Unique Properties of 30-μm Particles as the Catalyst of Fluidized-Bed Reactors

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The collapse properties of three kinds of fine particles (19, 30, and 59 μm) are studied with a new type of bed-collapse technique, "isolated dilute-phase bed collapse," to determine the dense-phase properties under high superficial gas velocities. The properties of the emulsion and bubble phases are investigated by a video camera. The influence of particle size on particle collapse properties is also discussed. When gas velocities are high the 30-μm particles take the longest to collapse, have the smallest emulsion density, and have largest bubble volumetric fraction. These observations indicate that the 30-μm particles have a property that the others lack.

Introduction

The bed-collapse technique is important for fluidization research. By collapsing analysis, the properties of the emulsion and bubble phases in a bubbling fluidized bed can be obtained, that is, the emulsion voidage, the apparent gas velocities of emulsion and bubble phases, and the volumetric fraction of bubble phase (Rowe et al., 1986; Kwauk, 1983; Khoe et al., 1991). More importantly, estimation of the fluidizing characteristics of particles can be made by using the collapsing test (Geldart et al., 1985; Jean et al., 1992). The range of gas velocities in the former researches was usually several times the minimum fluidization velocity. Obviously, it is quite different from the operating velocity in the commercial fluidized-bed reactor. Few investigations have focused on the collapsing process of fine particles at high gas velocities. The reason is that at high gas velocities, due to the fall-out of a large amount of entrained dust to the dense phase, it is difficult to carry out collapsing experiments.

In order to overcome this difficulty, a new type of bed-collapse technique, "isolated dilute phase bed collapse," was developed by Cai et al. (1988). In this article, the collapsing processes for fine particles (Geldart groups A and C) at relatively high operating gas velocities (up to 0.33 m/s) are studied, and the influence of particle size on the collapsing process is analyzed.

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Experimental Studies

Apparatus

The experiments are carried out in a rectangular Plexiglas fluidized bed, with dimensions of 0.1 m $\times$ 0.05 m $\times$ 0.5 m. Figure 1 gives the configuration of the bed. It consists of two beds, the main and accompanying beds. An overflow weir is located between the two beds and a hopper is fixed on the top of the main bed for feeding particles. During the experiments, the expanded bed height of the main bed is held the same as that of the overflow weir by adding solids from the hopper. For this reason, the solids in the dilute phase will be brought to the accompanying bed, and the interference of dilute-phase solids can be avoided during the collapsing process. Thus, the collapsing test can be performed under high gas velocities. The windbox is filled with two layers of fine particles to reduce the influence of residual gas leakage on the collapsing process. The gas distributor is a plate with 1% open area, whose pressure drop at the lowest gas velocity is around several hundred pascals.

Procedure

A run is made using a video camera whose time resolution is 0.04 s in order to obtain the curve of the bed height changing with collapsing time. By using this method, the rapidly collapsing bed height can be determined with reasonable accuracy. During each operation, solids in the hopper fall down continuously and the expanded bed height of the main bed is equal to that of the overflow weir. When the system reaches steady state, which is independent of the feeding rate, the air

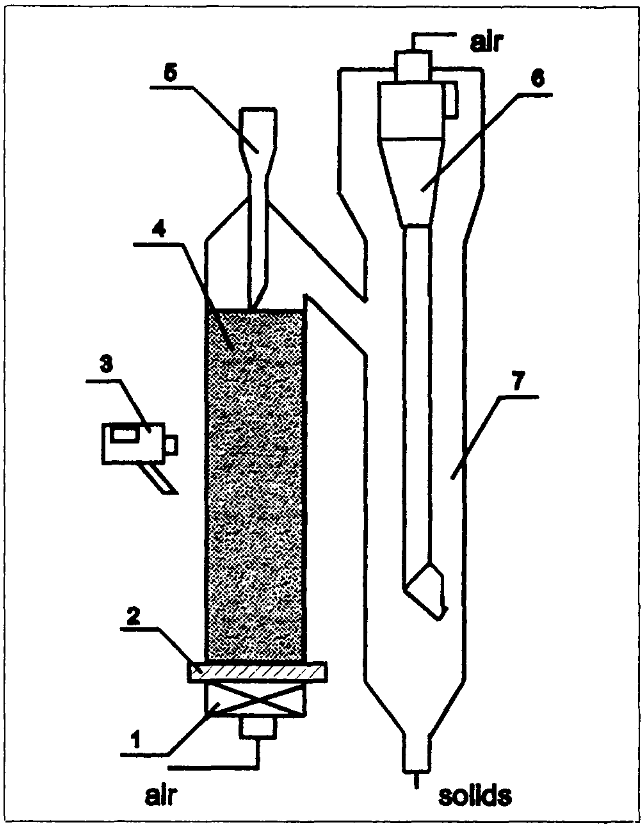

Figure 1. Experimental apparatus.

