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Bubble Behavior in Centrifugal Fluidized Bed of Fine Particles

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원심유동층에서 Al_2O_3의 기포 거동에 관한 연구

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Abstract The behavior of bubbles in a centrifugal fluidized bed with a 340㎜ inner diameter, 195㎜ high was observed by photographs using 10.5㎛ and 21.5㎛ mean diameter of Al_2O_3 particles as bed materials at each of 400rpm, 600rpm, 800rpm, and 1000rpm number of rotations of the rotor. At these experimental ranges, the experimental results clearly proved the effect of number of rotations of the rotor on the behavior of bubbles in the centrifugal fluidized bed. As the number of rotations of the rotor increased, the gas velocity at which bubbles begin to be formed also increased but diameter of bubbles decreased. And sizes of the bubbles were relatively small.

요 약 직경 340mm, 높이 195mm의 원심유동층에서 10.5㎛와 21.5㎛의 평균직경을 갖는 Al_2O_3를 유동물질로 하여 400, 600, 800, 1000rpm으로 기포의 거동을 규명하고자 2중사진 촬영에 의해 유동가시화현상을 실험하였다. 실험결과, 본 실험 범위에서 원심유동층에서 기포의 거동은 회전수에 영향을 받는 것을 알 수 있었으며, 회전수가 증가함에 따라 기포가 발생하기 시작하는 속도는 증가하였으나 기포의 직경은 감소하는 것을 알 수 있었고 기포의 크기는 상대적으로 작게 나타났다.

Key Words : Fluidization, Fluidized bed, Centrifugal fluidized bed, Bubble behavior, Fine particle, Pressure drop

1. INTRODUCTION

As new materials are developed recently, the use of fine particles is required more than ever before. The concept of centrifugal fluidized bed shows excellent promise for application where relatively small particles must be used[1-3]. Generally for a given bed geometry and particle density, the important variables are the total weight of bed materials, distributor angle, distributor pressure drop, angular velocity of the bed, and the particle diameter.

These variables interact in a complex manner to govern bed start up, minimum fluidization and particle elutriation. The centrifugal fluidized bed can be operated with properly varied number of rotations of the rotor at high gas velocity[1-4]. So fine particles under 20㎛ particle diameter which were difficult to be used in the gravitational fluidized bed can be used in the centrifugal fluidized bed.

As the production of larger bubbles is restrained in centrifugal fluidized bed, the contact between gas and solid in that system is improved. In this research, the behavior of bubbles - bubbles rising velocity, minimum bubbling velocity, and bubble size was taken photographs to be observed at various numbers of rotations of rotor and gas velocity in centrifugal fluidized bed using fine

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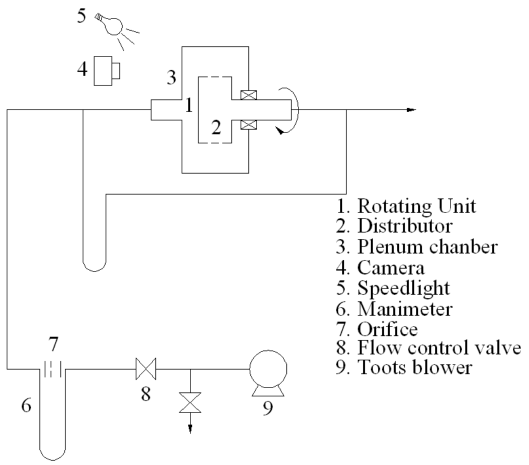
particles. Bed pressure drop and expansion were also examined.

2. EXPERIMENTAL APPARATUS AND PROCEDURE

A schematic diagram of the centrifugal fluidized bed is shown Fig. 1. The bed consisted of a plenum chamber, a rotor, and gas distributor. Both the plenum chamber and the rotor were made of stainless steel.

The rotor was 184㎜ internal diameter and 50㎜ wide. The gas distributor was a cylindrical sintered stainless steel plate of 100㎛ pore size. The rotor and the plenum chamber was covered with transparent acrylic resin plate in order to be taken pictures. 10.5㎛ and 21.5㎛ mean diameter of Al_2O_3 particles were used as bed materials usually at each of number of rotations of the rotor 400rpm, 600rpm, 800rpm, and 1000rpm and at the ranges of 0.01m/s~0.40m/s gas velocity. 400g of Al_2O_3 particles were put into the rotor, then rotor was rotated and the particles were fluidized by flowing air from blower.

