Bai et al. [7] and Mastellone and Arena [8] investigated the differences of the axial solid distribution caused by different particle sizes in the riser of a fast fluidized bed. Qi et al. [9], Xu et al. [10] and Chew et al. [11] showed more detailed differences of the gas solid suspension behavior of different particles in the riser. However, because of their paying main attention on the gas solid flow in the riser, many of these researches were carried out in an open system or systems with a strong inlet restriction condition. So the effect of the behavior of different particles in the riser on the operation of the whole solid circulation loop was not described.

The influence of particle properties on other components of a CFB system was explored in few researches. Kang et al. [12] tested two kinds of particles flowing through the same cyclone and noted that the pressure drop relied on the particles, but the differences were mainly caused by the density, not the size. Geldart et al. [13] studied the effect of particle properties on the gas solid flow in the standpipe, but the flow regime in the standpipe was limited in the bubbling fluidized bed, not including the moving bed that is found commonly in experimental test rigs [14]. For non-mechanic valve, Arena et al. [15] presented the L-valve behavior with solids of different size and density in a closed CFB system. Kim et al. [16] investigated the effect of particle properties on solids recycle in a loop seal of a CFB system, and concluded that the aeration requirement increases to maintain the same solid flow rate with increasing particle size. However, in their research, a vertical aeration is employed and a hopper is installed on the standpipe, inconsistent with the commercial CFB boiler system. Such a design will have a great

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effect on the pressure balance and material balance of the loop and affect the operation characteristics of the CFB system. For a better understanding and description on the hydrodynamics in a CFB boiler with bed material of wide size distribution, an investigation on the effect of particle size on the gas solid flow in each component of a CFB system seems to be necessary, especially from the perspective of the whole system.

In this study, two Geldart-B particles with different *Ar* numbers, which were in the size range of the circulating ash in a CFB boiler, were used as bed material to study the effect of particle properties on the gas solid flow in a CFB system.

2. Experimental

2.1. CFB cold test rig

Experiments were conducted in a CFB cold test rig consisting of a riser, a cyclone, a standpipe with a butterfly valve, and a loop seal, as shown in Fig. 1. The riser with a C-type smooth exit configuration has a cross section area of 0.1×0.1 m^2 and a height of 4.5 m. The cyclone is a standard Stairmand cyclone with high particle separation efficiency. The standpipe has a height of 3.0 m and a diameter of 0.08 m, connecting the cyclone on the top and the loop seal at its bottom. A total of 19 pressure taps are installed at different heights along the solid circulation loop to measure the local pressure drop online through pressure sensors. Pressure drops across riser, cyclone, standpipe and loop seal are measured at R1 and R3, C1 and C2, Ls1 and C2, Ls1 and Ls3, as shown in Fig. 1. The solid circulating rate G_s is measured by accumulating the time required to fill a known volume with solids after closing the butterfly valve at the top of the standpipe. The fluidization gas flow rate and loop seal aeration rate Q were measured individually by gas flow meters, and the superficial aeration velocity U_v through the loop seal was calculated by dividing Q by the area of the air distribution at the bottom of the loop seal, 0.08×0.2 m^2.

