

A STUDY ON BUBBLE SIZE AND BUBBLE RISE VELOCITY IN A SEMI-CYLINDRICAL FLUIDIZED BED WITH A LINEAR PITCHED PERFORATED PLATE DISTRIBUTOR

Yasuo HATATE, Mitsunobu MIGITA*, Atsushi IKARI
and Desmond F. KING**

(Received May 31, 1985)

A semi-cylindrical fluidized bed 15 cm in diameter, equipped with a transparent flat glass plate for the front wall, and a perforated plate distributor with 7 holes in a linear pitch, was employed to visually observe bubbles in a fluidized bed.

Bubble size and bubble rise velocity were measured for each well formed bubble by observation through the front window.

The experimental conditions were as follows : four kinds of sand were used (average particle size $d_p=75, 189, 281$ and $521 \mu\text{m}$) at excess gas velocities above minimum fluidization of 8, 12, 25 and 35 cm/s. The static bed height was 70 cm for all experiments.

No effect of particle size on bubble behavior was detected.

The average size of bubbles was well represented by Darton et al.'s model. The average velocity of the bubbles was in agreement with the model of Allahwalla and Potter. Each of these models was developed for three dimensional fluidized beds.

Introduction

It has been shown previously⁴⁾ that a semi-cylindrical fluidized bed with a perforated distributor could be a useful tool for the observation of fluidized bed bubble behavior. The results from the semi-cylindrical bed were found to be applicable to the estimation of bubble behavior in three-dimensional beds in the slugging regime. Quantitative comparisons between semi-cylindrical and three-dimensional beds are rare^{5,7,11)}, especially, with regard to bubbling and/or slugging behavior.

In the present work, to confirm and extend the applicability of semi-cylindrical beds to an analysis of bubble behavior in three-dimensional beds, a semi-cylindrical bed with a 7 hole distributor (perforated in a linear pitch and located just below a observation window) was used under a wide range of operating conditions. The effect of bed particles on the average size and the average rising velocity of bubbles and/or slugs was investigated at gas velocities above the onset of slugging.¹⁰⁾

* Nippon Steel Ltd.

** Chevron Research Company Ltd.

1. Experimental

Four cuts of quartz sand were used as shown in Table 1. Air was used as the fluidizing medium in all experiments.

Table 1 Properties of solid particles used

d_p [μm]	d_{p32} [μm]	U_{mf} [cm/s]	ϵ_{mf} [-]
75.2	119	0.890	0.513
189	334	3.30	0.496
281	461	10.2	0.479
521	925	33.2	0.476

density = 2.51 g/cm³

Experimental apparatus and procedure The experimental apparatus and procedure have already been outlined in a previous paper.⁴⁾ As shown in Fig. 1, the fluidized bed is semi-cylindrical with an internal diameter of 14.7 cm and a height of 186.2 cm. Observation windows are positioned on the front of the semi-cylindrical column. A perforated distributor shown in Fig. 2 was employed. This had 7 holes each of 3.4 mm in diameter arranged in a linear pitch. The distributor was located just below the lowest glass plate on the semi-cylindrical column. With this

