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Powder Coating Efficiency of Small Particles and Their Agglomeration in Circulating Fluidized Bed

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Abstract–The coating efficiency of fluidizing small particles and their agglomeration were investigated to evaluate the possibility of powder coating by the use of a circulating fluidized bed. Glass beads, whose mean diameter was 43 μm, and silica powder of 1 μm were used as a core and a coating material. Polyvinyl alcohol was used as a binder and its solution was supplied together with silica powder from a spray nozzle equipped in the circulating fluidized bed. Glass beads of 43 μm, which had been impossible to coat in a conventional fluidized bed coater, were successfully coated with silica powder in a circulating fluidized bed, and agglomeration among core particles was prevented. From this result, it was confirmed that a circulating fluidized bed performs excellently as a coater, especially for fine core particles, so a circulating fluidized bed coater has bright prospects for particle coating.

Key words : Coating, Circulating Fluidized Bed, Agglomeration, Binder, Spray

INTRODUCTION

Coating by the use of a fluidized bed has been broadly applied in the pharmaceutical, fertilizer, food and other industries for the addition of high quality and valuable performance to particle products. Until recently, coating in a fluidized bed has been mainly performed by the atomization of the organic solution of the coating material, especially in the pharmaceutical field. However, the use of atomization of a powder suspension in an aqueous solution is spreading because of problems in the organic solution, such as a remaining organic compound, environmental pollution and toxicity to health. Consequently, the powder coating of fluidizing particles has become of major interest lately. Nevertheless, few fundamental reports for powder coating in a fluidized bed have been published. Abe et al. [1985, 1986] reported the coating of Roseki, or clay on sands and limestones in a tumbling fluidized bed with rotating disk. In this paper, they evaluated the influence of thermal operating factors upon coating efficiency. Tsutsumi et al. [1996] investigated the possibility of fine particle coating by the use of supercritical fluid solution. They reported that microspheroidal catalyst particle 56 μm in diameter was coated successfully with fine paraffin particles by this method.

The authors coated glass beads by nylon or silica powder in a bubbling fluidized bed, and reported the relationship between operational conditions and the coating efficiency [Kage et al., 1996]. From these coating experiments, it was proved that in many cases of the powder coating of fluidizing particles, agglomeration among core particles is inclined to progress, and low quality coating products, including many cores, are easily made under the operating conditions where atomized powder coats the core particles effectively and a high coating efficiency is obtained [Kage et al., 1998]. Furthermore, the smaller fluidizing particle is liable to agglomerate markedly, and it is next to impossible for a conventional fluidized bed to coat particles smaller than 50 μm. Therefore, for excellent coating, some external forces, such as vibration, are required to act on core particles to prevent their agglomeration [Kage et al., 1999]. Whereas, high coating efficiency is obtained when the fluidizing particles are circulated regularly in the bed, because the adhesion of coating powder on core and the drying of binder solution take place in turn.

The authors have adopted a circulating fluidized bed as a coating apparatus from a judgment based on the idea that a circulating fluidized bed satisfies the conditions mentioned above, and have examined its possibility and performance as a coater [Kage et al., 1997]. The expected advantages of the circulating fluidized bed coater are as follows:

(1) Effective coating of core particle by powder is expected, because the core circulates in the bed regularly and constantly and then the adhesion of coating powder on the core and the drying of the binder solution take place in turn.

(2) Agglomeration among core particles is prevented by the violent particle movement in the circulating fluidized bed.

(3) Lower thermal energy is required for fluidizing gas, because the heat transfer between solid and gas in the circulating fluidized bed is much better than in a conventional bubbling fluidized bed coater.

The authors already confirmed that high coating efficiency was obtained without the progress of agglomeration among core particles in a wide range of operational variables, and reported that excellent coating of glass beads whose diameter was 198 μm was achieved [Kage et al., 1997]. In this paper,

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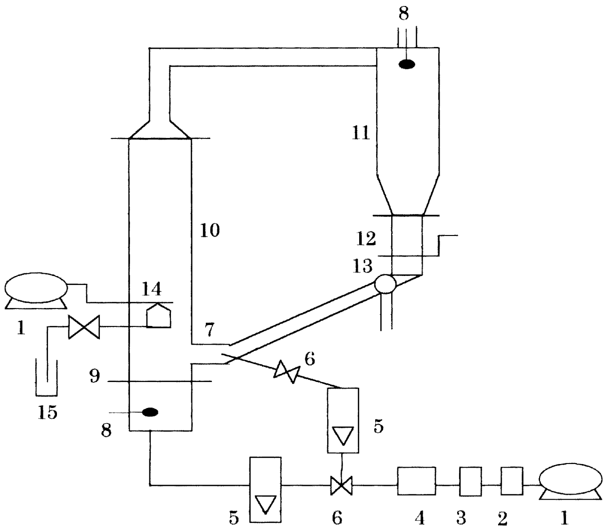

Fig. 1. Schematic diagram of experimental apparatus.

