Korean J. Chem. Eng., **18**(4), 567-570 (2001)

Slugging Bed Height of Polyethylene Particles in a Fluidized Bed with an Expanded Section

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(*Received 6 March 2001 • accepted 7 May 2001*)

Abstract−Slugging experiments were performed in a fluidized bed of 7 cm ID and 50 cm in height to examine the maximum bed height with an expanded section. High-density polyethylene (HDPE) particles of 0.5 mm were employed as the bed materials. The slugging bed height was linearly increased with the gas velocity in the beds of uniform cross section as well as expanded section with different slope. From the results of this study, it was found that the existing correlation to predict the slugging bed height based on the heavier particles for the uniform cross section area was satisfactorily applied for the lighter particles of HDPE and for the expanded section, a slight modification was made for the particle of HDPE in the slugging bed.

Key words: Slugging, Bed Height, Polyethylene Particles, Correlation, Fluidized Bed

INTRODUCTION

An understanding of flow regimes is very important for the stable operation and scale-up of fluidized beds of commercial units. Lee et al. [2000] and Tsutsumi et al. [1999], who studied the hydrodynamics characteristics from fixed to fully fluidized beds for the three phase fluidized bed, reported that the bubble behavior is the one of the key factors in the hydrodynamics of fluidized beds. A slugging bed is characterized by gas slugs of sizes close to reactor cross section that rise at regular intervals and divide the main part of the fluidized bed into alternate regions of dense and lean phases [Lee and Kim, 1989; Ryu et al., 1999]. The slugging phenomenon in fluidized beds has been extensively studied and is described in detail by Davidson and Harrison [1971]. The passage of these gas slugs produces large pressure fluctuations inside the fluidized bed. The bed height will reach the maximum when the first slug breaks the surface. Thereafter, the bed height will fluctuate between this maximum and minimum position that depends on the size of the gas slug [Yang and Keairns, 1980]. An effective way to suppress the slugging and to reduce the maximum slugging bed height is to expand the bed cross-sectional area toward the top of a fluidized bed reactor. The reason for designing the expanded section is that in the expanded section the bed tends to bridge at the conical transition between the bottom section and expanded section and bed tends to be defluidized, thus reducing the maximum bed height during the slugging. Therefore, it is interesting to investigate the slugging bed height with an expanded section. Baker et al. [1978], Canada et al. [1978], Geldart et al. [1978] reported the bed expansion data for slugging fluidized beds. Most of data reported are sand, glass bead and metals that are heavier than water. Only a few experiments were conducted in a fluidized bed with polymer particles. Cho et al. [2000] investigated the gas behavior in a fluidized bed of polyethylene particles.

In this investigation we are concerned with the slugging bed height

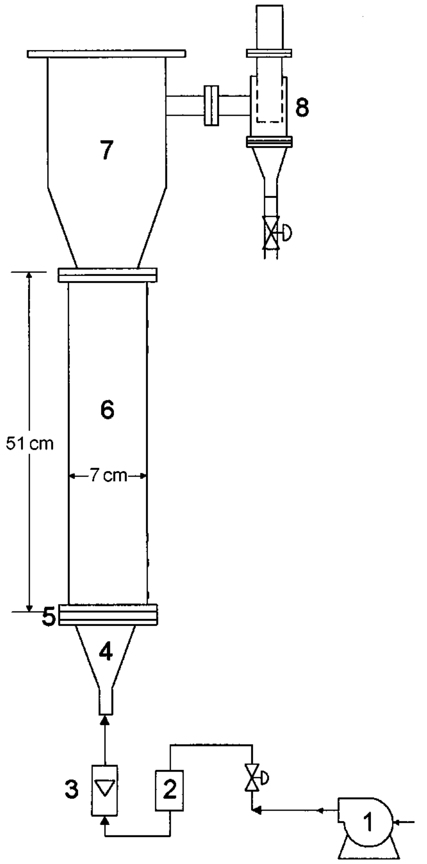

Fig. 1. Schematic diagram of experimental test set-up.

1. Blower
2. Filter & Regulator
3. Rotameter
4. Calming section
5. Distribution plate
6. Fluidization column
7. Disengaging section
8. Cyclone separator

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‡Presented at the Int'*l* Symp. on Chem. Eng. (Cheju, Feb. 8-10, 2001), dedicated to Prof. H. S. Chun on the occasion of his retirement from Korea University.

in a fluidized bed of polyethylene particles whose density is lighter than water. The expanded bed height was measured and compared with the existing correlation.

