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Vibro-Fluidization Characteristics for Size Arranged Agglomerates

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ABSTRACT

Fine cohesive powders (Geldart's group-C) were fluidized with a vibro-fluidized bed. Diameters of the powder used in this study were 0.2 μm. For 0.2 μm titanium oxide powder, stable and relatively large agglomerates were observed. In this study, the size distribution of agglomerates was arranged by sieving to examine its effect on the fluidization characteristics, such as the minimum fluidization velocity, the minimum bubbling velocity and the bed expansion ratio. The fluidization characteristics were drastically influenced by the size distribution of agglomerates. It was found that the size arrangement of agglomerates was one of the factors to obtain stable fluidization state for agglomerated cohesive powder.

INTRODUCTION

Fine powders have been noticed in various industries due to their attractive characteristics. Relatively large surface area of such fine powder can promote the reaction rate and product yield when fine powders are used in a catalytic reaction. Fluidized bed has an advantage in gas-solid contact characteristics; hence, various types of fluidized beds have been developed in various industries. However, fine powders less than 20 μm in diameter easily form agglomerates. Geldart (1) classified such fine cohesive powders into group-C in his powder classification. In the case of fluidized bed with fine powder, stable channel, which is a fixed gas flow channel, is formed in the whole bed and the bed fluidity becomes poor. Adding the vibration is one of the ways for improving the bed fluidity of fine cohesive powders. The vibration breaks stable channels intermittently, which causes well dispersion of fluidizing gas in the whole bed. Mawatari *etal*. (2-5) examined the effect of vibration on the flow patterns of fine cohesive powders. Under vibrating condition, the lower limit of gas velocity for channel breakage was an index for improvement of bed fluidity.

Agglomerates size is important factor to clarify the fluidization mechanism for fine cohesive powders because such cohesive powders are not fluidized in original size but in agglomerates. However, whether the agglomerate size can evaluate or not depends on the strength of agglomerate structure. There are some reports on the fluidization behaviors for nano-order powder with or without vibration (6-10). Agglomerate size was evaluated by direct sampling from the bed. The strength of agglomerates formed by very fine powder was high; hence, direct sampling and evaluation of agglomerates was possible in these reports.

In this study, size arranged agglomerates were used to examine the effect of size distribution of agglomerates on fluidization characteristics under vibrating conditions.

EXPERIMENT

Figure 1 shows the schematic diagram of vibro-fluidized bed used in this study. Fluidized bed was made of transparent glass column and it can be separated into four parts, which were plenum, gas distributor, main chamber and freeboard, respectively. Internal bed diameter was 65 mm and height was 1100 mm. A sintered stainless plate was used as gas distributor. Gas velocity was controlled with a mass flow controller and dry nitrogen was used as a fluidizing gas. Two pressure taps were placed at the plenum and the upper region of the freeboard, respectively. In this study, serious problem during ΔP measuring was not observed. After several experiments, pressure tap was cleaned to prevent the clogging of the pressure tap. Pressure drop across the bed was measured with a differential pressure gauge (Druck Inc.).

Vibration frequency and amplitude were set with an inverter and vibro-motors mounted on the side of vibrator, respectively. In this study, vibration frequency was set at 40 Hz and the amplitude was varied up to 2.0 mm. Vibration direction was twist mode, which was three-dimensional vibration caused by crosswise setting of two vibro-motors inclined 45 degrees against horizontal direction. Vibration intensity was defined as the ratio of vibration acceleration to gravitation acceleration as follows,

$$\Lambda = A(2\pi f)^2 / g \quad (1)$$

where A, f, and g were the vibration amplitude, the vibration frequency and acceleration of gravity, respectively.

Powder used in this study was titanium dioxide powder, which is 200 nm in diameter. Before packing the powder into the bed, relatively large agglomerates were excluded by sieving. In this study, three kinds of sieves (d_{cut}= 250, 500, 1000 μm) were used to arrange the size distribution of agglomerates. Table 1 shows the mean size of agglomerates arranged by three different sieves. d_{cut} is a maximum diameter which can through the sieve mesh; hence, in the case of using 1000 μm mesh, agglomerates larger than 1000 μm can be excluded from the products. Agglomerate size was determined by image analysis, and an equivalent diameter of circle was used as agglomerate diameter. In this study, the mean diameters of agglomerate arranged with different sieves were 128 μm, 260 μm and 390 μm for d_{cut}= 250, 500, 1000 μm, respectively. The standard deviation of agglomerates size were 63.6 μm, 148.2 μm and 253.0 μm for d_{cut}= 250, 500, 1000 μm, respectively. The ratio of bed diameter to the agglomerate size was more than 150 times in the case of d_{cut} =1000 μm (d_{agg} =390 μm). Although the wall effect affects the fluidization behavior, its effect was not investigated in the present stage.