1. Compressor
2. Air filter
3. Oil eliminator
4. Air drier
5. Rotameter
6. Valve
7. Air injection nozzle
8. Thermometer
9. Distributor
10. Raiser
11. Cyclone
12. Shutter
13. Sampling port
14. Spray nozzle
15. Suspension tank

we try coating a 43 μm core particle in a circulating fluidized bed, and the experimental results are compared with the coating data of the 198 μm core.

EXPERIMENTAL APPARATUS AND PROCEDURE

A schematic diagram of the experimental apparatus is illustrated in Fig. 1. The diameter of the riser and its height above the distributor were 85 mm and 1.5 m, respectively. A cyclone was attached on the top of the riser. The downcomer, whose diameter was 19 mm, was connected to the bottom of the cyclone through a sampling port. Glass beads were used as core particles and were coated with silica fine powder. Silica was suspended in binder aqueous solution and atomized upward by a two-phase nozzle equipped in the riser. The nozzle height was 19 cm from the distributor. Polyvinyl alcohol (PVA, average molecular weight was 22000) was used as a binder. Glass beads prepared in the bed column in advance were conveyed upward by the air which was supplied from distributor and whose temperature and humidity were adjusted by the preheater and the drier, and separated from gas by the cyclone. They fell inside of the downcomer and were forced to be recycled by the air injected from an air injection nozzle. The solid circulation rate was measured by a shutter inserted between the cyclone and the sampling port.

After the circulating fluidized bed was sufficiently preheated by the air, silica powder suspension began to be atomized from the nozzle. The experimental period for coating was 60 minutes. During the experimental run, small amounts of particles were sampled from the sampling port every 10 to 20 minutes and the weight of silica deposited on the core was measured to determine the coating rate and efficiency. The coating efficiency was defined by Eq. (1).

Table 1. Particulate data

	Core	Coating material
Material	Glass	Silica
Particle size, mesh	330-425, 60-80	Monodispersed
Mean diameter, μm	43, 198	1.0
Density, kg/m^3	2520	2200

Table 2. Experimental condition

Content of core particle, kg	0.3
Weight ratio of fine particle to binder solution, -	0.117
Feed rate of suspension, F_s, m^3/min	0.5-5.41×10^{-6}
Mass fraction of binder in solution, C_b, -	0.0025-0.015
Superficial gas velocity in riser, u, m/s	0.68-2.12
Solid circulation rate, G_s, kg/m^{2}s	0.35-3.75
Inlet temperature of fluidizing gas, T, °C	30-70

$$E=\frac{\text{(Rate of powder deposition on core particles)}}{\text{(Feed rate of powder supplied from the spray nozzle)}} \quad (1)$$

The particles coated in the bed were sieved by 60 or 330 mesh screen at the end of each coating experimental run. The weight fraction of particles that were passed through the screen was measured, and it was regarded as the weight fraction of a single-core particle, Y, in order to evaluate the degree of agglomeration among core particles.

The data of used particles and experimental conditions are summarized in Tables 1 and 2.

RESULTS AND DISCUSSION

1. Effects of Suspension Feed Rate and Fluidizing Gas Temperature on Coating Efficiency

Figs. 2 and 3 show the effect of the feed rate of suspension on the coating efficiency of core particles 43 μm and 198 μm in diameter, respectively. In the coating of the 198 μm core, a high coating efficiency was achieved in wide ranges of gas temperature, T, and suspension feed rate, F_s. However, the coating efficiency of the 43 μm core particle was lower than the 198 μm core, because the coating was performed with the heavier fluidization in order to prevent the progress of agglomeration among smaller core particles. The coating efficiency indicated in Fig. 2 increases with the suspension feed rate, while it is almost independent of the gas temperature.

2. Effects of Suspension Feed Rate and Fluidizing Gas Temperature on Agglomeration

The progress of agglomeration among core particles makes a multi-core coating product and deteriorates its quality. In the extreme case, large agglomerates grown up in the bed stop the fluidization. Therefore, the performance of the circulating fluidized bed against agglomeration was examined.

