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Favorable vibrated fluidization conditions for cohesive fine particles

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Abstract

The present study was performed to clarify the operational range for vibro-fluidization of fine cohesive particles (glass beads, $d_p = 6$ μm). Decreasing and increasing gas velocity methods were examined to clarify the favorable vibro-fluidization region. The upper limit of the gas velocity for intermittent channel breakage was higher in the case of the increasing gas velocity method than the decreasing gas velocity method. This was because the changes in the bed flow pattern from a favorable (intermittent channel breakage) to an unfavorable fluidization state (stable channels) were moderate in the case of the increasing gas velocity method. In the increasing gas velocity method, two kinds of cross-points were obtained from the relationship between the gas velocity and the bed pressure drop. At one of the gas velocities at these cross-points, the bed void fraction reached its maximum. In the present study, the above-mentioned gas velocity was defined as the upper limit of gas velocity for favorable vibro-fluidization, u_{chu}. A favorable vibro-fluidization region was determined by combining u_{chu} with u_{chl}, which is the lower limit of gas velocity for intermittent channel breakage obtained in a previous study. The value of u_{chu} was found to have a maximum corresponding to a certain vibration strength.

Keywords: Fluidized bed; Vibration; Fine particle

1. Introduction

Fluidized beds have been used in several industries involving gas–solid contacting systems. Fluidized particles are suspended by an upward gas flow, and a particle suspension state has several advantages, such as good gas–solid contact, relatively high mass and heat transfer rates and particle mixing. Various types of fluidized beds have been developed to utilize gas–solid contacting system.

Characteristics of fine particles, such as their large surface area, are attracted in various industries. However, due to the strong interaction forces acting between particles, fine particles easily form agglomerates. In the case of a fluidized bed with cohesive particles, it is difficult for a gas to flow freely through the bed because the agglomerate constitutes a complex bed structure. Under such conditions, the gas tends to flow through fixed paths, called stable channels. When stable channels are formed in the bed, both the efficiency of gas–solid contact and the fluidity of the bed are reduced. Geldart [1] classified these fine cohesive particles into group-C. There are a number of methods for improving the fluidity of fine cohesive particles.

The addition of vibration is one method to achieve good fluidization of fine particles. Mori et al. [2] developed a new type of vibrating system that added twist vibration to the bed. They fluidized several fine cohesive particles and classified them into three groups according to their bed expansion characteristics. Marring et al. [3] added vertical vibration to the bed to fluidize some fine cohesive particles. Wank et al. [4] studied the fluidization of fine particles under vibrated conditions at reduced pressure. They reported that the agglomerate decreased in size with increasing intensity of vibration. Tasirin and Anuar [5] fluidized three types of starch powders under vibration. They measured the entrainment of the particles at different gas velocities to modify the entrainment constant proposed by Ma and Kato [6].

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In our previous studies [7–9], we focused on the flow patterns under vibrated conditions to examine the fluidizing mechanism of vibro-fluidization for fine cohesive particles. Noda et al. [7] investigated the flow patterns of fine particles under twist vibration. Mawatari et al. [8] investigated the effects of particle diameter on the fluidizing behavior of fine particles under twist vibration. They compared the fluidization characteristics of three vibrational modes: vertical, horizontal, and twist vibration [9]. Based on the studies cited above, we concluded that vibration plays an important role in fluidizing cohesive particles. Vibration breaks the stable channels intermittently, which promotes the dispersion of the fluidizing gas over the bed. Therefore, the lower limit of the gas velocity for intermittent channel breakage was observed carefully to allow its use as an index for favorable vibro-fluidization of fine particles [8].

In the present study, the upper limit of gas velocity for intermittent channel breakage was examined experimentally to clarify the range for favorable vibro-fluidization. The decreasing and increasing gas velocity methods were examined to clarify the favorable vibro-fluidization region. The clarification of the upper limit of gas velocity for vibro-fluidization will be useful in terms of obtaining suitable operational conditions for fine particles with vibro-fluidized beds.