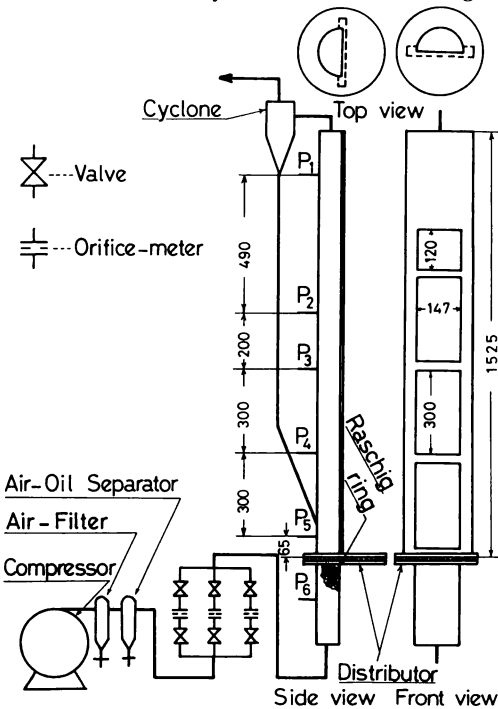


Fig. 1 Experimental apparatus

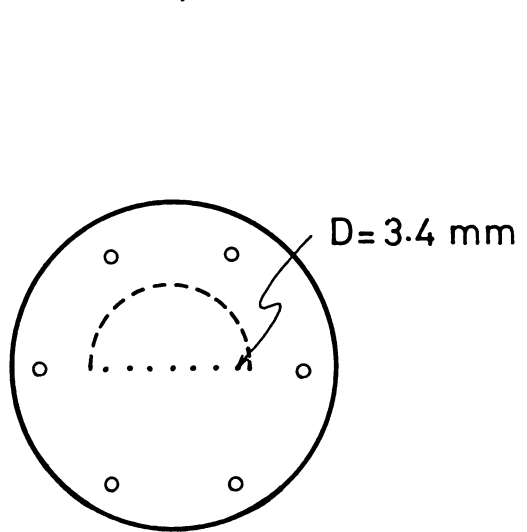


Fig. 2 Distributor (iron plate of 6.0 mm thick)

distributor, a lot of bubbles were visible at the window because gas is introduced into the bed along the glass wall.

A high speed video-camera system (by Sony Co. Ltd., exposure time = 1/1800 sec, 60 frames/s) was employed to photograph the bubbles. The VTR pictures were analyzed to deter-

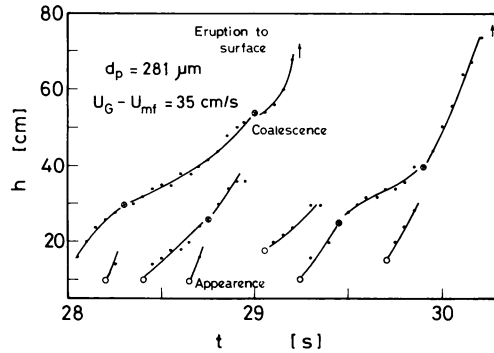


Fig. 3 Behavior of bubbles

mine the average size and the average rising velocity of bubbles.⁴¹ An example of the relationship observed between the bubble height and the elapsed time is shown in Fig. 3.

The average size and average rising velocity of bubbles were determined by the following methods.

Average bubble size From the detailed observation of bubbles, bubble shape was found to depend on \$L/D\$, where \$L\$ and \$D\$ are, respectively, the longitudinal and lateral dimensions of a bubble. Here, a bubble is assumed to have a shape determined only by \$L/D\$ as described in Fig. 4.

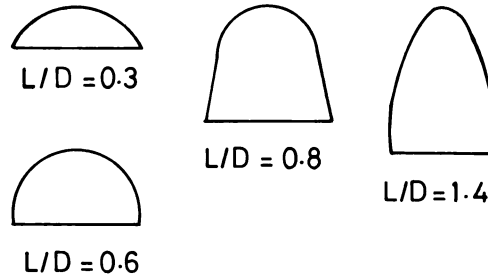


Fig. 4 Change of bubble shape with \$L/D\$

Depending on \$L/D\$, the equivalent bubble diameter \$D_E\$ can be calculated from the following equations.⁴¹

$$D_E = D[(L/D)\{(L/D)^2 + 3/4\}]^{1/3} \text{ for } L/D \leq 0.5 \quad (1)$$

$$D_E = (1/2)D_{max}[4f^3 + 2\{2(L/D_{max}) - f\}\{1 + f + f^2\}]^{1/2} \text{ for } 0.5 < L/D \leq 1.0 \quad (2)$$