Before the experiment, the bed was well fluidized with relatively higher gas velocity, and then the gas velocity was decreased. The bed pressure drop, bed height and bed flow patterns were measured or observed. The minimum fluidization velocity, u_{mf}, was obtained from the relationship between superficial gas velocity and bed pressure drop.

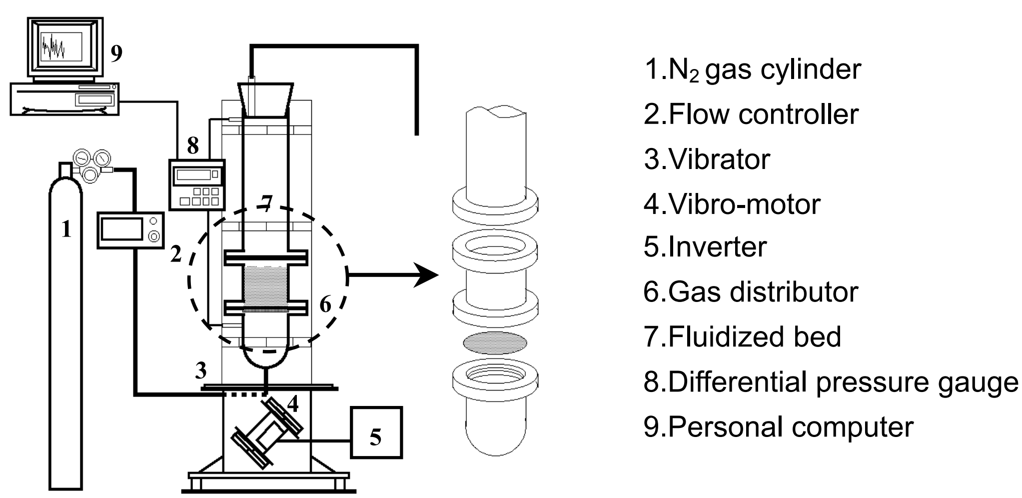

Figure 1 Experimental apparatus

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Table 1 Mean agglomerate size arranged by sieves

d_{cut} [μ m]	$\overline{d_{agg}}$ [μ m]	σ [μ m]
1000	390.7	253.0
500	259.9	148.2
250	128.2	63.6

RESULTS AND DISCUSSION

Figure 2 shows the relationship between superficial gas velocity and bed pressure drop for different d_{cut} without vibration. For all cases, the fact that the bed was not fluidized only by gas supply was confirmed from the pressure drop curves. From the bed flow pattern observation, flow pattern profile was recognized. In the bottom of the bed, relatively larger agglomerates were observed, while smaller agglomerates were in the upper region. Furthermore, bubbling behavior was observed in the upper region of the bed. This phenomenon can be observed in the cases of powder bed with wide size distribution.