1. windbox; 2. distributor; 3. video camera; 4. main bed; 5. hopper; 6. cyclone; 7. accompanying bed.

supply is suddenly cut off by a solenoid valve and the collapsing height is recorded visually by the camera. At the moment when the air is cut off, the flow of solids from the hopper to the main bed is simultaneously cut off. During our experiments, large bubbles nearly the same size as the bed thickness are not observed. And for each operating condition, reproducible results are obtained.

Particles

The physical properties of the particles used in this work are given in Table 1, as is the minimum fluidization velocity. During the experiments, the superficial gas velocities are high, ranging from 0.05 to 0.33 m/s.

Table 1. Physical Properties of Particles

Particles	FCC (CRC-1)	FCC (CRC-1)	FCC (Y-15)
$\bar{d}_p$ (μm)	19	30	59
ρ_p (kg/m^3)	1,670	1,670	1,105
ρ_b (kg/m^3)	1,000	1,028	532
U_{mf} (cm/s)	0.04	0.12	0.52
Classification	C	C or A	A

*The bulk density is detected under the operating condition and without vibration.

Results and Discussion

Collapsing curve

Typical bed-collapsing curves obtained at high gas velocities with the improved method are shown in Figure 2. The bed-collapsing curve can be divided into three sections: the bubble escaping, sedimentation, and consolidation sections. When the air supply is cut off, the bed surface collapses very quickly at first, corresponding to the bubble escaping process. The decreasing rate of the bed height then slows down, indicating that the bubbles have completely escaped and the collapse enters the emulsion-gas escaping process. This slow collapsing rate is extrapolated to $t = 0.0$ s to obtain the bubble-free bed height (H_e), from which the voidage and apparent gas velocity in the emulsion phase can be derived.

As shown in Figure 2, the largest particles (59 μm) have the shortest collapsing time. As the particle size decreases to 30 μm, the collapsing time increases significantly, but after further reducing the particle size to 19 μm, the collapsing time will decrease. This happens because the finest particles have a strong tendency for aggregation, and this aggregation allows gas to escape easily from the bed.

Emulsion voidage

The emulsion voidage can be estimated from the collapsing curve as follows:

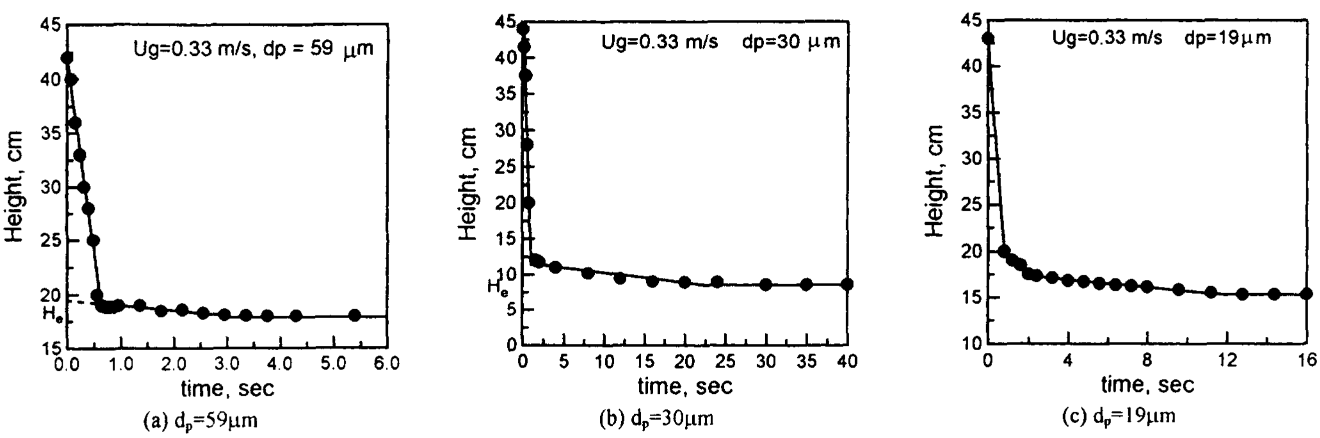

Figure 2. Typical collapsing curves for three kinds of fine particles.

(a) $d_p = 59$ μm; (b) $d_p = 30$ μm; (c) $d_p = 19$ μm.

