Experimental Investigation on the Influence of Bed Height and Bed Particle Size on Bed Expansion for a Bubbling Fluidized Bed

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1 Introduction

The quality of fluidization has been quantified with reference to the fluctuation of bed and their expansion ratios. Several investigations on the bed expansion ratio have been carried out [1–4] chiefly to describe bubble size and properties, as well as to check the average residence time of the gas in a typical bubbling fluidized bed. Mazumdar and Gunguly defined the bed expansion ratio, R, as the ratio of the difference between the expanded bed (He) and the static bed height (Hs) to the static bed height, i.e. R = (He − Hs)/Hs [5]. The bed expansion ratio (R) is also known as the ratio of the mean of the largest (H2) and smallest (H1) heights of an expanded to the initial static bed height (Hs) for a particular flow rate of gas, i.e. R = (H1 + H2)/2Hs [6].

The bed expansion ratio is one of the most reported properties of fluidized beds [7, 8] and hence should be very important. The knowledge about it is needed due to numerous reasons [9–12] highlighted that the bed expansion ratio is important in the designing of fluidized beds [9]. Hepbasli also noted that a good design for the cyclone separators is entirely dependent on the bed height expansion. It was further added that the automatic adjustments of the heat transfer to different loads on a boiler can be controlled as a function of the bed expansion ratio [13]. It has been noted that the expansion ratio for fluidized beds influences the correct positioning of heat exchanger tube bundles immersed in the fluidized bed, as well as the correct calculation of heat transferred to the furnace walls [12]. Bed expansion ratios give an

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indication of the fluidization and its quality and hence directly affect the heat transfer coefficient [14].

2 Literature Review and Objective

The successful and economical design, scale-up, and operation of fluidized bed reactors depend upon the true prediction of its bed hydrodynamics [15]. The hydrodynamic description is necessary for an in-depth understanding of the processes taking place in a fluidized bed. Philippsen et al. found that the knowledge of fluidized bed hydrodynamics is not only important in establishing correct operational parameters but is also useful for making decisions about reactor performance [16]. Zhang et al. investigated Geldart B fine particles ($\leq$20 μm), i.e. Coal-15, GB- 6 and SiO_2-5, and added them to that of A (FCC-76) type to check the behaviour of fluidization [17]. It was found that the distribution of particle size affects the hydrodynamics of the system. Zhou and Zhu and Nguyen and Chian found that a higher conversion rate can be obtained through the addition of additives. It was found that when nano-particles (Group C+) were added to Geldart C powder, the gas-solid holdup increased for the dense phase and decreased for the bubble phase, resulting in more contact and conversion efficiency [18, 19].

The accurate prediction of bed expansion is therefore of prime importance in the design of fluidized beds. The objective of this study was to investigate the effect of bed height and particle size on bed expansion in a bubbling fluidized bed. Investigation on bed expansion properties is very important to expand the application of Geldart B particles in bubbling fluidized beds.

3 Materials and Methods

Four grades of white fused alumina (White Aluminium Oxide) loose grains of the Geldart Type-B powders were used as the granular material for bed. The specifications for the material-alumina are given in Table 1.

Table 1 Technical specifications for the alumina used in the hydrodynamic studies

Grit size	Colour	Average particle size (μm)	Minimum particle size (μm)	Maximum particle size (μm)	Pour density approx. (kg/m^3)	True density (kg/m^3)
MW54	White	320	210	460	1720	3700
MW60	White	250	177	390	1670	3700
MW80	White	177	125	274	1620	3700
MW100	White	125	74	194	1560	3700

