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Force measurement and calculation of the large immersed particle in dense gas–solid fluidized bed

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ABSTRACT

The force characteristic of the large immersed particle in the dense gas–solid fluidized bed is the significant foundation to study the kinetic behavior of the large particle. We designed three steel balls with the density of 7500 kg/m^3 and the mean diameters of 8 mm, 10 mm, and 12 mm as the basic investigated objects. The coarse-sand particles and fine-glass powders were employed as different types of fluidized mediums. We used the self-designed measurement system to measure the force values of different steel balls with variable gas velocities, and the fluctuation characteristic of the forces was obtained finally. The experimental measurement results indicate that the force fluctuation of the large immersed particle with different diameters basically keeps stable after achieving the complete fluidization of the gas–solid fluidized bed. Meanwhile, the results show that the force fluctuation of the same large immersed particle is more stable when the coarse-sand particles are selected as the fluidized medium. The approach of theoretical calculation and numerical simulation has been combined to validate the reliability of measurement results. The comparison conclusions indicate that the measurement results agree well with the calculation and simulation results.

1. Introduction

Large size particles, such as fuel particles, catalyst granules, reactant particles, condensation particles and so on, widely exsit in different types of bubbling fluidized beds. In the study, large particle mainly refers to large size particle in the dense gas–solid fluidized bed, compared with the fluidized medium of fine particles. Its dynamical behavior is greatly influenced by the joint effect of the gas phase and dense-phase fine particles. It has great significance to investigate the kinetic behavior and characteristic of the large particle in the dense gas–solid fluidized bed. The force characteristic and regularity of the large immersed particle are the foundations which determine its subsequent kinetic behavior. A few researchers have carried out a series of studies on the force characteristic and movement regularity of the immersed particles in fluidized beds [1–3]. However, most of the research studies lay particular emphasis on the experiment and calculation of the drag force models between dense-phase particles or the interaction force between gas and solid phases [4–7]. Especially, there are only a few research emphasis on the force measurement and calculation of large immersed particle in the gas–solid fluidized bed [8–12].

Kunii and Levenspiel [13] reviewed the movement behavior of large immersed particle in the fluidized bed for the first time. Rios et al. [14] investigated the movement behavior of large particle in two dimensional and three dimensional space of the gas–solid fluidized bed, and discussed the process of floating and settlement. The results indicate that the displacement of large particle is mainly influenced by two factors. One is the dynamical equilibrium of the particle gravity, buoyancy and drag force of fluid, the other is jumping effort caused by the movement of bubbles and entrained fine particles. Lim and Agarwal [15] discovered that the settling velocity of large particle in the fluidized bed agreed with the velocity calculation model of dense phase after the correction by Kunii and Levenspiel. Rees et al. [16] measured the rising velocity of single spheroidal particle moved from the bottom of bubbling and slugging fluidized bed, whose diameters are 9.0 mm and 13.2 mm and the density distribution is 900–1210 kg/m^3. The velocity calculation models were proposed finally. Nguyen and Grace [17] put forward that the net buoyancy of large particle was not only related with the bed density, but also was influenced by the rising velocity of bubbles, because of the “reflux cap effort” of the fluidized medium on the top of large particle. Daniels [18] measured the drag force of the spheroidal particle moving in the gas–solid fluidized bed. Wei et al. [11] analyzed the force composition of the moving large particle in the dense gas–solid fluidized bed.

The researchers from different countries have carried out some investigation on the force characteristic and kinetic behavior of large particles in fluidized beds with different viewpoints and acquired some valuable achievements [19–21]. However, there are a few studies concentrated on the force measurement and analysis of large immersed particle in dense gas–solid fluidized bed with direct

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measurement approach. Therefore, the special measurement device has been designed and established to carry out the force measurement experiments of the large immersed particle in dense gas–solid fluidized bed, in order to obtain more precise force characteristic and provide more reliable mechanical information for the further investigation on the kinetic behavior of large particle, especially in the benefication field based on the density differences of large particles.

2. Experimental and calculation

2.1. Experimental set up

The diagrams of force measurement system of large immersed particle in dense gas–solid fluidized bed are shown in Fig. 1. A cylindrical fluidized bed with the diameter of 90 mm and height of 280 mm was designed as the basic apparatus. The compressed air is supplied into the gas–solid fluidized bed through the gas distributor, and the air flowrate is controlled by an air valve. The specific value of air flowrate is displayed by the flowmeter. The fluidized medium is packed in the bottom of fluidized bed initially. The steel ball is connected to the force sensor through flexible line. The flexible line refers to the connecting line between the sensor and steel ball, which only plays a connecting role and doesn't exert its own effort on the ball. After achieving complete fluidization, the successive instantaneous forces are transferred to the force sensor with the movement of large immersed particle. The mechanical signals are converted into the voltage signals with the signal converter. The force data are collected by the data receiver and displayed on the monitor with the special software of Strip Chart. Then, the fluidized medium is changed and the steel ball with different diameters is selected to carry out the further experiments.