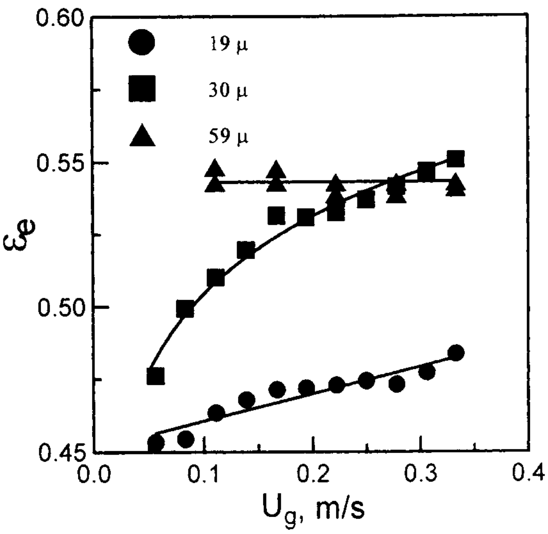

Figure 3. Emulsion voidage for three kinds of fine particles.

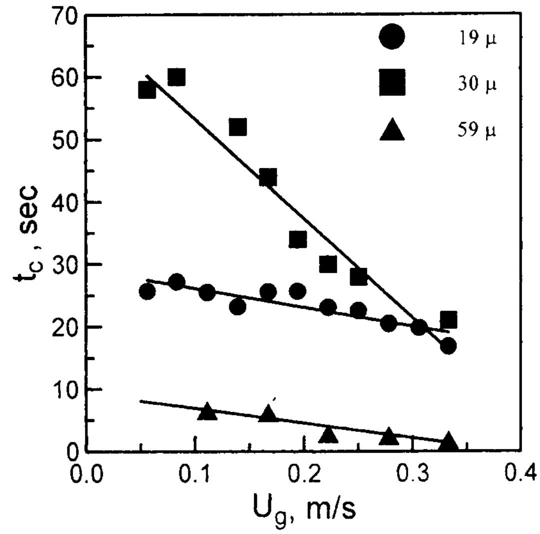

Figure 4. Total collapsing time for three kinds of fine particles.

$$\epsilon_e = 1 - \frac{H_s}{H_e}(1 - \epsilon_s), \tag{1}$$

where ϵ_s is the voidage of the packed bed, which can be calculated by the following equation:

$$\epsilon_s = 1 - \frac{\rho_b}{\rho_p}. \tag{2}$$

Figure 3 shows the emulsion voidage changing with gas velocity. The emulsion voidage for 59-μm particles keeps constant as the gas velocity changes from 0.11 m/s to 0.33 m/s, indicating a consistency with the two-phase model, which hypothesizes that the emulsion voidage is constant when the gas velocity increases. However, for 30- and 19-μm particles, the emulsion voidage will increase as the gas velocity increases. This is especially true for 30-μm particles. This is contrary to the ordinary two-phase model. This happens because the small particles have a strong tendency for aggregation and can form relatively stable agglomerates, which cannot be destroyed at low gas velocities. Due to the many agglomerates in the emulsion phase, the voidage at low gas velocities is small. As the gas velocity increases, the agglomerates will be destroyed and the emulsion voidage will gradually increase. The increase in emulsion voidage may be different for different particle sizes. The agglomerates of 30-μm particles are more easily destroyed and the emulsion voidage will increase quickly with gas velocity. The agglomerates of 19-μm particles have a relatively strong form and are not easily destroyed. For 59-μm particles, no agglomerates are formed in the emulsion phase and the emulsion voidage will remain constant as gas velocity increases.

The total collapsing time of the bubble and emulsion phases, t_c, for three kinds of fine particles is shown in Figure 4. It is found that 30-μm particles show the longest collapsing time over the experimental range of the gas velocity. At lower gas velocities, the collapsing time for 30-μm particles can be as long as 60 s, which is nearly twice as long as for 19-μm particles. This observation indicates that the aggregation ability of the 30-μm particles is smaller than that of 19-μm particles. For 59-μm particles, because of the larger particle size and larger space for gas to escape, the bed-collapsing speed is fast and the collapsing time is only several seconds, much shorter than that for 30- and 19-μm particles. For 19-μm particles, because of strong interaction among particles, the fine particles will form larger agglomerates and the collapsing time is not long, ranging from 20 to 30 s. For 30-μm particles, their size is relatively small and their aggregation tendency is also low, so they show the longest collapsing time. In other words, the fluidized bed with 30-μm particles is the most difficult to be defluidized.