Pressure drop was measured by U-tube manometer at each of air velocities. The double exposure photographs were taken with two speed lights of intervals of 0.0035 second operated. Table 1 shows the properties of Al_2O_3 particles and the experimental ranges.



[Fig. 1] Experimental apparatus

[Table1] Properties of Al_2O_3 particles and experimental ranges

Al_2O_3			Experimental ranges	
Mean diameter (㎛)	Ranges of diameter (㎛)	Density (kg/㎥)	Rotor (rpm)	Gas velocity (m/s)
21.5	18.0~25.0	1900	400, 600, 800, 1000	0.01 ~ 0.40
10.5	8.5~12.5	1900		

3. EXPERIMENTAL RESULT AND DISCUSSION

3.1 MINIMUM FLUIDIZATION VELOCITY

As the gas velocity through the distributor of fluidized bed is increased, fluidization begins at surface of the packed bed. With more increased gas velocity, the fluidization expand to the whole bed. Equation for the bed pressure drop needed to fluidize this bed is following :

$$\triangle P_{bed} = \frac{\int_{ri}^{ro} 2\pi(\rho_p - \rho_f)(1-\varepsilon) r^2 \omega^2 dr}{2\pi r_o} \tag{1}$$

$$= \frac{W\omega_o^2}{2\pi L}\left(\frac{2}{3}\frac{1-R^3}{1-R^2}\right) \tag{2}$$

$$R = r_i / r_o \tag{3}$$

The pressure drop through a packed bed with a differential radius of dr can be expressed as correlated by Ergun[5].

$$\frac{dp}{dr} = \phi_1 U_r + \phi_2 U_2^2 \tag{4}$$

where ϕ_1 and ϕ_2 are defined, respectively, as

$$\phi_1 = 150(1-\varepsilon)^2 \mu_f / \left(\phi_s^2 \varepsilon^3 d_p^2\right)$$
$$\phi_2 = 1.75(1-\varepsilon)^2 \rho_f / \left(\phi_s \varepsilon^2 d_p\right)$$

The continuity of fluid requires that

$$U_r = U_o(r_o / r) \tag{5}$$

Thus,

$$\triangle p_{bed}(packed) = \phi_1 U_{ro} r_o \ln\frac{r_o}{r_i} + \phi_2 U_{ro}^2 r_o^2 \left[\left(\frac{1}{r_i} - \frac{1}{r_o}\right)\right] \quad (6)$$

where

g : gravitational acceleration(m/s^2)

ΔP : pressure different(mmH_2O)

r : radius(mm)

r_i : inside radius of bed(mm)

r_o : outside radius of bed(mm)

U : superficial fluid velocity in packed bed(m/s)

U_{mb} : minimum bubbling velocity(m/s)

U_{mf} : minimum fluidization velocity(m/s)

ρ_f : fluid density(kg/m^3)

ρ_p : particle density(kg/m^3)

ε : voidage fraction

ω : angular velocity(rad/s)

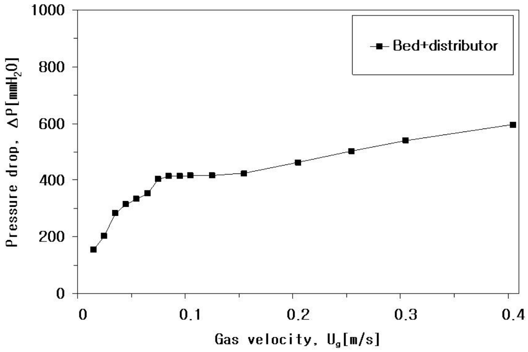
ϕ_s : sphericity of the solid particles

μ_f : fluid viscosity($kg \cdot s/m^2$)

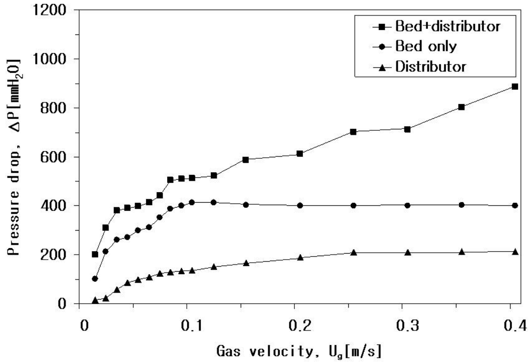
Minimum fluidization velocity can be obtained solving U_r at equation (1) equal to equation (2), [6-9].