Figs. 4 and 5 show the relationships between the suspension

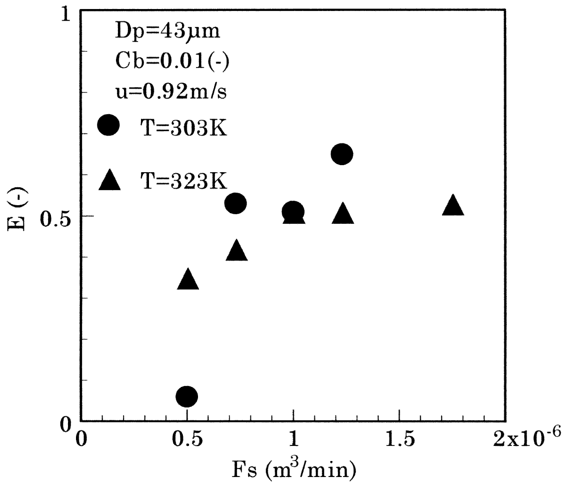

Fig. 2. Effects of suspension feed rate and gas temperature on coating efficiency.
(D_p: 43 μm)

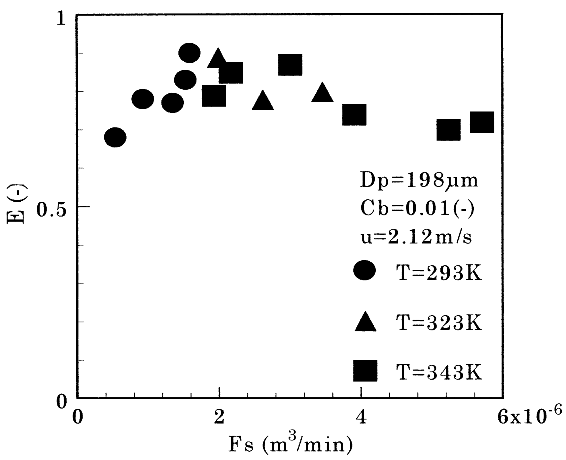

Fig. 3. Effects of suspension feed rate and gas temperature on coating efficiency.
(D_p: 198 μm)

feed rate and the weight fraction of a single-core particle under the same operating conditions as Figs. 2 and 3. In the powder coating in a conventional bubbling fluidized bed coater, agglomeration usually progresses markedly when feed rate suspension increases, even for the coating of the 198 μm core. However, Y in Fig. 5 is close to unity regardless of the operating conditions, which shows that agglomeration was almost completely prevented. Furthermore, it is confirmed that powder coating without agglomeration among core particles was possible enough even by the use of the fluidizing gas of 20 or 30 °C, which is almost room temperature, because the weight fractions of single-core particles in Figs. 4 and 5 are sufficiently high except at some high suspension feed rates of the coating of 43 μm core. In practice, the coating has been very difficult to achieve by room temperature gas in a conventional bubbling fluidized bed coater, because of insufficient heat supply and incomplete drying. From these results, it was confirmed that lower thermal energy is required for the coating in a circulating fluidized bed because of its effective heat transfer between fluidi-

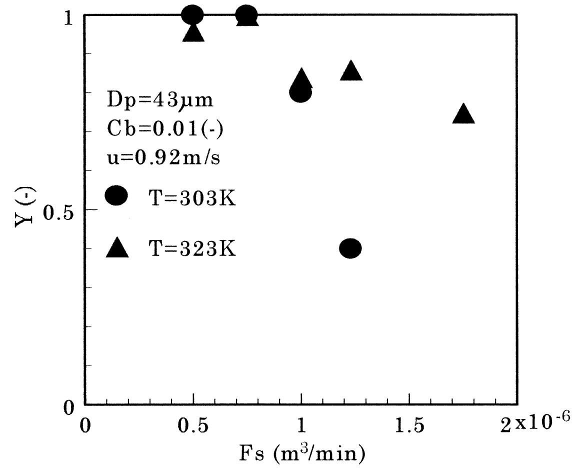

Fig. 4. Effects of suspension feed rate and gas temperature on agglomeration.
(D_p: 43 μm)