2.2. Experimental materiels

According to the requirements of this studying, three steel balls with the density of 7500 kg/m^3 and the mean diameters of 8 mm, 10 mm and 12 mm were selected as the large particles in dense gas–solid fluidized bed. The coarse-sand particles and fine-glass powders with the particle size distribution of 100–300 μm and 70–110 μm were employed as basic fluidized mediums, respectively. These two types of fluidized medium have the similar real densities of 2500 kg/m^3.

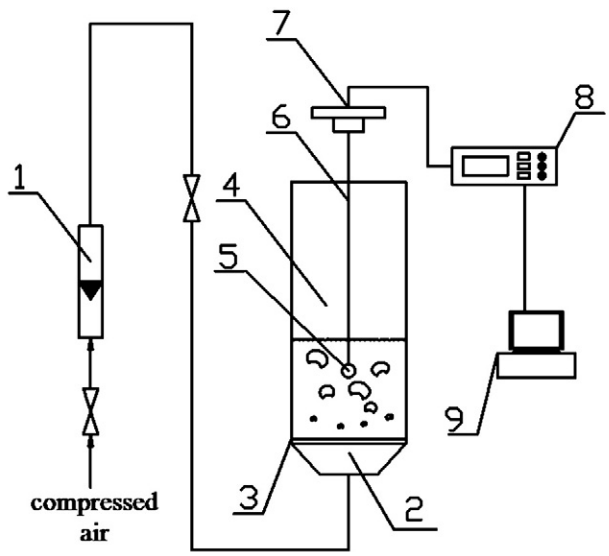

Fig. 1. 1. Gas flowmeter; 2. air chamber; 3. gas distributor; 4. gas–solid fluidized bed; 5. steel ball; 6. flexible line; 7. force sensor; 8. signal converter; 9. data receiver and monitor. Force measurement system of large immersed particle in dense gas–solid fluidized bed.

2.3. Calculation approach

Firstly, the force analysis of the large immersed particle in dense gas–solid fluidized bed was carried out, as shown in Fig. 2. The large immersed particle is mainly subjected to its own gravity force G, buoyancy F_B, drag force caused by fluid F_D and acting force by other immersed particles F_P. However, assuming that the large particles concentration inside the bed is small enough, so the single large particle was considered as the research object, indicating that F_P is negligible. Therefore, the composite force of the large immersed particle is mainly determined by G, F_B and F_D. The direction of the drag force F_D is opposite to the movement direction of large immersed particle, which could present downward or upward at different times with the variation of composite force on the large particle. Hence, the dash line was used for illustrating the drag force F_D in Fig. 2.

The force calculation formula could be summarized as Eq. (1) below.

$$\vec{F} = G + \vec{F_B} + \vec{F_D} \tag{1}$$

In addition, the mean density of the fluidized bed could be obtained by Eq. (2).

$$\rho_f = \frac{W}{A \cdot H} = (1-\varepsilon)\cdot\left(\rho_s - \rho_g\right) \approx (1-\varepsilon)\cdot\rho_s \tag{2}$$

So the mean density of the fluidized bed mainly depends on the porosity of fluidized bed and the real density of fluidized medium. The fundamental fluidization experiments were carried out with the coarse-sand particles and fine-glass powders as fluidized mediums, respectively. The measurement results show that the minimum fluidization velocity U_{mf} is 2.6 cm/s for the coarse-sand particles and the bed porosity distributes from 0.33 to 0.43 with increasing the fluidization velocity from 2.6 cm/s to 8.7 cm/s. For the fine-glass powders,

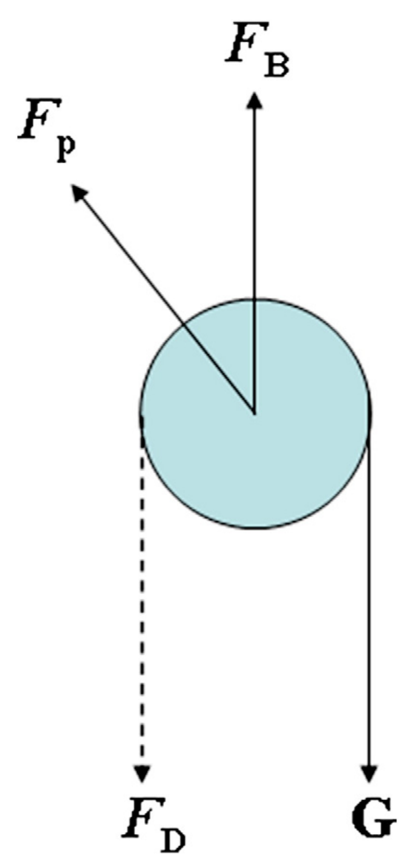

Fig. 2. Force analysis of the large immersed particle.