Equation for the Superficial Bubble-Phase Gas Velocity in Fluidized Beds

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Superficial bubble-phase gas velocity (U_{bs}) is an important parameter in the fluidized-bed reactor design, since it influences many other parameters such as volume fractions of each phase and the superficial gas velocities for other phases. The earliest popular postulate of computing U_{bs}, which is known as the two-phase theory of fluidization (Toomey and Johnstone, 1952), suggested that the gas flow rate in the bubble phase is equal to the excess gas flow above what is required for minimum fluidization: $U_{bs} = U - U_{mf}$. This method presents one key feature that U_{bs} remains constant throughout the fluidized bed. This suggestion, however, is contrary to what Werther (1974) has observed in his experiments. Werther's data indicate that the U_{bs} increases monotonically with the bed height. The data also show that the smaller diameter bed gives significantly higher U_{bs} than that in the larger diameter bed. This observation has obvious practical implication that the correlation of U_{bs} should reflect these characteristics.

In 1982, Peters et al. used the following equations in their model development to estimate U_{bs}:

$$U_{bsi} = \delta_{bi}[U_0 - U_{mf} + 0.71\sqrt{gD_{bi}}] \tag{1}$$

in which δ_{bi} is the bubble-phase volume fraction in the ith compartment, and D_{bi} is evaluated by $[D_{bm} - (D_{bm} - D_{bo})\cdot \exp(-0.3h/D_t)]$. Since δ_{bi} and D_{bi} are the functions of the bed height (h) and bed diameter (D_t), their U_{bsi} is related indirectly to the bed height and bed diameter. Although Peter's method has showed monotonical increase in U_{bs} with the bed height, their results have not properly reflected the effect of bed diameter on U_{bs}. Apparently, a more accurate correlation equation is needed for the U_{bs} calculation.

This note presents a new correlation equation that would reasonably reflect the characteristics of U_{bs}.

Proposed Equation

The variation of U_{bs} in fluidized beds of different sizes has been investigated by Werther (1974). In his work, two significant phenomena related to the bubble flow were observed:

1. While bubbles rise in a fluidized bed, the dense phase continues to yield gas to the rising bubble. This, in turn, makes the bubble size grow and the bubble gas flow more rapidly.
2. Because of wall effect, the bed diameter has a strong influence on the degassing of the dense phase. Due to lesser wall effect in a larger-diameter bed, the degassing of the dense phase proceeds more slowly. Consequently, the bubble size as well as the bubble gas flow at a given height will be smaller in a larger-diameter bed.

These two phenomena prove that U_{bs} does change along the bed, and the bed diameter has strong influence on U_{bs}. In addition, it is likely from Werther's observation that the variation of U_{bs} in the beds seems to have similar trend to that of bubble size. Therefore, in view of all the aspects mentioned above and based on the bubble-size correlation concept of Mori

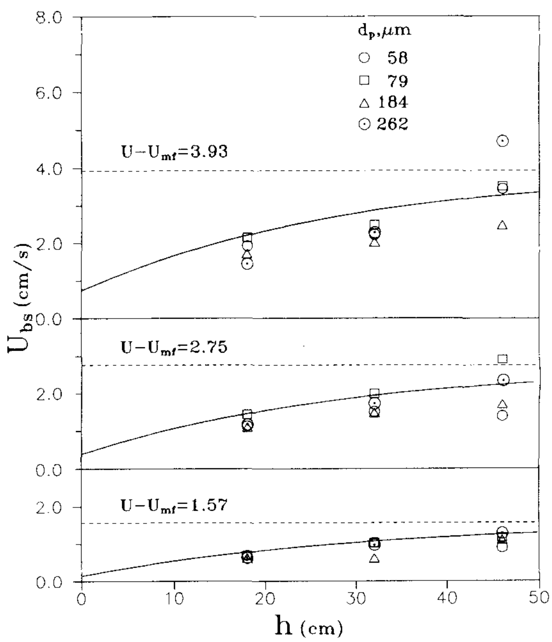

Figure 1. Calculated U_{bs} vs. the experimental data of Rowe and Yacono (1976).

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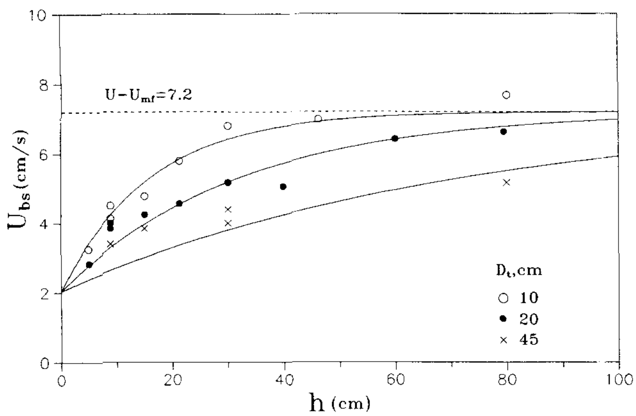

Figure 2. Calculated U_{bs} vs. the experimental data of Werther (1974).

and Wen (1975), the following equation is suggested for the U_{bs} calculation:

$$\frac{U_{bsm}-U_{bs}}{U_{bsm}-U_{bso}}=\exp\left(-\frac{55h}{H_{mf}D_t}\right) \tag{2}$$

In Eq. 2, U_{bsm} is the maximum superficial bubble-phase gas velocity, which is equal to $(U-U_{mf})$ (Pyle and Harrison, 1967; Rowe and Yacono, 1976), and U_{bso} is the initial U_{bs} at the distributor, which can be evaluated by the following equations:

$$U_{bso}=\delta_{bo}\cdot U_{bo} \tag{3}$$

in which

$$\delta_{bo}=\frac{H-H_{mf}}{H} \tag{4}$$

$$U_{bo}=(U-U_{mf})+0.71\sqrt{gD_{bo}} \tag{5}$$

and D_{bo} can be calculated by the correlation equations of Miwa et al. (1972).

Validation of Proposed Equation

Above equations have been tested with two sets of experimental data. One is the work of Rowe and Yacono (1976), whose data were taken from a 3-D fluidized bed with an equivalent diameter of 23 cm. The other is Werther's data (1974) taken from 3-D fluidized beds with different bed diameters.

The experimental data points have been plotted against the calculated values of Eq. 2 in Figures 1 and 2. As can be observed, there are good agreements in all cases. Furthermore, the proposed equation predicts the effect of bed diameter on U_{bs} quite well.

Conclusion

Although the two-phase theory has the simplest form of calculating U_{bs}, it tends to overpredict it. This may affect the prediction of volume fractions and superficial gas velocities for other phases, and consequently affect the prediction of reaction performance in a fluidized-bed reactor. The equation proposed here apparently gives a more accurate value for U_{bs}. This simple equation includes terms that are readily measurable or easily estimated.

Notation

D_b = bubble diameter, cm
D_t = bed diameter, cm
h = height above distributor, cm
H = expanded bed height, cm
H_{mf} = bed height at minimum fluidization, cm
g = gravitational acceleration, cm/s^2
U = superficial gas velocity, cm/s
U_b = bubble rising velocity, cm/s
U_{bs} = superficial bubble phase gas velocity, cm/s
U_{mf} = minimum fluidization velocity, cm/s
δ_b = volume fraction of bubble phase in fluidized bed

Subscripts

i = ith compartment
o = at distributor
m = maximum

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