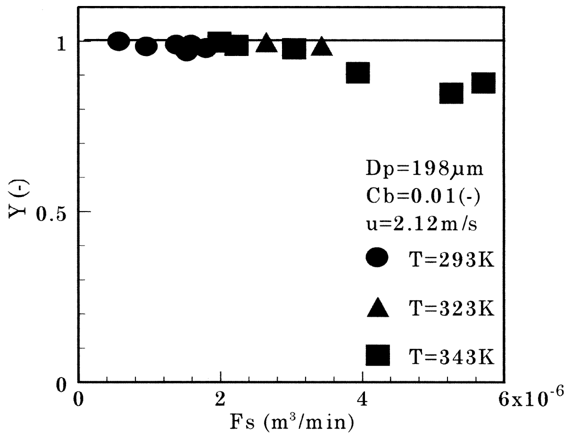

Fig. 5. Effects of suspension feed rate and gas temperature on agglomeration.
(D_p: 198 μm)

zing particles and gas. Further, a circulating fluidized bed is considerably effective for the prevention of agglomeration and is expected to be used as an excellent coater, especially for small core particles. Nevertheless, agglomeration in the coating of the smaller core particle progressed more easily with low temperature gas and with high feed rate of suspension than that in the coating of 198 μm core.

3. Effect of Binder Concentration on Coating Efficiency and Agglomeration

The effect of binder concentration in the atomized suspension on the coating efficiency and the agglomeration is shown in Figs. 6 and 7. In the coating of the smaller particle, lower coating efficiency was obtained. Further, both coating efficiency of 43 and 198 μm decreased, as the binder concentration became low. When the binder concentration is low, the binding forces between silica particle and glass bead and between silica particles become weaker. In this case, the coating layer formed on the fluidizing core particles is easily worn away by the violent particle movement in a circulating fluidized bed, because it is not so strong and does not settle incompletely on the core surface.

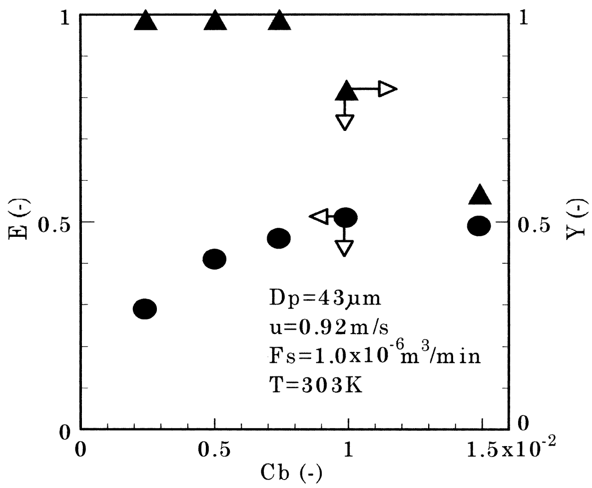

Fig. 6. Effect of binder concentration on coating efficiency and agglomeration.
(D_p: 43 μm)

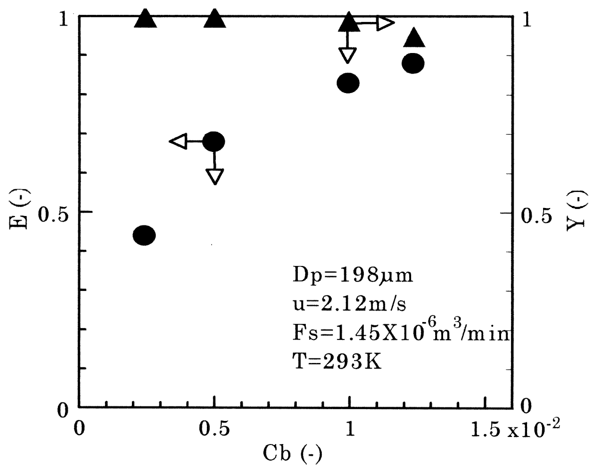

Fig. 7. Effect of binder concentration on coating efficiency and agglomeration.
(D_p: 198 μm)

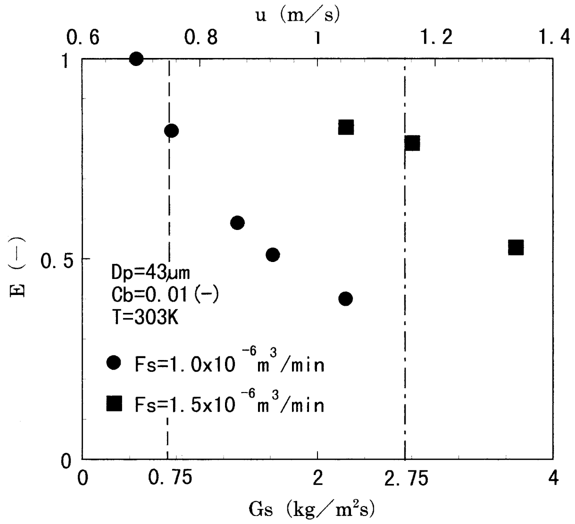

Fig. 8. Effects of solid circulation rate and suspension feed rate on coating efficiency.