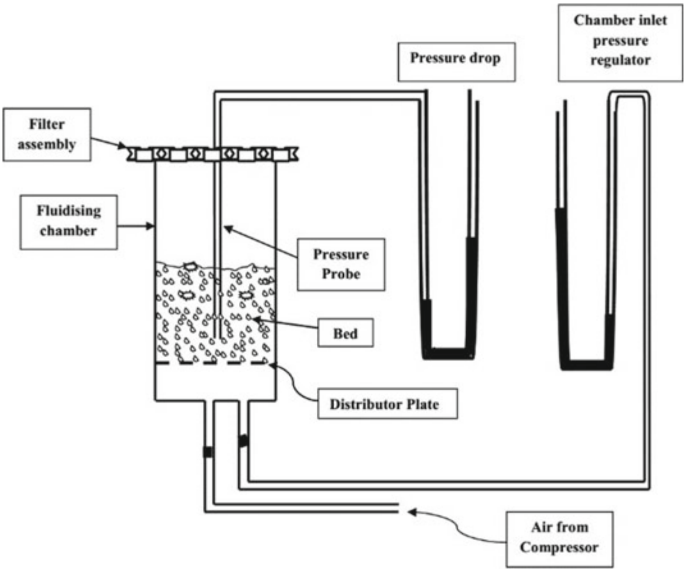

Fig. 1 Schematic of the fluidization and fluid bed heat transfer unit

The investigations were performed under ambient conditions in the Hilton Fluidization and Fluid Bed Heat Transfer Unit H694. The experimental set-up is shown schematically in Fig. 1.

The unit consists of a strong glass fluidizing cylinder closed at the bottom portion by an air distributor system, whereas filter assembly at the top end. A pressure probe is fitted to measure the drop in differential pressure across the bed. The fluidizing air the effect of superficial gas velocity on bed expansion for white fused alumina bed particles was investigated first by determining the minimum fluidization velocity for the bed particles. The determinations for the minimum fluidization velocity for all experiments in this current work were carried out according to the standard procedure reported by Davidson and Harrison [20]. The standard procedure was adopted by several investigators [13, 21–24]. The minimum fluidization velocities for the bed materials employed at a bed height of 60 mm are presented in Table 3.

The fluidizer was first charged with alumina particles of MW100 grit size to a height of 60 mm using the standard method reported by Canada, McLaughlin, & Staub [25] to determine the bed expansion. The static bed height was determined by applying an airflow rate above the minimum fluidization velocity for a short time so as to achieve a thoroughly mixed bed. The settled bed height was then measured from the transparent scale inscribed along the height of the fluidising column, and this was taken as the static bed height. The airflow rate controller was then adjusted to give an output of 10 l/min, and it was allowed to run for 3 minutes to achieve a steady state. Several measurements were taken for the minimum (hmin) and maximum (hmax) bed heights to determine fluctuation of bed surface at this airflow rate. The airflow

Table 2 Dimensions of the fluidization and fluid bed heat transfer unit

Bed chamber parameter	Dimension
Nominal heightof fluidizing column	220 mm
Nominal diameter of the fluidizing column	110 mm
Cross sectional area	8.66×10^{-9} m^2
Volume of the plenum chamber	3.33×105 mm^3
Type of distributor plate	Perforated plate consisting of six discs of filter paper sandwiched between two stainless gauze discs, all enclosed by a U-shaped rubber ring seal

Table 3 Minimum fluidization velocities attained for bed particles at a height of 60 mm

Mean bed particle size (µm)	Minimumfluidization velocity (m/s)
(MW100) 125	0.06
(MW80) 177	0.09
(MW60) 250	0.11
(MW54) 320	0.128

rate was then raised incrementally in small steps up to 120 l/min at the same static bed height and measurements for hmin and hmax were taken. The bed height was then adjusted to 90 mm and 120 mm, respectively, by adding more MW100 grit size alumina bed material, and the measurement procedure was repeated for each of the new bed heights. The same procedure was repeated for MW80, MW60, and MW54 grit size bed material. The bed expansion ratio was determined from the average for the highest and lowest bed heights to the static bed height for a particular airflow by applying the expansion ratio, R = (hmin + hmax)/2hs [1].

4 Results and Discussion

The variation in bed expansion ratio, R, with the gas velocity ratio, Uo/Umf, was determined for three different bed heights using fused alumina bed materials of mean particle diameters of 125–320 µm (Fig. 2a, b). Generally, the bed expansion is negligible at low gas velocity ratios (Fig. 2a, b) thereafter increasing linearly with superficial air velocity to values that seem to be somewhat dependent on the mean particle size diameter of the bed material as well as the bed height (Fig. 2c, d). The bed material remains in a static condition at gas velocity in the range 1–2 for the small particle size (125 and 177 µm), thereafter expanding to ratios between 1.3 and 1.5 depending on bed height (Fig. 2a, b). A low expansion of bed (ratio 1.2–1.4) is observed with large size (250–320 µm) material. The bed, however, remains static up to values of the gas velocity ratios between 5 and 8, thereafter showing marginal expansion depending on the bed height selected.