Fig. 2 to 9 show the relationship between bed pressure drop and gas velocity using 10.5㎛ and 21.5㎛ mean diameter of Al_2O_3 particles at each of the number of rotations of the rotor.

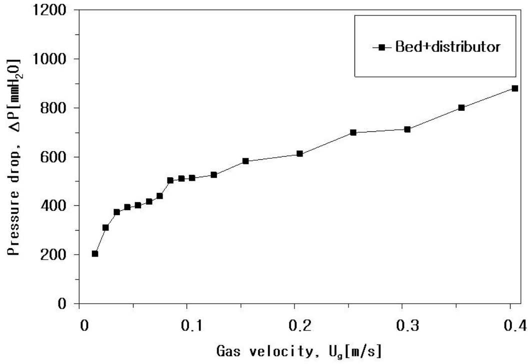
As shown in these figures, the minimum fluidization velocities were presented at the gas velocity of around 0.08 m/s. It will be clearly improved the fluidization at each experimental conditions.



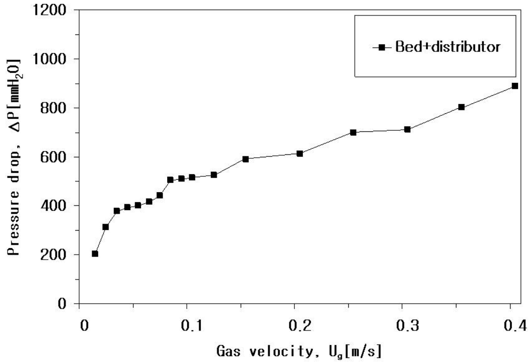
[Fig. 5] Pressure drop versus gas velocity at room temperature(Al_2O_3, 10.5㎛, 1000rpm)



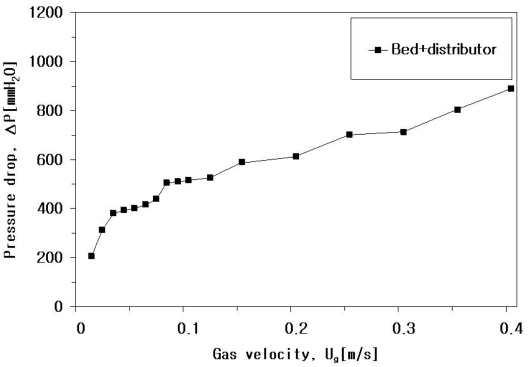
[Fig. 6] Pressure drop versus gas velocity at room temperature(Al_2O_3, 21.5㎛, 400rpm)



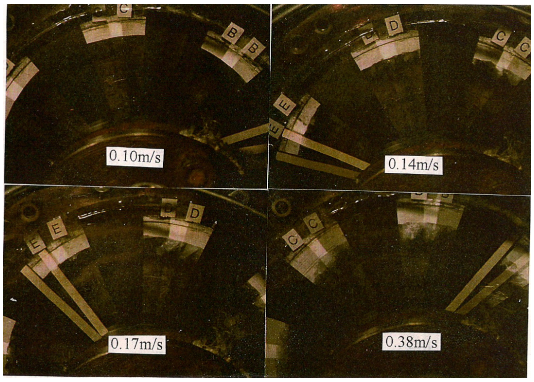
[Fig. 7] Pressure drop versus gas velocity at room temperature(Al_2O_3, 21.5㎛, 600rpm)



[Fig. 8] Pressure drop versus gas velocity at room temperature(Al_2O_3, 21.5㎛, 800rpm)



[Fig. 9] Pressure drop versus gas velocity at room temperature(Al_2O_3, 21.5㎛, 1000rpm)



[Fig. 10] Photographs for the behavior of bubbles (21.5㎛, 400mm)