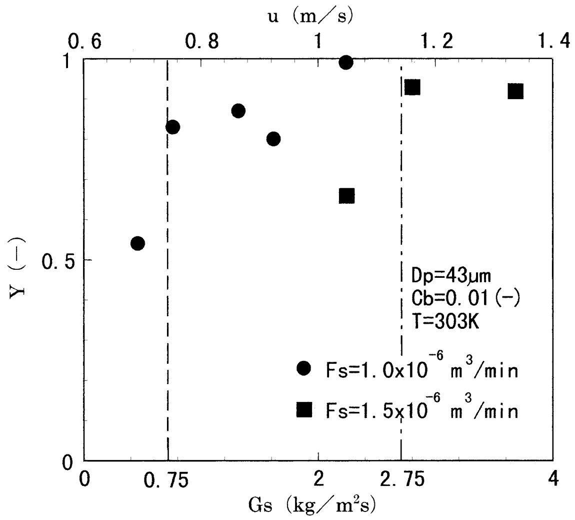

Fig. 9. Effects of solid circulation rate and suspension feed rate on agglomeration.

In the coating of 198 μm glass beads, the agglomeration among core particles was almost completely prevented. In the case of 43 μm, the agglomeration gradually progressed due to the strong adhesive force of binder, as the binder concentration increased.

4. Effect of Solid Circulation Rate on Coating Efficiency and Agglomeration

Figs. 8 and 9 indicate the effect of solid circulation rate, G_s, on the coating efficiency and the agglomeration among 43 μm core particles, respectively. The solid circulation rate was adjusted by the velocity of fluidizing gas supplied from distributor. u of the upper abscissa shows the superficial gas velocity corresponding to the solid circulation rate, G_s, indicated by the lower abscissa. The coating efficiency decreases, as the solid circulation rate becomes large, because the coating layer formed on the core is worn out due to violent particle movement in a circulating fluidized bed. The agglomeration is also prevented by the heavy movement of particles. According to Figs. 8 and 9, when the solid circulation rate is adjusted at 0.75 kg/m^{2}s, both a coating efficiency higher than 0.8 and a weight fraction of single-core particle larger than 0.8 are realized. Thus, an excellent coating of 43 μm particle with high efficiency and prevented agglomeration is achieved by this circulation rate for 1.0×10^{-6} m^3/min of the suspension feed rate. For 1.5×10^{-6} m^3/min of the feed rate, it is also done at 2.75 kg/m^{2}s of solid circulation rate. If an adequate solid circulation rate is chosen, the low coating efficiencies of 43 μm core particle shown in Figs. 2 and 6 are also expected to be higher.

Glass beads of 43 μm, which had been impossible to coat in a conventional fluidized bed coater, could be coated effectively by silica powder in a circulating fluidized bed. This success has an important meaning in the field of coatings and reforming of particle surfaces. Furthermore, from this result, it was confirmed that circulating fluidized beds have excellent performance as a coater, especially for fine core particles.

CONCLUSIONS

The following conclusions were drawn for the silica coating of glass beads in a circulating fluidized bed.

1. The coating of glass beads of 43 μm in diameter was less effective than that of 198 μm core, because of the generation of agglomerates.
2. For effective coating of the 43 μm core, the suspension feed rate and the binder concentration should be increased and the solid circulation rate should be decreased.
3. For a high quality coating of the 43 μm core without agglomeration among cores, the suspension feed rate and the binder concentration should be decreased and the solid circulation rate should be increased.
4. It was confirmed that the 43 μm particle, which had been impossible to coat in a conventional fluidized bed coater, was successfully coated in a circulating fluidized bed with the fluidizing gas at room temperature, providing that the adequate operating condition was chosen.

A circulating fluidized bed has bright prospects for the prevention of agglomeration in the coating of particles smaller than 50 μm.

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NOMENCLATURE

C_b : mass fraction of binder in binder solution [-]
D_p : diameter of core particle [μm]
E : coating efficiency defined by Eq. (1) [-]
F_s : feed rate of suspension [m^3/min]
G_s : solid circulation rate [kg/m^2s]
T : temperature of fluidizing gas at distributor [ºC]
u : superficial gas velocity in riser [m/s]
Y : weight fraction of single-core particle [-]

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