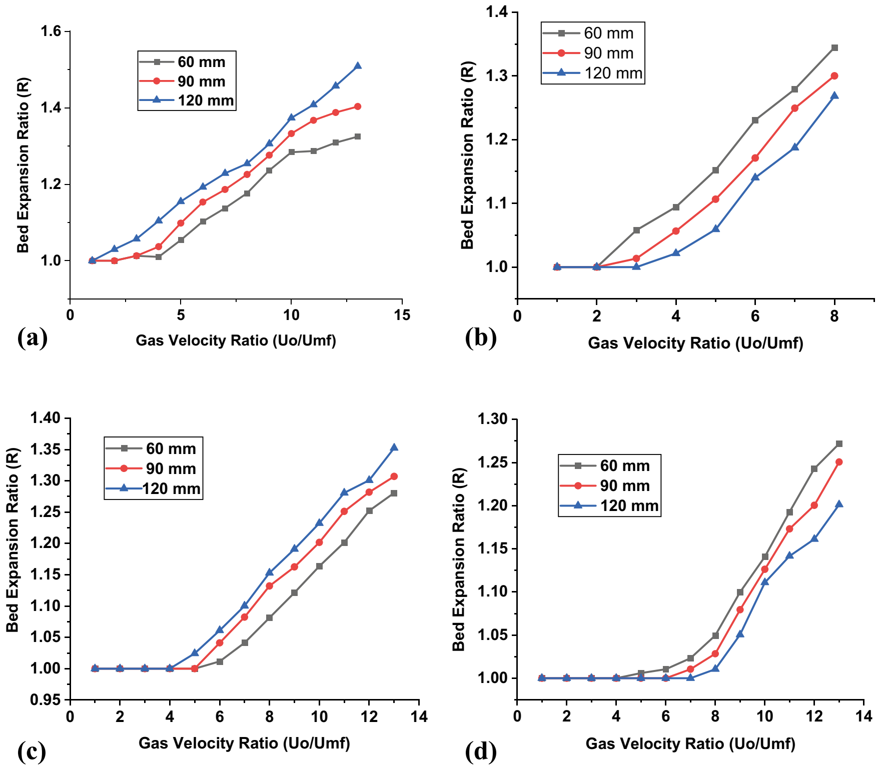

Fig. 2 Comparison of the bed expansion ratio (R) as a function of Gas velocity ratio (Uo/Umf) for bed heights of 60, 90, and 120 mm with particles of the mean diameter of **a** 125 µm, **b** 177 µm, **c** 250 µm and **d** 320 µm

As can be noted the bed expansion is also inversely proportional to the bed height, with higher bed heights experiencing less bed expansion when compared to smaller bed heights.

The initial static bed at low gas velocity ratios may be associated with the packed bed condition of relatively small particle size and low-pressure drop. The effect is more pronounced with large bed particles; here the slip velocity required to produce the all-important drag force is less than the gravitating particle velocity leading only to upward gas flow without any consequentially bed expansion effect. As the gas velocity ratio is increased, the packed bed is transformed into a fluidized state resulting in a linear bed expansion. Similar trends in bed expansion with gas velocity ratio have been reported [26, 27]. This is attributed to the number of gas bubbles formed above the distributor plate.

In contrast to low fluidizing gas velocities, there is a considerable high number of bubbles generated at high gas velocities. These bubbles coalesce as they rise up the fluidizing chamber increasing the bed expansion ratio. It has also been observed that the bed expansion ratio is inversely proportional to the increase in bed height [8, 11, 28]. The decrease is attributed to an increase in bed mass which requires high gas velocities to fluidize it; more so, it offers high bed resistance owing to its increased pressure drop. This has a negative impact on the power required to fluidize the bed under high static bed heights.

The relationship of bed expansion with bed height was also reported in previous studies [13, 29]. The authors also observed that bed expansion is inversely proportional to the bed height; they related the decrease in bed expansion ratio to the creation of high resistance to the flow of fluidizing gas owing to the increased static bed. A high bed offers a greater weight than a low bed; this implies that a higher drag force will be required to lift the bed. High operating velocities required for high beds result in the formation of large gas bubbles which creates large voids causing an appreciable reduction in the vertical lift of the particles. The effect is a sudden bed collapse due to the voids, resulting in the reduction of overall height of the expanded bed and consequently bed expansion.

