Published in Institute of Engineers-India Chemical Engineering Division Vol 84 March 2004

Bubble Behaviour in Gas-solid Fluidized Beds with Co-axial Rod, Disk and Blade Type Promoters

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In this article, the bubble behaviour in terms of minimum bubbling velocity, bubble size and minimum slugging velocity for gas-solid fluidized beds with co-axial promoters have been studied. Three different types of promoters namely, rod, disk and blade having equal blockage volume and supported by a multi-orifice distributor plate have been used. The minimum bubbling velocities in beds with and without promoters have been observed experimentally with five different particle sizes and the constants of Geldart[1] formula have been obtained for the respective beds. For identical operating conditions, the comparative values for the minimum bubbling velocities, bubble dia and minimum slugging velocities (experimental and calculated) in case of un-promoted and promoted beds have also been obtained. Important inferences with respect to bubbling and slugging in promoted beds have been presented in this study.

Keywords: Gas-solid beds; Fluidization; Promoter; Bubbling; Slugging

NOTATION

A_e : area of fluidizer, m^2
BP : bed with blade type promoter
d_b : bubble dia, m
d_p : particle size, m
d_s : mean surface dia, m
D_c : dia of fluidizer, m
D_k : disk dia, m
DP : bed with disk promoter
g : acceleration due to gravity, m/s^2
h : bed height above distributor level, m
h_{mf} : bed height at minimum fluidization, m
h_o : a measure of the initial bubble size [which is characteristic of the distributor and is effectively zero for porous plate], m
K_{mb} : constant for minimum bubbling velocity
n : number of orifices in distributor plate
RP : bed with rod promoter
t : disk thickness, m
U_{mb} : minimum bubbling velocity, m/s
U_f : fluidization velocity, m/s
U_{mf} : minimum fluidization velocity, m/s
U_{ms} : minimum slugging velocity, m/s
UP : un-promoted bed
X_i : weight fraction of particle of dia d_s
ρ_s : density of solid, kg/m^3

INTRODUCTION

A turbulent promoter in gas-solid fluidized bed has been found to be effective in controlling the bubble behaviour that is hindering the formation and growth of bubbles, and limiting their sizes and thereby delaying bubbling and slugging. The use of promoters would arrest bubble growth, re-distribute the gas and improve the homogeneity of the fluidized bed.

In the present study, the effect of rod, disk and blade type of promoters on bubble behaviour and slug formation in case of gas-solid fluidized beds have been examined and compared with the conventional un-promoted bed.

LITERATURE REVIEW

Kono and Jinnai[1] reported that the bubble sizes can be kept significantly smaller than those in the conventional beds and maintained almost constant regardless of the bed height. Xiaogang and Heqing[2] observed the effect of operating conditions on bubble behaviour in a fluidized bed with perforated promoters and resolved that for the same superficial gas velocity, bubble frequency and rise velocity are independent of aperture ratio, hole dia (baffle plate) and baffle plate distance. In gas-liquid or gas-liquid solid contacting devices, Tsuchiya and Fan[3] explained that the bubble coalescence and breakup play a crucial role in determining the distribution of bubble size and rise velocity and gas-liquid interfacial area.

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This paper (modified) was received on June 13, 2003. Written discussion on the paper will be received until May 31, 2004.

Geldart[4] suggested a correlation for minimum bubble velocity as

$$U_{\mathrm{mb}} = K_{\mathrm{mb}}\,\bar{d}_{\mathrm{s}} \tag{1}$$

where

$$\bar{d}_{\mathrm{s}} = 1/\Sigma_{\mathrm{i}}\left(\frac{X_{\mathrm{i}}}{d_{\mathrm{si}}}\right) \tag{2}$$

and K_{mb} is the constant whose value is 100 (in CGS system).

The large contrast in stability between gas and liquid fluidized beds is related to the presence of bubbles in most of the gas-fluidized beds and their absence from most liquid-fluidized beds. Hence, the gas-fluidized bed is associated with the rapid growth of instability with bubble formation. Davidson and Harrison[5] observed that the interval between minimum bubbling velocity and minimum fluidization velocity represents the stable uniform fluidization, which shrinks rapidly as the size of the particles increases.

Rowe[6] proposed a correlation to predict bubble size in a gas-solid fluidized bed (when size is not restricted by the column dimension) as

$$d_{\mathrm{b}} = \frac{\left(U_{\mathrm{f}} - U_{\mathrm{mf}}\right)^{1/2}\left(h + h_{\mathrm{o}}\right)^{3/4}}{g^{1/4}} \tag{3}$$

where $\left(U_{\mathrm{f}} - U_{\mathrm{mf}}\right)$ is the excess gas velocity.