$$D_E = (1/2)D[6 + 12(L/D) - 1]^{1/3} \text{ for } L/D > 1.0 \quad (3)$$

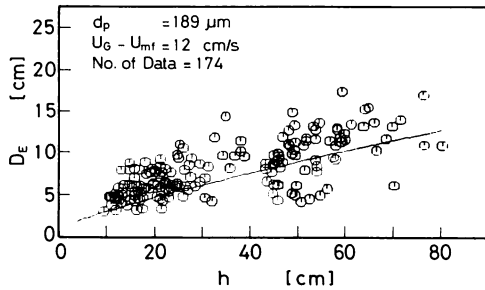
Where \$D_{max} = D[\{(2-f)/f\} - \{2(1-f)/f(L/D)\}]\$

$$f = 1.455 - 0.91(L/D)$$

Calculated values for \$D_E\$ from the above equations are, in most cases, almost the same as those from a previously reported method³⁾ described by the following equations.^{61,9)} Here the bubble diameter is assumed as a factor to determine the bubble shape. However, this approach is thought to be in error for long and slender bubbles.

$$D_E = 1.002D^{0.98} \text{ for } D \leq (1/3)D_T \quad (4)$$

$$D_E = D[(2/3)(L/D) - 0.495(L/D)^{1/2} + 0.061]^{1/3} \text{ for } D > (1/3)D_T \quad (5)$$

Fig. 5 Relation between D_E and h for each bubble

A representative example of bubble growth in terms of equivalent bubble diameters is shown in Fig. 5.

Average rising velocity Figures such as Fig. 3 were used to determine the bubble rise velocities at 20, 40 and 60 cm above the distributor.

2. Results and Discussion

Even when using the present experimental apparatus bubbles smaller than 2 cm in size are difficult to see through the front window. Smaller bubbles tend to move toward the interior of the bed and disappear from view. Hence, a semi-cylindrical bed seems to be most suitable for bubble observation at comparatively high gas velocities as pointed out in the previous paper.⁴⁾

The experimental conditions are summarized in Table 2. Gas velocities equal to or greater

Table 2 Experimental conditions

Particle : Sands shown in Table 1 Static bed height : 70 cm $U_G - U_{mf}$: 8, 12, 25 and 35 cm/s
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than 8 cm/s were chosen ... 8 cm/s is the calculated gas velocity from Stewart's criterion for the onset of slugging¹⁰⁾ in a 14.7 cm I. D. bed. Almost all combinations of operating parameters in Table 2 were investigated to measure both bubble size and rising velocity.

2. 1 Average bubble size

The effect of solid particle size The effect of the sand size on bubble size is shown in Fig. 6, where the change of bubble size with height is given for all four sand types at $(U_G - U_{mf})$ of 12 cm/s. Within the range of experimental error, the sizes of bubbles at a given height are independent of particle size. The solid line in the figure shows the calculated relation between D_E and h from the following correlation by Darton et al.²⁾

$$D_E = 0.54(U_G - U_{mf})^{0.4}(h + 4\sqrt{A/n})^{0.8}/g^{0.2} \quad (6)$$

Although the above equation was proposed to predict the equivalent diameter of bubbles in the truly bubbling regime, it is evident from Fig. 6 that it also applies in this region of the slugging regime.

Excess gas velocity above minimum fluidization

In Fig. 7, the observed average bubble sizes are plotted against bed height for the range of excess gas velocities above minimum fluidization ($U_G - U_{mf}$) from 8 to 35 cm/s. The particles employed are 281 μm sand. The solid lines calculated from Eq. (6) show good agreement with the experimental data.