2. Experiment

A fluidized bed was composed of a transparent glass column with an I.D. of 65 mm and height of 1100 mm. A sintered glass plate was used as a gas distributor. Two pressure taps were attached; one was placed 600 mm above the gas distributor, and the other was placed below the gas distributor. These pressure taps were used to measure the bed pressure drop with a differential pressure gauge (Druck Incorporated). Dry nitrogen was used as the fluidizing gas. The flow rate of the fluidizing gas was controlled using a mass flow controller (Brooks Instruments). The accuracy of the above equipment was stated in a previous paper [8].

A vibrator (Chuo-Kakoki) was used to provide vibrations to the fluidized bed. Two vibro-motors were attached in a crosswise manner on both sides of the vibrator, resulting in twist vibration. The amplitude and frequency of vibration–the vibration parameters–were controlled by the vibro-motors and an inverter, respectively. The vibration strength, which is the ratio of the vibration acceleration to the gravitational acceleration, was defined as follows:

$$\Lambda = \frac{A(2\pi f)^2}{g} \tag{1}$$

where A, f, and g are the amplitude of vibration, the frequency of vibration and the acceleration due to gravity, respectively. In the present study, the frequency of vibration was set to 40 Hz because the broadest range of the vibration strength could be adjusted using a vibrator. The amplitude of vibrations was varied up to 2.3 mm.

In the present study, spherical glass beads with a mean diameter and density of 6 μm and 2500 kg/m^3, respectively, were used as a powder. The height of the static bed was set to approximately 65 mm, which corresponded to the bed diameter.

3. Results and discussion

3.1. Decreasing gas velocity method

Fig. 1 shows the relationship between the superficial gas velocity and the bed pressure drop for a 6-μm powder without vibration. The broken line indicates the calculated value of the bed pressure drop on the basis of the bed weight per unit cross-sectional area ($\Delta P_{mf}=mg/S$). The highest initial gas velocity is 1.78×10^{-2} m/s, which is approximately 20–36 times the minimum fluidization velocity under vibration obtained in a previous study [10]. The experiment was conducted by decreasing the gas velocity beginning with the initial gas velocity. The initial bed height before the experiment was about 65 mm, which corresponded to the bed diameter. In the case of all initial gas velocities, the bed pressure drop did not attain the value of ΔP_{mf} due to the formation of stable channels.

Fig. 2 shows the schematic diagram of the bed flow patterns after the gas was supplied to the bed. When gas velocity was applied to the bed, the entire bed rose upward from the distributor (Fig. 2(a)); the bottom part of the rising particle bed began to drop (Fig. 2(b)). Finally, the other part of the rising bed also dropped to the gas distributor. Large stable channels were observed in the case of all initial gas velocities (Fig. 2(c-1)), which indicated that the fluidity of the bed was poor. Some studies have indicated the fluidization of fine powders [11–20]. The common experimental observation in these studies was that fine powders formed stable

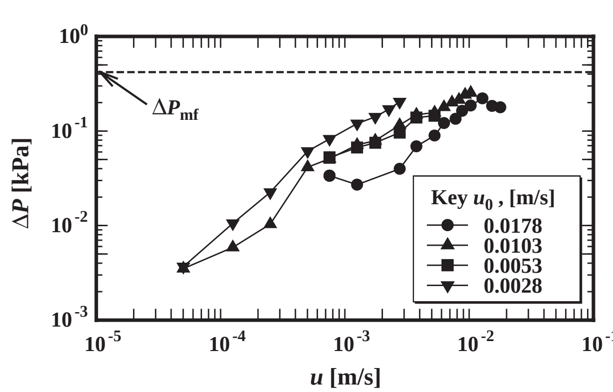

Fig. 1. Relationship between superficial gas velocity and bed pressure drop for 6-μm powder without vibration.