Darton, *et al*[7] have suggested another correlation for bubble size and the same is represented as

$$d_{\mathrm{b}} = \frac{0.54\left(U_{\mathrm{f}} - U_{\mathrm{mf}}\right)^{0.4}\left(h + \sqrt{\frac{A_{\mathrm{c}}}{n}}\right)^{0.8}}{g^{0.2}} \tag{4}$$

Bubbles formed at the distributor, coalesce in the normal way until they reach the size of a slug. Stewart and Davidson[8] stated that at superficial gas velocity below the following bubble rise velocity, slugging should not take place

$$U_{\mathrm{ms}} = U_{\mathrm{mf}} + 0.07\sqrt{gD_{\mathrm{c}}} \tag{5}$$

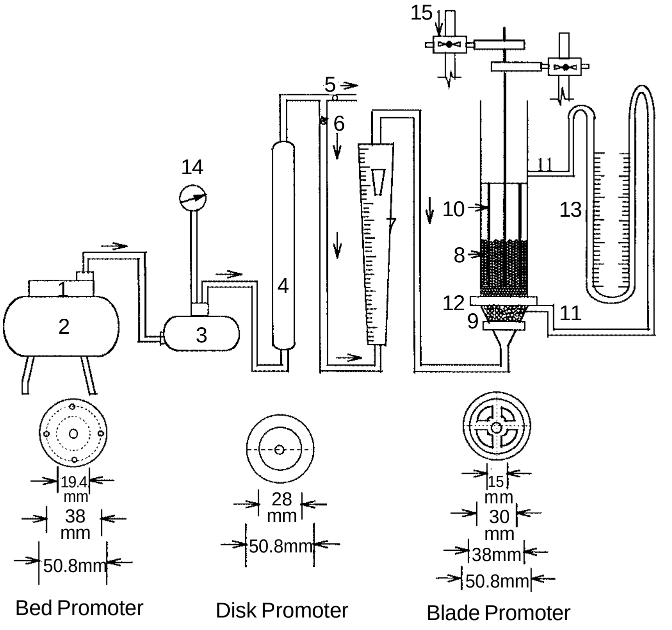
The bed must sufficiently be deep for coalescing bubbles to attain the size of a slug .

Baeyens and Geldart [9] felt that the above condition is applicable only if $h_{\mathrm{mf}} > 1.3D_{\mathrm{c}}^{0.175}$ in SI units, otherwise the minimum slugging condition is expressed as

$$U_{\mathrm{ms}} = U_{\mathrm{mf}} + 0.07\sqrt{gD_{\mathrm{c}}} + 0.16\left(1.3D_{\mathrm{c}}^{0.175} - h_{\mathrm{mf}}\right)^2 \tag{6}$$

EXPERIMENTATION

A schematic representation of the experimental set-up with details is shown in Figure 1. Compressed air was used as the fluidized medium. Three different type of promoters, namely, rod, disk and blade of equal blockage volume, supported on a multiorifice distributor plate having 37 numbers of 2.5 mm dia holes arranged in triangular pattern at a pitch of 7.5 mm centre-to-centre were used in the experiment. To minimize the accumulation of bed material over the disks, these were fixed at an inclination of 10^0 with the horizontal alternatively in the opposite direction. Figure 1 shows the experimental set-up along with promoter details. The scope of the experiment has been given in Table 1.



1. Compressor
2. Receiver
3. Constant Pressure Tank
4. Silicagel Tower
5. By-pass Valve
6. Line Valve
7. Rotameter
8. Fluidizer with Bed
9. Calming Section with Glass Bead Packing
10. Promoter
11. Pressure Tappings
12. Distributor
13. Manometer
14. Pressure Gauge
15. Clamps for Promoter

Figure 1 Schematic representation of the experimental set-up with promoters

For a particular run, data for bed pressure drop, expansion and fluctuation with varying flowrate have been noted. The appearance of first bubble in the bed has been observed and the corresponding flowrate has been noted. The procedure has been repeated for all the system variables (Table1).

RESULTS

Geldart's[4] equation [that is equation (1)] for minimum bubbling velocity has been used to obtain the constants K_{mb} for the un-promoted bed and the beds with rod, disk and blade type promoters. The slopes of the experimental plot between the observed values of minimum bubbling velocities and sizes of the bed material give constants at minimum bubbling velocities (K_{mb}) in the respective cases of un-promoted and promoted beds with rod, disk and blade type of promoters.