EXPERIMENTAL

The experimental test set-up is shown in Fig. 1. The fluidized bed column is made of acrylic pipe of 7 cm ID and 51 cm in height and is connected to cyclone. The disengaging section is located between fluidized bed column and cyclone as shown in Fig. 1 and was designed to simulate the dimensional similarity of commercial fluidized bed reactor of the Unipol process. Air is supplied from the compressor and flow to calibrated flow meter and introduced to the bottom of the bed through the perforated distributor. The static bed height was 75% of the bed volume and it was about 37 cm above the distributor. The bottom section was 7 cm in inside diameter and the expanded section was 13 cm in inside diameter. The transition between two sections was a conical section with a 78 deg inclined angle. In a typical experiment to measure the slugging bed height, the gas velocity was first set. Values of maximum bed height were then recorded visually and by marking on the column wall. The bed height was determined by taking the five minute time-averaged values at specific operating conditions. The operating gas velocity covered the 1.2-5.0 U_{mf} ranges and the slug flow was observed for that gas velocity ranges.

The Hanwha Petrochemical Ltd., Korea, provided the HDPE powders for these experiments. The physical properties of HDPE particles employed in this study are given in Table 1.

RESULTS AND DISCUSSION

The maximum bed height of the slugging fluidized bed is measured for particles of HDPE. There was a wide variation of slugging bed heights, and the variation of slugging bed height is the result of a distribution of slug velocities due to coalescence in the grid region of the bed. Matsen et al. [1969] proposed the correlation with over 60 sets of data as given in the Eq. (1).

$$\frac{H_m}{H_{mf}}-1=\frac{U-U_{mf}}{k_1\sqrt{gD}} \tag{1}$$

Satija and Fan [1985] modified the correlation for maximum bed height of the slugging bed for uniform cross section by an equation of the form

$$\frac{H_{max}}{H_{mf}}=1+\frac{k_2(U-U_{mf})}{k_1\sqrt{gD}} \tag{2}$$

$k_1=0.35$ for axial slugs

Table 1. Physical properties of employed particles (HDPE)

Properties	Value
Particle diameter, d_p	0.0603 cm
Particle density, ρ_s	0.82 g/cm^3
Particle bulk density, ρ_b	0.44 g/cm^3
Voidage at incipient fluidization, ε_{mf}	0.46
Minimum fluidization velocity, U_{mf}	10.5 cm/s

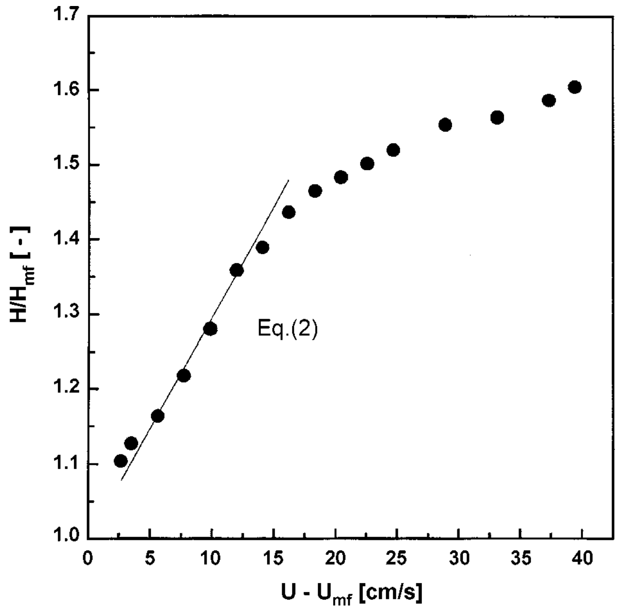

Fig. 2. Comparison of experimental slugging bed height with Eq. (2).

$k_1=0.5$ for wall slugs

$$k_2=2.43\left(\frac{d_p}{D_t}\right)^{0.5}\left(\frac{\rho_s}{1000\rho_g}\right)^{-4.2} \quad \text{for } d_p<1.12 \text{ mm}$$

Fig. 2 shows the comparison of experimentally determined maximum bed height in the slug flow for the fluidized bed of polyethylene particles with the proposed correlation of Eq. (2). The experimentally determined maximum bed height increased with gas velocity and the slope was changed when the bed height reached the expanded section due to change of cross sectional area. In the application of Eq. (2), $k_1=0.35$ was applied due to axial slugs of the HDPE particles. As can be seen in Fig. 2, the correlation was very successful for the lower gas velocity which corresponded to the uniform cross sectional area of the bed. Beyond the uniform cross sectional area ($D>D_1$), Eq. (2) could no longer be applied because at the higher gas velocity the maximum bed height reached the height of the bed transition. Yang and Keairns [1980] developed the modified correlation that follows closely that of Matsen et al. [1969] for expansion of fluidized bed in slug flow. They divided the expansion of a slugging fluidized bed with an expanded section into three different stages and suggested the different correlations for expansion stages.