The variation of the bed expansion ratio with bed particle size at a bed height of 120 mm is presented in Fig. 3. At a fixed bed height of 120 mm, the bed expansion ratio remains constant up to a value of 3 of the Uo/Umf ratio, thereafter changing with a change in particle size. It was found that with the increase in particle size, the expansion of bed decreases.

Beds of smaller particle sizes show a steep bed expansion rise with gas velocity ratio compared to those of larger particle sizes. At the same bed height and operating gas velocities, the bed expansion ratio is thus inversely proportional to particle size. It was also shown that bed expansion decreases with increasing particle size [30]. On the contrary, Glicksman, Yule and Dyrness concluded that no influence on bed expansion could be related to particle size when same excess gas velocity (U-Umf) is applied [2]. This discrepancy can be explained as arising from the different variable parameters used in the analysis. While Glicksman, Yule and Dyrness used the excess gas velocity (U-Umf) for comparing the bed expansion ratio with varying particle

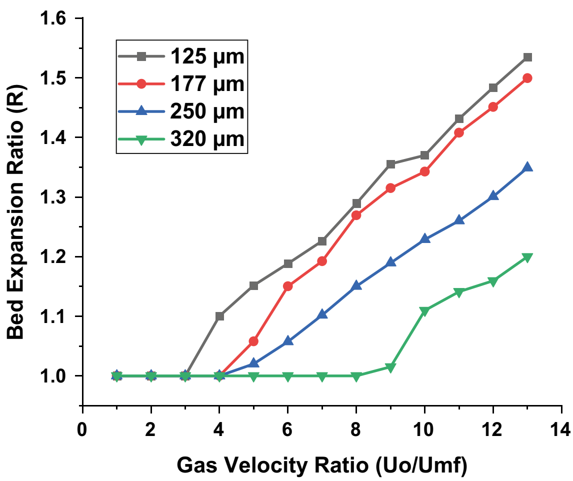

Fig. 3 Comparison of the bed expansion ratio (R) as a function of gas velocity ratio (Uo/Umf) at bed height of 120 mm for particles of the mean diameter of 125, 177, 250, and 320 μm

sizes; in this work gas velocity ratio (Uo/Umf) was used on the contrary [2]. Using the gas velocity ratio puts the comparison at the same footing since it considers the magnitude by which the gas velocity is applied as opposed to the unequal supply of excess gas velocity. The application of the excess gas velocity criterion does not provide an equal threshold increment for the comparisons given the different minimum fluidization velocities of the material.

Since minimum fluidization velocity increases with particle size; it can be noted that the fluidization quality of two beds having different particle sizes cannot be compared on the basis of the same excess gas velocity [27]. Hence for the same bed height and operating gas velocities, the bed expansion ratio decreases with bed particle sizes. This is partly due to a reduction of fines in the bed constituents which are generally lifted up to relatively great heights. There is decreased bubble density when large bed particles are used. The large interstitial spaces formed do not promote bubble formation in the bed. While an increase in the particle size is designed to reduce the bed expansion ratio, the opposite is true when smaller particles are included [31]. In the latter, the interstitial gas flow increases by three orders of magnitude, resulting in an increased bed expansion ratio. Geldart also noted that fine particles have an effect of decreasing the viscosity, thus leading to the formation of numerous gas bubbles which on coalescing results in increased bed expansion [32].

5 Conclusions

In this study, the effect on bed expansion ratios by varying the bed particle sizes and bed height is presented. The result indicates that the expansion ratio of bed increased with increasing superficial gas velocity. Within the range of the fluidizing velocities employed in the experiment, the bed expansion ratio was found to be inversely proportional to both bed height and particle size. Smaller bed particles gave rise to a higher bed expansion when compared to larger-sized bed particles. The use of bed particles of relatively large size resulted in reduced bed expansion owing to decreased bubble formation, a process necessary for lifting the bed. Higher gas velocities would be required to lift the bed of larger particles, implying the need for high power in order to fluidize the bed. Fluidized beds of large bed heights and particles generally require high pumping power since it is difficult to fluidize such eds; this entails high operational costs. The design and operation of the heat transfer tubes immersed in fluidized beds and the consequent heat transferred from the bed material were found to be influenced by bed expansion. This parameter has been found to increase with an increase in gas fluidization, bed height of a bubbling fluidized bed and size of bed particles used.

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