Table 1 Scope of the experiment

Properties of Bed Material			
Materials	$d_p \times 10^3$, m	$\rho_s \times 10^{-3}$, kg/m^3	
Dolomite	1.125	2.82	
Dolomite	0.725	2.82	
Dolomite	0.463	2.82	
Dolomite	0.390	2.82	
Dolomite	0.328	2.82	
Promoter Details			
Promoter Specification	$D_k \times 10^3$, m	$t \times 10^3$, m	**Number of Promoters (dia : 4 mm)**
Rod	—	—	8
Disk	28.00	6.36	—
Blade	38.00	6.36	—
Flow Properties			
Maximum, kg/h-m^2		Minimum, kg/h-m^2	
5500		200	

Table 2 Values of K_{mb} for different beds

Bed Particulars	K_{mb}
UP	572.31
RP	631.93
DP	593.84
BP	657.23

Table 3 Comparison of minimum bubbling velocity (U_{mb}) in different beds

Bed Particulars	Bed Materials	Particle Size $d_p \times 10^4$, m	$U_{mf} \times 10^2$ m/s	$U_{mb} \times 10^2$ m/s
UP	Dolomite	7.25	39.03	41.49
RP	Dolomite	7.25	43.24	45.82
DP	Dolomite	7.25	40.39	43.05
BP	Dolomite	7.25	42.78	47.65

Table 2 and Table 3 present these values of K_{mb} for each case and the comparison of relative minimum bubbling velocities.

Equation (4) which is more suitable for the case for multi-orifice distributor plate has been used to calculate the bubble dia for the different cases of un-promoted and promoted beds and their comparison have been given in Table 4. Further, the use of equation (4) has been extended to calculate the minimum velocity corresponding to the formation of slug in respective beds. For the analysis of minimum slugging velocities using available equation (4) and equation (6), the correlations developed by Kumar and Roy[10,11] have been used to interpolate the expanded bed heights. The minimum slugging velocities thus obtained have been compared with the values obtained by equation (6) (as $h_{mf} < 1.3 D_c^{0.175}$ in SI units) and experimentally observed. Their comparison has been given in Table 5.

DISCUSSIONS AND CONCLUSION

From Table 2, it has been found that the minimum bubbling velocity depends on particle dia and the bed properties. Further, it has been observed that for the same particle size, minimum bubbling velocity is minimum in case of un-promoted bed followed by beds with disk and rod promoters and the maximum in the case of bed promoted with blade type of promoter. This observation can be explained in terms of peripheral contact of the bed geometry with the fluid. In case of un-promoted bed, the periphery of column only is in contact with the fluid flow and give minimum peripheral contact resulting minimum bubbling velocity. In case of promoted beds, the surfaces of the promoter also contribute to periphery and hence more peripheral contact with the fluid flow. The maximum peripheral contact is in the case of bed with blade type of promoter followed by beds with rod and disk promoters. The maximum peripheral contact in the case of bed with blade type of promoter results in maximum bubbling velocity. In other words, bubble formation is delayed in the case of bed having more peripheral contact with the fluid flow.

The comparison of bubble dia (Table 4) for the identical operating conditions and equal blockage volume of the rod, disk and blade type promoters, with the bubble dia in unpromoted bed, reveals that the bubble dia is maximum in case of un-promoted bed and minimum in case of the bed with blade type promoters. The variation in bubble dia in different beds affirms the explanation given in the line of peripheral contact surface. On the basis of still and movie photographs, Jin, *et al*[12,13] observed improvement in the breaking up of bubbles and the circulation of the solid particles in the bed with pagoda-shaped promoter.

Table 4 Comparison of bubble dia in different beds

Fluid Velocity ($U_f \times 10^2$), m/s	Height from Distributor, (h × 10^2), m	$D_b \times 10^2$, m			
		UP	RP	DP	BP
68.39	2.0	1.89	1.78	1.86	1.79
68.39	4.0	2.48	2.34	2.44	2.35
68.39	6.0	3.04	2.86	2.98	2.88
68.39	8.0	3.57	3.36	3.51	3.38
68.39	10.0	4.09	3.84	4.01	3.87

Table 5 Comparison of minimum slugging velocity (U_{ms}) in different beds

Bed Particulars	Particle dia ($d_p \times 10^4$), m	$U_{ms} \times 10^2$, m/s		
		Darton's, *et al* Method	Baeyens and Geldart Method [Equation (6)]	Experimental Mental
UP	7.25	56.05	50.77	48.60
RP	7.25	60.56	54.98	55.01
DP	7.25	60.62	52.13	53.17
BP	7.25	62.66	54.52	54.10

