Int. J. Multiphase Flow Vol. 9, No. 2, pp. 219–220, 1983
Printed in Great Britain.

0301–9322/83/020219–02$03.00/0
Pergamon/Elsevier

LETTER TO THE EDITOR

COMMENTS ON BUBBLE HOLD UP IN FLUIDIZED BEDS

K. VISWANATHAN and D. S. RAO
Department of Chemical Engg., Indian Institute of Technology, Hauz Khas, New Delhi—110016, India

(*Received* 18 *January* 1982; *in revised form* 28 *June* 1982)

Recently Bar-Cohen *et al.* (1981) developed semi-empirical equations to predict bubble diameter using measured bubble frequency data. In the development they used different equations for bubble hold-up for slow and fast rising bubbles. In this note, available equations to predict bubble fraction in fluidized beds are re-examined and it is shown that a single equation is applicable to slow and fast rising bubbles. The presence of wake phase is not considered here. Though the wakes are responsible for the vigorous circulation of solids, their contribution to total gas flow can perhaps be neglected (Peters *et al.* 1982) for fast bubbles where bubble fraction is relatively small.

Assuming Davidson & Harrison's (1963) model of a bubble, Bar-Cohen *et al.* (1981) following Kunii & Levenspiel (1969) related bubble fraction to bubble rise velocity through material balance equations. For slow bubbles they obtained

$$u_0 = \delta(u_b + 3u_{mf}) + (1 - \delta)u_{mf} \qquad [1]$$

where u_0 is the inlet superficial velocity; δ is the bubble fraction; u_b is the absolute bubble rise velocity; and u_{mf} is the minimum fluidization velocity.

For very fast bubbles the following relationship was used

$$u_0 = \delta u_b + (1 - \delta)u_{mf}. \qquad [2]$$

This equation also suggests the existence of a bubble phase at a velocity u_b and dense phase with gas velocity, u_f ($= u_{mf}/\epsilon_{mf}$, where ϵ_{mf} is the porosity of minimum fluidization). However, the dense phase consists of cloud phase and possibly emulsion phase. The gas in emulsion travels up at u_f. In the cloud, due to the downward flowing recirculating gas the actual upward velocity u_c will be different from u_f. For example, when the cloud size is not restricted by vessel dimensions, gas in the cloud travels up at absolute bubble rise velocity u_b and not u_f (Fryer & Potter 1972, Bukur 1978).

In view of the above, the existing equations describing material balance of gas under cloud formation are re-examined.

PRESENT ANALYSIS

Depending upon the size of bubbles the possible cases are

Case 1. Slow bubbles with no cloud. The overall gas balance for this case is given in [1].

Case 2. Bubbles, clouds and emulsion exist together in the bed. Here cloud size is not restricted by vessel dimensions and is given by (Viswanathan & Rao 1980; Peters *et al.* 1982)

$$\beta = 3u_f/(u_b - u_f). \qquad [3]$$

The original equation obtained by Davidson & Harrison (1963) for an isolated bubble contained u_{br} instead of u_b in [3]. For a swarm of bubbles we use u_b in [3] so that the gas velocity in the cloud becomes equal to u_b (see [6] and the following discussion).

UPWARD VELOCITY OF GAS IN CLOUD

Since the velocity of gas circulating between cloud and bubble is $3u_{mf}$ inside the bubble, this recirculating gas moves down in cloud at a velocity equal to $3u_{mf}/(\beta\epsilon_{mf})$ where ϵ_{mf} is also the porosity of cloud. There has to be upward moving gas in cloud, at u_c, to keep the particles in a suspended state. For the particles in cloud to be at minimum fluidization, the condition to the satisfied is

$$u_c - \frac{3u_{mf}}{(\beta\epsilon_{mf})} = \frac{u_{mf}}{\epsilon_{mf}} \qquad [4]$$

or

$$u_0 = u_f(1+3/\beta). \qquad [5]$$

For case 2, from [3] and [5]

$$u_c = u_b. \qquad [6]$$

Since the downward moving recirculating gas in cloud ultimately moves up in bubble it does not contribute for any net upward or downward flow. Hence the net upward gas velocity due to cloud is u_c given by [6]. It may be pointed out that [6] has in fact been used by investigators who in their models divided the bed into bubble, cloud-wake and emulsion phases (e.g. Fryer & Potter 1972). However, if u_{br} instead of u_b had been used in [3] then [5] would have yielded u_c to be equal to u_{br} which is incorrect (Fryer & Potter 1972; Viswanathan & Rao 1980; Peters *et al.* 1982).

Now an overall gas balance yields

$$u_0 = \delta u_b + \beta\delta\epsilon_{mf}u_c + (1-\delta-\beta\delta)u_{mf}. \qquad [7]$$

Equations [3], [6] and [7] simplify to [1].

Thus, for both the cases of slow and fast rising bubbles the gas balance is given by [1] which can be expressed for bubble fraction as

$$\delta = (u_0 - u_{mf})/(u_b + 2u_{mf}). \qquad [8]$$

Hence, Bar-Cohen *et al.*'s (1981) equation for slow rising bubbles should be applicable to all cases and different equations should not be used.

REFERENCES

BAR-COHEN, A., GLICKSMAN, L. R. & HUGHES, R. W. 1981 Semi-empirical prediction of bubble diameter in gas fluidized beds. *Int. J. Multiphase Flow* **7**, 101–113.

BUKUR, D. B. 1978 Analysis of gas flow in fluidized bed reactors. *Ind. Engng Chem. Fundls* **17**, 120–123.

DAVIDSON, J. F. & HARRISON, D. 1963 *Fluidized Particles.* Cambridge University Press, Cambridge.

FRYER, C. & POTTER, O. E. 1972 Countercurrent backmixing model for fluidized bed catalytic reactors. Applicability of simplified solutions. *Ind. Engng Chem. Fundls* **11**, 338–344.

KUNII, D. & LEVENSPIEL, O. 1969 *Fluidization Engineering.* Wiley, New York.

PETERS, M. H., FAN, L. S. & SWEENEY, T. L. 1982 Reactant dynamics in catalytic fluidized bed reactors with flow reversal of gas in the emulsion phase. *Chem. Engng Sci.* **37**, 553–565.

VISWANATHAN, K. & RAO, D. S. 1980 A model for fluidized bed catalytic reactor. *Proc. 33rd I.I.Ch. E. Conf.*, New Delhi, 1, 61–66.