3.2 BUBBLE FORMATION AND GROWTH

The variation of bed expansion, bubble formation and growth were observed from the photographs at each of particle diameter and rotation number of the rotor according to gas velocity. Rough voidage of the bed was calculated based on the bed height of before bubble formation.

$$\varepsilon = \frac{H - H_o}{H_o} \qquad (7)$$

where

H : bed height of after bubble formation

H_0 : bed height of before bubble formation

Fig. 10 shows the photographs for the bed expansion before and after bubble formation and behavior of bubbles at each "C" marked spot according to gas velocity in the centrifugal fluidized bed using 21.5㎛ mean diameter of Al_2O_3 particle at 400rpm the number of rotations of rotor as function of gas velocity.

As shown in the photographs, only bed height is varied with gas velocities at the ranges of gas velocity 0.007m/s~0.10m/s. Bubbles were fully produced at 0.14m/s gas velocity then the bubble grew actively. The bed height increased 31.0% than before the gas velocity of bubble production(at the gas velocity of 0.10m/s) as shown in table 2.

[Table 2] Variations of bed height and bed voidage (21.5㎛, 400rpm, * : Minimum bubbling velocity)

Gas velocity (m/s)	0.04	0.10	0.14	0.17	0.38
Bed height (mm)	9.21	8.21	10.13	9.87	10.75
Voidage		A basis	* 0.23	0.20	0.31

In case of 600rpm, bubbles begin to be formed at 0.20m/s gas velocity. And the bed height at fully bubbling velocity increased 10.7% than before the gas velocity of bubble production(at the gas velocity of 0.16m/s) as shown in table 3.

[Table 3] Variations of bed height and voidage (21.5㎛, 600rpm)

Gas velocity (m/s)	0.03	0.05	0.16	0.20	0.40
Bed height (mm)	9.03	9.03	1.74	9.61	10.78
Voidage	A basis		0.08	0.06	0.19

In case of 800rpm, bubbles begin to formed at 0.36m/s gas velocity. And the bed height at the velocity increased 15.4% than before bubble production (at the gas velocity of 0.25m/s)

[Table 4] Variations of bed height and bed voidage (21.5㎛, 800rpm)

Gas velocity (m/s)	0.14	0.25	0.36
Bed height (mm)	6.90	17.15	8.25
Voidage		A basis	0.15

In case of 1000rpm, none were observed at these experimental ranges 0.001m/s to 0.35m/s gas velocity. And in case of 10.5㎛ mean diameter of Al_2O_3 particle at 400rpm, bubbles begin to be formed at 0.10m/s gas velocity, lower than that of 21.5㎛ at the same number of rotations of the rotor. Therefore, the bed height increased to be maximum 13.25mm, ratio of increasing was 228.4%.

[Table 5] Variations of bed height and voidage (10.5㎛, 400rpm)

Gas velocity (m/s)	0.03	0.10	0.17	0.17	0.27
Bed height (mm)	5.80	8.34	18.05	19.05	18.70
Voidage	A basis	0.44	2.11	2.28	2.22

In case of 600rpm using 10.5㎛ mean diameter particle, bubbles begin to be formed at 0.26m/s gas velocity. But none were observed at 800rpm and 1000rpm even at 0.30m/s gas velocity. Table 6 shows the summary of the minimum bubbling velocities at each number of rotations of the rotor with 10.5㎛ and 21.5㎛ mean diameter Al_2O_3 particle.

As number of rotations of the rotor increased, the gas velocity at which bubbles begin to be formed also increased as shown in table 6.

[Table 6] Summary of minimum bubbling velocity : U_{mb}

Particle mean diameter (㎛)	Number of rotations (rpm)	Umb (m/s)
21.5	400	0.14
21.5	600	0.20
21.5	800	0.36
21.5	1000	-
10.5	400	0.10
10.5	600	0.26
10.5	800	-
10.5	1000	-

3.3 SIZE OF BUBBLE

Diameter of the bubbles was calculated with arithmetic mean of two axes of the bubbles, that is

$$D_b = (L_b + T_b)/2\ (mm) \tag{8}$$

where

D_b : bubble diameter(mm)

L_b : longitudinal length of bubble(mm)

T_b : transverse length of bubble(mm)