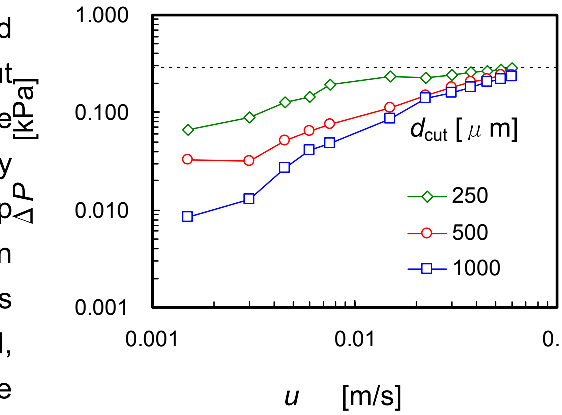

Figure 2 Relationship between u and ΔP without vibration

Figure 3(a) shows the relationship between superficial gas velocity and bed

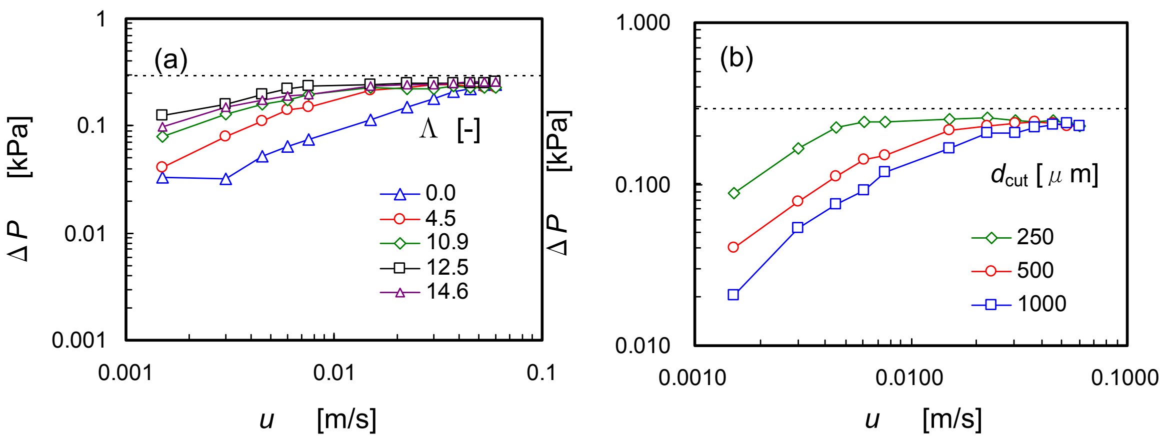

Figure 3 Relationship between u and ΔP;

(a) for different Λ at d_{cut}= 500 μ m, (b) for different d_{cut} at Λ = 4.5

pressure drop for d_{cut} = 500 at different vibration strengths. The bed was fluidized by vibration, and the minimum fluidization velocity decreased as the vibration strength increased. Figure 3(b) shows the relationship between superficial gas velocity and bed pressure drop for different d_{cut} at Λ = 4.5. The minimum fluidization velocity was decreased as the d_{cut} decreased. This is because that the average size of agglomerates becomes smaller and its size distribution also becomes narrower by excluding the larger agglomerates.

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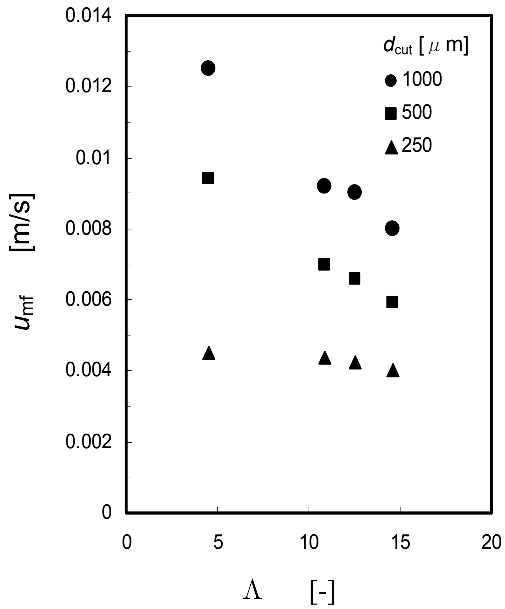