From Table 5, it has been observed that in case of un-promoted bed, slugging appears at comparatively lower velocity than in promoted beds. Charles, *et al*[14] also observed that minimum slugging velocity is increased or slugging is suppressed in baffled bed with vertical rods. The present study indicates that the supression of the slugging is to different amount based on the type of promoter as is evident from Table 5. Among promoted beds, the bed with blade type promoter exhibits maximum slugging velocity. This also confirms the explanation on the basis of peripheral contact surface. The difference in slugging velocities for the case of beds with rod and disk promoters has been found to be marginal which may be due to close values of peripheral contact and their configurations. Also, the comparison of minimum slugging velocities calculated with the use of Darton's equation [equation (4)] and those obtained from direct calculation using Baeyens and Geldart[9] show that the values in the later case are lower. This may be attributed to the inactivity of some of the distributor orifices which reduces the total number of active orifices and thereby higher value of minimum slugging velocities in the case of Darton's method.

The experimental values of the minimum slugging velocities in case of promoted beds, show close agreement with those obtained from Baeyens and Geldart[9] equation. Also the experimentally observed slugging behaviour of the promoted beds shows that in bed with rod promoter slugging is relatively violent, inclined, non-uniform and of higher magnitude where as in beds with disk and blade promoters, more number of slug have been observed which move smoothly upwards, and are almost horizontal, uniform and of insignificant height. Among beds with disk and blade promoter, the later bed has slug of comparatively more uniform and of lesser height for the entire range of flow. Thus, the introduction of disk and blade promoters in the bed improves the slugging behaviour not only by delaying the slug formation but also by breaking slug of large height into a number of slugs of smaller heights. This is in conformity with the findings of Williams[15] who from his investigations, observed that baffles within a fluidized bed lead to more frequent and smaller bubbles, of a more uniform size and distribution within the bed. In the present study, the above observation of Williams[15] has been found to be true for the slugging behaviour also.

REFERENCES

1. Kono and M Jinnai. 'The Influence of Baffle Design on Fluidization Characteristics in a Fluid Bed Unit System.' *A I Ch E Symposium Series,* vol 80, no 241, 1983, p 169.

2. J Zhao Xiaogang and X Heqing. 'Study on Bubble Behaviour in Fluidized Bed with Perforated Baffles.' *Journal of Huaxue Fanying Gongcheng Yu Gongyi,* vol 8, no 1, 1992, p 54.

3. T Miyahara Tsuchiya and L S Fan. 'Visualization of Bubble-wake Interaction for a Strem of Bubbles in a Two-dimensional Liquid-solid Fluidized Bed.' *International Journal of Multiphase Flow,* vol 15, no 1, 1989, p 35.

4. Geldart. 'Type of Gas Fluidization.' *Powder Technology,* vol 7, 1973, p 285.

5. R Clift Davidson and D Harrison. 'Fluidization (Second Edition).' *Academic Press,* 1985, p 57.

6. Rowe. 'Prediction of Bubble Size in a Gas Fluidized Bed.' *Chemical Engineering Science,* vol 31, 1976, p 285.

7. R D Darton, J F Davidson LaNauze and D Harrison. 'Bubble Growth Due to Coalescence in Fluidized Beds.' *Transactions of the Institution of Chemical Engineers,* vol 55, 1977, p 274.

8. B Stewart and J F Davidson. *Powder Technology,* vol 1, 1967, p 61.

9. J Baeyens and D Geldart. 'An Investigation into Slugging Fluidized Beds.' *Chemical Engineering Science,* vol 29, 1974, p 255.

10. A Kumar and G K Roy. 'Effect of Different Type of Promoters on Bed Expansion in a Gas-solid Fluidized Bed with Varying Distributor Open Area.' *Journal of Chemical Engineering of Japan,* vol 35, 2002, p 681.

11. A Kumar and G K Roy. 'Effect of Co-axial Rod, Disk and Blade Type Promoters on Bed Fluctuation in a Gas-solid Fluidized Bed with Varying Distributor Open Area.' *Journal of The Institution of Engineers (India),* vol 82, pt CH2, March 2002, p 61.

12. Z Yu Jin, J Shen and L Zhang. 'Pagoda-type Vertical Internal Baffles in Gas-fluidized Beds.' *International Chemical Engineering,* vol 20, no 2, 1980, p 191.

13. Z Yu Jin, L Zhang, J Shen and Z Wang. 'Pagoda-shaped Internal Baffles for Fludized-bed Reactors.' *International Chemical Engineering,* vol 22, no 2, 1982, p 269.

14. C Coronella, S Y Lee and J D Seader. 'Minimum Slugging Velocity in Fluidized Beds Containing Vertical Rods.' *Fuel,* vol 73, 1994, p 1537.

15. Williams. 'The Effect of Baffles on Fluidized Bed Behaviour.' *Ph D Dissertation, Cambridge University,* October 1972.