[Table 7] Variations of bubble size(21.5㎛, 400rpm) (A basis is "D")

Gas velocity(m/s)	0.14	0.17	0.38
Bubble diameter(mm)	5.03	9.28	13.90

Table 7 to 10 show diameter of the bubble at each of the particle diameter, rotation number of the rotor, and the gas velocity of same marked spot. Generally at each of particle diameter as the gas velocity increased, diameter of bubbles also increased as shown in table. But as the rotation number of the rotor increased, diameter of bubble decreased. The suggested reason is the larger bubble production is restrained as the gravitational acceleration increased with increasing rotation number of the rotor[10, 11]. And the diameter of the bubbles is from 1.51 to 13.90mm and mean diameter of the bubble is 5.99mm in this experiments. Therefore, the contact between gas and solid in centrifugal fluidized bed will be improved.

[Table 8] Variations of bubble size(21.5㎛, 600rpm) (A basis is "E")

Gas velocity(m/s)	0.25	0.39
Bubble diameter(mm)	2.33	7.98

[Table 9] Variations of bubble size(21.5㎛, 800rpm) (A basis is "E")

Gas velocity(m/s)	0.33	0.38
Bubble diameter(mm)	3.75	5.00

[Table 10] Variations of bubble size(10.5㎛, 400rpm) (A basis is "F")

Gas velocity(m/s)	0.10	0.17	0.27	0.20
Bubble diameter(mm)	4.49	7.33	7.08	7.85

3.4 RISING VELOCITY OF BUBBLE

Two rising bubbles with intervals of 0.0035 second was observed from the double exposure photographs. Rising velocity of the bubbles was obtained by measuring difference of rising heights of two bubbles.

$$V = \triangle H / 0.0035 \ (m/s) \tag{9}$$

where

△H : difference of rising distance between two bubbles(mm)

V : rising velocity of bubble(m/s)

Table 11, table 12, and table 13 show rising velocity of the bubbles at each of number of rotations of the rotor and particle diameter.

As shown in table 11 to table 13, rising velocity of the bubbles have nothing to do with the size of bubbles and gas velocity, and the ranges of the velocity are 0.0m/s to 1.97m/s.

Accordingly, the rising velocity of bubbles in the centrifugal fluidized bed will be influenced by local voidage in the bed[12, 13].

[Table 11] Bubble rising velocity(21.5㎛, 400rpm)

Gas velocity (m/s)	Bubble diameter (mm)	Bubble rising velocity(m/s)
0.14	8.69	0.62
	4.08	0.0
	5.03	0.33
	3.43	0.60
0.25	5.83	0.48
	8.66	1.97
	8.42	0.04
	8.22	0.04
0.38	3.74	0.27
	3.62	0.14
	13.21	0.16
	8.62	0.34

[Table 12] Bubble rising velocity(21.5㎛, 600rpm)

Gas velocity (m/s)	Bubble diameter (mm)	Bubble rising velocity(m/s)
0.20	3.75	0.32
0.26	8.58	0.26
	3.82	0.13
	5.98	0.17
	4.08	0.19
0.40	5.65	0.83
	7.22	0.12
	4.85	1.02
	4.38	1.92

[Table 13] Bubble rising velocity(10.5㎛, 400rpm)

Gas velocity (m/s)	Bubble diameter (mm)	Bubble rising velocity(m/s)
0.10	4.49	0.07
0.20	7.85	0.57
	3.11	0.36
0.27	7.08	0.58
	4.11	0.37

4. CONCLUSION

The behavior of bubble in a centrifugal fluidized bed with a 340mm inner diameter, 195mm high was observed by photographs using 10.5㎛ and 21.5㎛ mean diameter of Al_2O_3 particles as bed materials at each of 400rpm, 600rpm, 800rpm and 1000rpm number of rotations of the rotor.

At these experimental ranges, the number of rotations of the rotor shows strong effects on the behavior of bubbles in the centrifugal fluidized bed.

As the number of rotations of the rotor increased, the gas velocity a which bubbles begin to be formed also increased but diameter of the bubbles decreased.

And sizes of the bubbles in the centrifugal fluidized bed were relatively smaller than that in a conventional bubbling fluidized bed.

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