Figure 4 Effect of vibration on u_{mf} for different d_{cut}

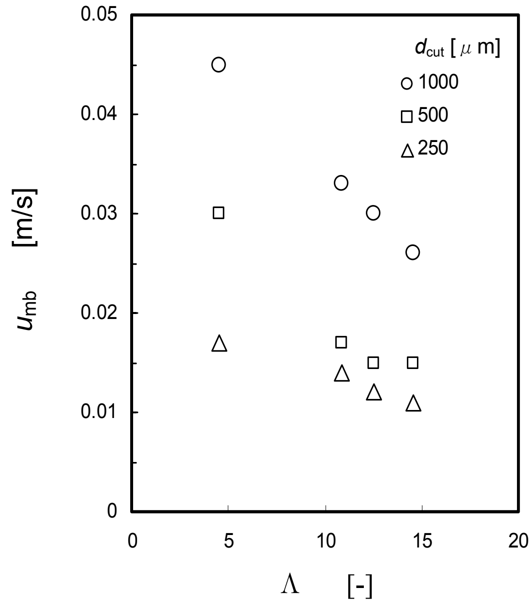

Figure 5 Effect of vibration on u_{mb} for different d_{cut}

Figure 4 shows the effect of vibration strength on minimum fluidization velocity for different d_{cut}. For all cases of d_{cut}, the minimum fluidization velocity decreased with an increasing in the vibration strength. The decrement degree of minimum fluidization velocity on vibration strength became larger as the d_{cut} increased. For larger d_{cut}, size segregation of agglomerate in the axial direction of the bed easily occurs due to their broad size distribution. Once the segregation occurs, relatively larger agglomerates are near the bottom of the bed, while the smaller agglomerates are in the upper region of the bed. In such a circumstance, it is difficult to achieve a whole bed fluidization state. The partially fluidization state, where the bubbling behavior appears in the upper region and the large agglomerates were fixed at the bed bottom, is formed. The larger vibration enhances the mixing of agglomerates to form a non-segregated bed structure, which leads the reduction of minimum fluidization velocity. In this study, long term experiment to investigate the change in the agglomerate size was not carried out enough. Xu *etal.*(8) reported about the size change of agglomerate during fluidization with time. It is considered that the effect of vibration on the change of agglomerate size was more significant as the d_{cut} increases. The interrelations between size reduction of agglomerate and the reduction of u_{mf} under vibration are future works.

Figure 5 shows the effect of vibration strength on minimum bubbling velocity for different d_{cut}. The minimum bubbling velocity decreases as the vibration strength increases for all cases. The decrement degree of minimum bubbling velocity on vibration strength becomes larger as the value of d_{cut} increases. As the d_{cut} increases (size distribution becomes broader), agglomerate size segregation easily occurs during fluidization. However, the vibration effect on the improvement of size segregation becomes more effective as the d_{cut} increases, while the effect of agglomerate segregation on bed structure becomes lower as the d_{cut} decreases. This is the reason that large reduction of minimum bubbling velocity against vibration strength can be seen for larger d_{cut}.

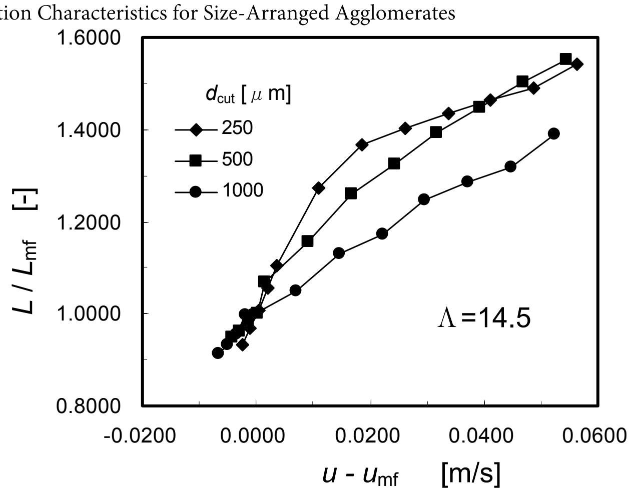

Figure 6 Comparison of bed expansion ratio (Λ=14.5)

Figure 6 shows the comparison of bed expansion ratio as a function of excess gas velocity. The bed expansion ratio becomes larger as the excess gas velocity increases. Higher bed expansion ratio was obtained for the smallest d_{cut}. As the agglomerate size distribution becomes narrower, the whole bed is smoothly expanded because the effect of size segregation becomes smaller. Therefore, the bed expansion ratio becomes higher as the value of d_{cut} decreases.

CONCLUSIONS

The vibro-fluidization characteristics for size arranged agglomerates were examined. The fluidization characteristics were drastically influenced by the size distribution of agglomerates. It was found that the size arrangement of agglomerates was one of the factors to obtain stable fluidization state for agglomerated cohesive powder.

NOTATION

A	:	Amplitude of vibration	[mm]
f	:	Frequency of vibration	[Hz]
g	:	Acceleration of ravity	[m/s2]
u	:	Superficial gas velocity	[m/s]
u_{mb}	:	Minimum bubbling velocity	[m/s]
u_{mf}	:	Minimum fluidization velocity	[m/s]
L	:	Bed height	[m]
L_{mf}	:	Bed height at u_{mf}	[m]
ΔP	:	Bed pressure drop	[Pa]
Λ	:	Vibration strength	[-]

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