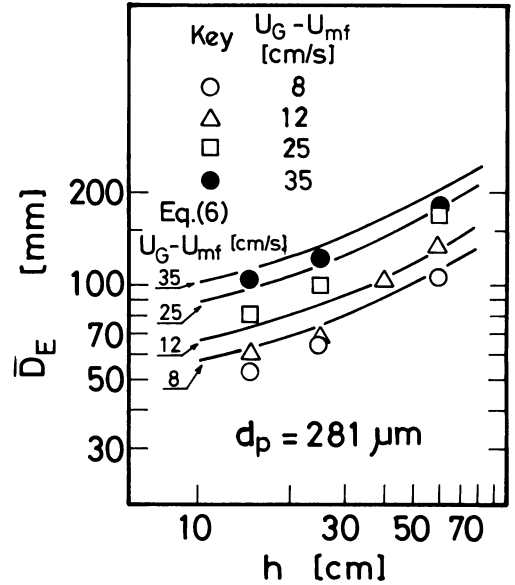
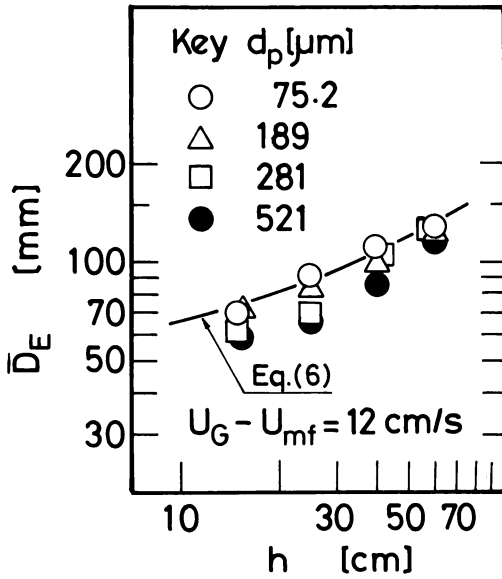


Fig. 6 Effect of particle size on \bar{D}_E vs. h relation

Fig. 7 Effect of $(U_G - U_{mf})$ on \bar{D}_E vs. h relation

The comparisons between the observed bubble sizes and those calculated from Darton et al.'s equation are shown in Fig. 8 to demonstrate the applicability of Eq. (6) over the whole range of operating parameters.

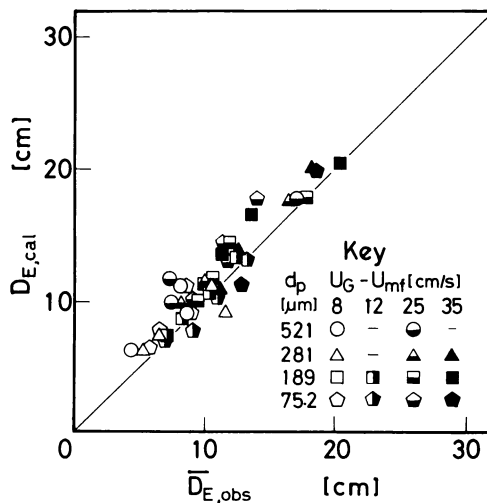


Fig. 8 Comparison of observed \bar{D}_E with calculated \bar{D}_E from Eq. (6)

2. 2 Average rising velocity

d_p The effect of d_p on U_B is shown in Fig. 9, where the change of average bubble rising velocity with height is given for four sands at $U_G - U_{mf} = 25$ cm/s. It is obvious from the figure that bubble rising velocities are independent of particle size. Only the 521 μm sand shows slightly smaller rising velocities at lower bed heights than the other three sands. The solid line in the figure, which is calculated from the following correlation by Allahwalla and Potter¹⁾, shows comparatively good agreement with the experimental data.

$$U_B = 0.35\sqrt{gD_T} \tanh^{1/1.8} \{3.6(\sqrt{D_E/D_T})^{1.8} + U_G - U_{mf}\} \quad (7)$$

$U_G - U_{mf}$ In Fig. 10, the observed average rise velocities are plotted against bed height for a range of $(U_G - U_{mf})$ from 8 to 35 cm/s using 189 μm sand. The solid lines calculated from Eq. (7) show comparatively good agreement with the experimental data. Similar agreement was also obtained for the other sands in this study.