Fig. 3(a) shows the configuration of the expanded section of Yang and Keairns [1980] for the correlation of maximum bed height in a slugging fluidized bed and the proposed correlation for the expanded section is given in Eq. (3) for $H_{max}<h$,

$$\frac{H_{max}}{H_{mf}}=\frac{h}{H_{mf}}+\left(\frac{D_1}{D_2}\right)^2\left[1+\left(\frac{D_1}{D_2}\right)^2\frac{(U-U_{mf})}{U_{b2}}\right]\left[1-\frac{h}{H_{mf}}\frac{1}{\left\{1+\frac{U-U_{mf}}{U_{b1}}\right\}}\right] \tag{3}$$

In this equation, subscript 1 represents the uniform cross-sectional area and subscript 2 represents the expanded section of the bed. When

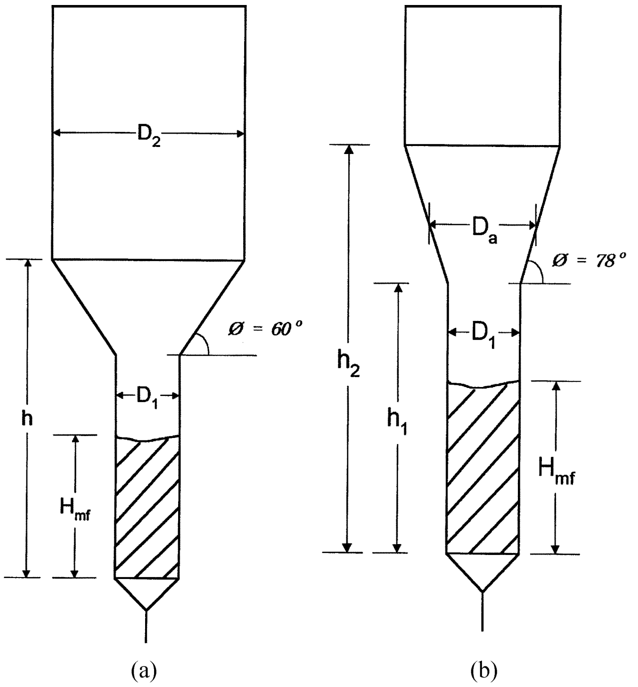

Fig. 3. (a) Configuration of bed for Eq. (3) of Yang and Keairns [1980]. (b) Configuration of bed for proposed correlation of Eq. (4).

$D_1=D_2$, $U_{b1}=U_{b2}$, and $U_{b1}=0.35\sqrt{gD_1}$, Eq. (3) reduced to Eq. (2), the slugging bed height equation for a bed of uniform cross section. Fig. 3(b) shows the configuration of the expanded bed employed in this study. In this experiment we observed that the maximum bed height reached the expanded section of the bed at $(U-U_{mf})$=15 cm/sec. Eq. (3) was applied for the prediction of maximum bed height when the $(U-U_{mf})$ was larger than 15 cm/sec. The agreement of experimental data with Eq. (3) was not satisfactory. The discrepancy of experimental results and proposed correlation may result from the difference of particle properties and the geometry of expanded section. It was guessed that the sand particles employed for the derivation of Eq. (3) may have shown different slugging behaviors such as slug rise velocity, slug frequency and types of slugs (axial slugs, and wall slugs) which determined the maximum bed height as well as bed diameters as along with different conical transition angle as shown in Fig. 3(a) and (b). With the experimental data at the higher gas velocity, we proposed the modified correlation that follows closely that of Yang and Keairns [1980] for expanded section of the bed and is given in Eq. (4).

During operation, the maximum bed height reached the transition section ($h_{max}<h_2$) only so that the average diameter of transition section was chosen as the characteristic length for expanded section.

$$\frac{H_{max}}{H_{mf}}=\frac{h}{H_{mf}}+\left(\frac{D_1}{D_a}\right)^2\left[\frac{h}{\left\{1+\frac{(U-U_{mf})}{U_{b1}}\right\}}-h_1+H_{mf}\right]\frac{1}{H_{mf}} \tag{4}$$

The comparison of correlations for maximum bed height at the uniform cross section and at the expanded section in the slugging fluidized bed with experimental results is shown in Fig. 4 and the comparison is found to be satisfactory.

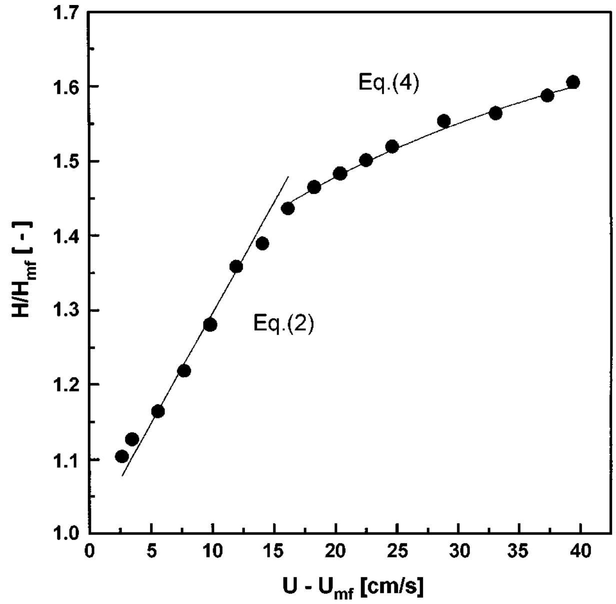

Fig. 4. Comparison of experimental results with correlations for uniform cross section of Eq. (2) and expanded section of Eq. (4).