Apparent gas velocity of emulsion and bubble phases

The apparent gas velocity of the emulsion phase, U_e, can be obtained by calculating the slope of the sedimentation section in the collapsing curve. Figure 5 shows the relationship between operating gas velocity and U_e. For 19-μm and 59-μm particles, the apparent gas velocities of the emulsion phase slightly increase with the operating gas velocities, but U_e for 30-μm particles increases with operating gas velocity remarkably. This observation explains why the emulsion voidage of 30-μm particles greatly increases with the operating gas velocity, as is shown in Figure 3. The change of U_e with the operating gas velocity for 30-μm particles is obviously inconsistent with the two-phase model, which assumes that the properties of the emulsion phase will keep constant at different gas velocities.

The apparent gas velocity of bubble phase, U_b, can be obtained by the following equation:

$$U_b = U_g - U_e. \tag{3}$$

Because the apparent gas velocity of emulsion phase, U_e, is much smaller than the superficial gas velocity, U_g, the apparent gas velocity of the bubble phase is very close to the super-

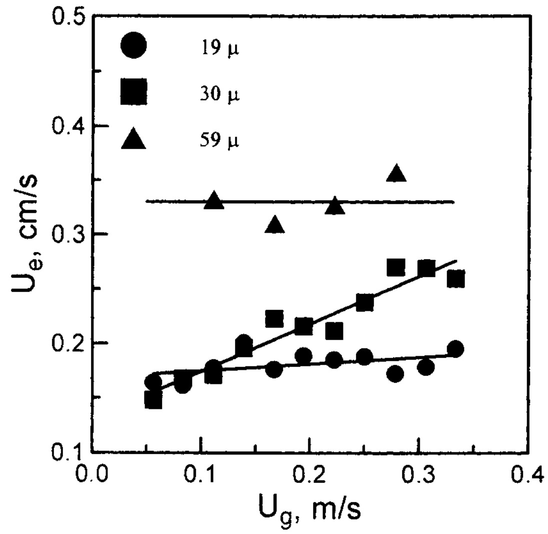

Figure 5. Influence of gas velocity on U_e for three kinds of fine particles.

ficial gas velocity. This means that most of gas passes through the bed in the form of bubbles.

Volumetric fraction of bubble phase

The volumetric fraction of bubble phase, f_b, is a better representation of the fluidization quality from the viewpoint of reaction engineering. The volumetric fraction of the bubble phase can be calculated from the following equation:

$$f_b = \frac{H_{ex} - H_e}{H_{ex}} \tag{4}$$

Figure 6 plots the influence of the gas velocity on f_b. For all three kinds of particles, the volumetric fraction of the

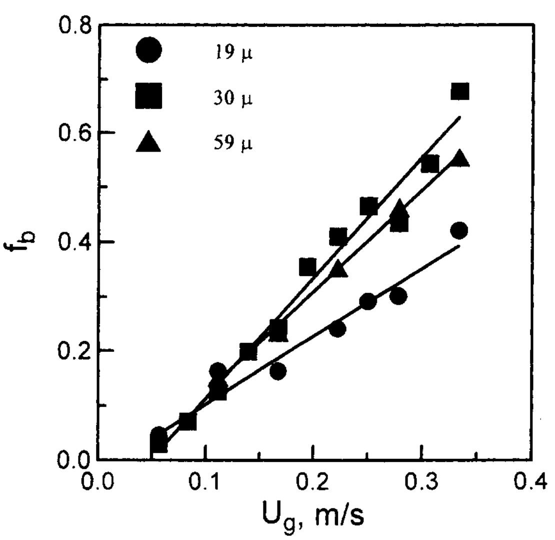

Figure 6. Influence of gas velocity on f_b for three kinds of fine particles.

bubble phase increases linearly with gas velocity, as shown in Figure 6. Among the three kinds of particles, 30-μm particles have the largest volumetric fraction of the bubble phase; that is, the largest bed expansion can be achieved by 30-μm particles. A further reduction of particle size will cause strong particle aggregations and thus decrease the volumetric fraction of the bubble phase.

In general, the preceding changes in collapsing properties for different particle sizes may have a large influence on the heat and mass transfer and the reaction selectivity of the fluidized bed reactor. Further studies of the effects of particle size on fluidized bed properties are urgently needed.

Conclusions

The influence of the particle size on particle-collapsing properties has been discussed. It was found that under high gas velocities the 30-μm particles have the longest collapsing time, the smallest emulsion density, and the largest volumetric fraction of the bubble phase. It may therefore be supposed that the 30-μm particle is the best size of catalyst for future fluidized-bed reactors. It was also found that the two-phase model for the bubbling fluidized bed can cause problems for 30-μm particles

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Notation

A = cross-sectional area of the column, m^2
d_p = particle diameter, μm
H_{ex} = expanded bed height, m
H_S = settled bed height, m
U_{mf} = minimum fluidization velocity, m/s
ρ_p = particle density, kg/m^3
ρ_b = bulk density of particles, kg/m^3

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