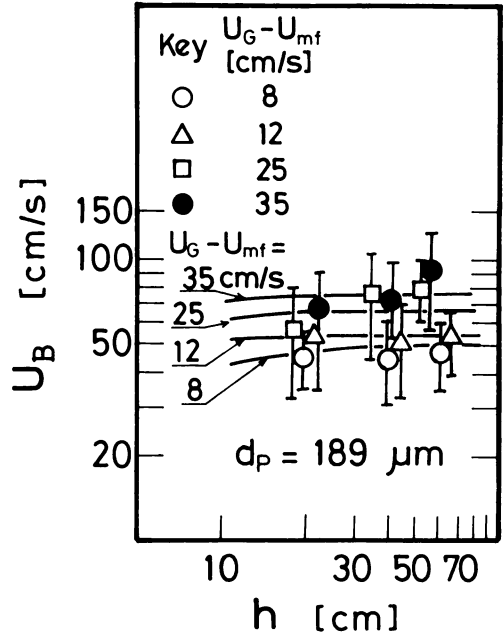
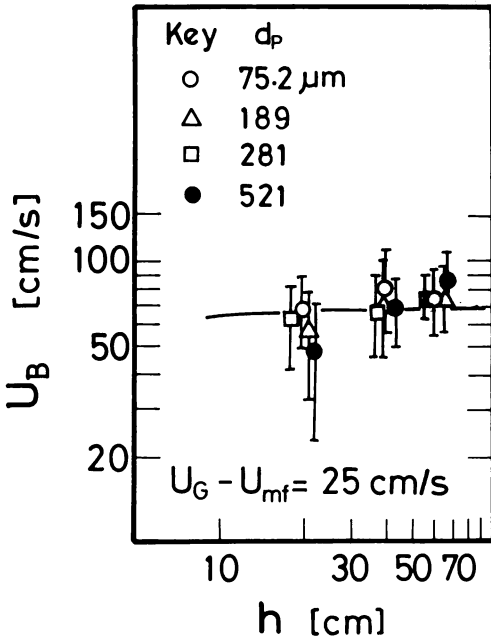


Fig. 9 Effect of distributor on U_B vs. h relation

Fig. 10 Effect of particle size on U_B vs. h relation

Conclusion

Using a semi-cylindrical bed equipped with a transparent front window and a 7 hole distributor (linear pitch arrangement), the average size and average rising velocity of bubbles were measured over a wide range of experimental conditions. The effects of particle size and excess gas velocity above minimum fluidization on the bubble size and the bubble rise velocity were investigated.

The following results were obtained.

- 1) Employing particle sizes from 75 to 521 μm , no effect of d on D_E and U_B was detected. The values obtained for D_E and U_B were found to be well represented by the expressions of Darton et

al. and Allahwalla et al. respectively. These expressions were developed for three-dimensional fluidized bed. These results are similar to those obtained in a previous semi-cylindrical bed with a distributor of 88 holes (square pitch arrangement). This work has demonstrated the applicability of a semi-cylindrical bed to estimate the behavior of a swarm of bubbles in a three-dimensional bed operating in the slugging regime.

2) Due to the ease of visually observing bubbles and/or slugs through the transparent front wall, a semi-cylindrical bed could be a useful tool for fundamental research into bubble behavior in fluidized beds at elevated temperatures.

Nomenclature

- A = cross-sectional area of bed [cm²]
D = lateral length (= maximum diameter) of bubble [cm]
D_E = equivalent diameter of bubble [cm]
 \bar{D}_E = volume average diameter for a swarm of bubbles [cm]
D_{max} = maximum diameter of fictitious bubble defined in a previous paper⁴⁾ [cm]
D_T = bed diameter [cm]
d_p = average diameter of solid particles by a sieve analysis [μm]
d_{p32} = volume to surface average diameter by photography [μm]
f = shape factor [-]
g = gravitational acceleration [cm/s²]
H = total height of bed [cm]
h = bed height above distributor [cm]
L = longitudinal length of bubble [cm]
n = number of orifices on distributor plate [-]
U_B = bubble rise velocity [cm/s]
U_G = superficial gas velocity [cm/s]
U_{mf} = minimum fluidization velocity [cm/s]
ε_{mf} = bed voidage at minimum fluidization [-]

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