CONCLUSIONS

The maximum bed height for slugging in a fluidized bed of polyethylene particles with an expanded section was experimentally determined. It was found that when the bed expansion reached below the transition section of the bed, the correlation proposed by Satija and Fan was satisfactory for the uniform cross section and when the bed height reached the expanded section of the bed, the modified correlation proposed in this study showed a good agreement with the experimental results for the expanded section. From the results of this study, it was concluded that the correlation based on the heavier particles was satisfactorily applied to the lighter particles such as HDPE for the uniform cross-sectional area, and for the expanded section a slight modification of the existing equation was required for the prediction of maximum bed height of HDPE particles.

NOMENCLATURE

D : bed diameter [cm]
D_1 : bed diameter of uniform cross section [cm]
D_a : average diameter of expanded section for Eq. (4) [cm]
d_p : particle diameter [cm]
g : acceleration of gravity [m/sec^2]
h : height of transition section for Eq. (3) [cm]
h_1 : height of uniform cross sectional area for Eq. (4) [cm]
H_m : slugging bed height [cm]
H_{mf} : height of minimum fluidization bed [cm]
k_1 : parameter for Eq. (2) [-]
k_2 : parameter for Eq. (2) [-]

U : superficial gas velocity [cm/sec]
U_1 : superficial gas velocity at uniform cross section [cm/sec]
U_2 : superficial gas velocity at expanded section [cm/sec]
U_{b1} : bubble rise velocity at uniform cross section [cm/sec]
U_{b2} : bubble rise velocity at expanded section [cm/sec]
U_{mf} : minimum fluidization velocity [cm/sec]

Greek Letters

ρ_g : gas density [kg/m^3]
ρ_s : particle density [kg/m^3]

REFERENCES

Baker, C. G. J. and Geldart, D., "An Investigation into the Slugging Characteristics of Large Particles," *Powder Technology*, **19**, 177 (1978).

Canada, G. S., McLaughlin, M. H. and Staub, F. W., "Flow Regimes and Void Fraction in Gas Fluidization of Large Particles in Beds without Tube Banks," *AIChE Symp. Ser.*, **74**, 14 (1978).

Cho, H. I., Chung, C. H., Han, G. Y., Ahn, G. R. and Kong, J. S., "Axial Gas Dispersion in a Fluidized Bed of Polyethylene Particles," *Korean J. Chem. Eng.*, **17**, 292 (2000)

Davidson, J. F. and Harrison, D., "Fluidization," Chap. 5, Academic Press, NewYork (1971).

Geldart, D., Hurt, J. M. and Wadia, P. H., "Slugging in Beds of Large Particles," *AIChE Symp. Ser.*, **74**, 60 (1978).

Lee, D. H., Epstein, N. and Grace, J. R., "Hydrodynamic Transition from Fixed to Fully Fluidized Beds for Three-Phase Inverse Fluidization," *Korean J. Chem. Eng.*, **17**, 684 (2000).

Lee, G. S. and Kim, S. D., "Rise Velocities of Slugs and Voids in Slugging and Turbulent Fluidized Beds," *Korean J. Chem. Eng.*, **6**, 15 (1989).

Matsen, J. M., Hovmand, S. and Davidson, J. F., "Expansion of Fluidized Beds in Slug Flow," *Chem. Eng. Sci.*, **24**(1), 743 (1969).

Ryu, H. J., Choi, J. H., Yi, C. K., Shun, D. W., Son, J. E. and Kim, S. D., "Minimum Slugging Velocity in a Gas Fluidized Beds," *HWAHAK KONGHAK*, **37**, 472 (1999).

Satija, S. and Fan, L. S., "Characteristics of Slugging Regime and Transition to Turbulent Regime for Fluidized Beds of Large Coarse Particles," *AIChE J.*, **31**(9), 1554 (1985).

Tsutsumi, A., Chen, W. and Kim, Y. H., "Classification and Characterization of Hydrodynamic and Transport Behaviors of Three-Phase Reactors," *Korean J. Chem. Eng.*, **16**, 709 (1999).

Yang, W. C. and Keairns, D. L., "The Effect of and Expanded Section on Slugging," *AIChE J.*, **26**(1), 144 (1980).