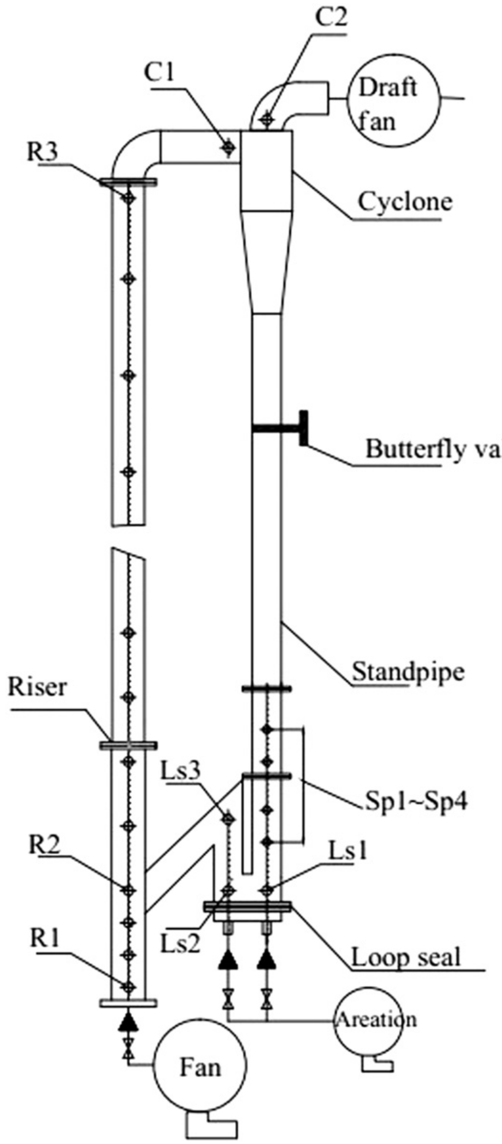

Fig. 1. Schematic diagram of the experimental test rig.

2.2. Flow behavior measurement in the standpipe

High purity CO$_2$ has been applied as the tracer gas to study gas flow behavior in the standpipe. As shown in Fig. 2, CO$_2$ is injected into the system at point A and its concentrations at taps 1, 2 and 3 are measured simultaneously by a CO$_2$ detecting system with three channels. In the control volume enclosed by the dotted lines and the solid walls in Fig. 2, the CO$_2$ and air mass balance can be expressed by the following equations when CO$_2$ is injected with a certain volumetric flow rate q:

$$Q_v + Q_h = Q + \mathrm{q} \tag{1}$$

$$Q_v C_3 + Q_h C_1 = q \tag{2}$$

where Q_v is the net volumetric gas flow rate in the standpipe (negative value means gas flows downwards), Q_h is the volumetric gas flow rate crossing the horizontal section of the loop seal, and C_1 and C_3 are the CO$_2$ volumetric fractions at taps 1 and 3, respectively. According to Eqs. (1) and (2), Q_v and Q_h can be calculated when Q, q, C_1 and C_3 are measured. More details can be found in a previous research [14]. In addition, a laser fiber was used at taps 2 and 3 to measure the solid volumetric fraction in the standpipe. Signals from the CO$_2$ sensors and the laser fiber were recorded online through a data acquisition system.

All experiments were carried out at ambient temperature and atmospheric pressure. The bed materials used were quartz sand, whose physical properties are listed in Table 1. The total bed inventory in the system was kept constant at 11 kg and the solid circulating rate G_s was controlled by adjusting aeration rate Q through the loop seal.

3. Results and discussion

3.1. Fluidization performance of Geldart-B particles with different Ar number

The fluidization phenomenon of gas solid system depends very much on particle properties, and Archimedes number A_r can be used as a criteria for fluidization performance [3,17,18]. This study tested the minimum fluidization velocity U_{mf} and the transport velocity U_{tr} of the two type B particles with different *Ar* values, 4298 for the coarse particles and 377 for the fine particles. U_{mf} was determined by measuring the pressure drop of a small bubbling bed between two pressure taps with a certain height differential and calculating the pressure drop gradient at different superficial aeration velocities, as shown in Fig. 3. The superficial U_{mf} for the coarse particles and for the fine particles are 0.09 and 0.02 m/s, respectively. These U_{mf} values are well in accordance with the values derived from the correlations of Wen and Yu [19].

The transport velocity U_{tr} is the transition velocity between the turbulent and fast fluidized bed [20], and the minimum gas velocity if a strong solid circulation is realized. In this study, U_{tr} was determined by both the emptying time method and the flooding point method [21]. As shown in Fig. 4, both methods are efficient in determining U_{tr}, and the results are similar. The values of U_{tr} used in this paper are averages