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Research Article

Direct prediction of Expanded Bed Height as a function of Reduced Reynolds Number in a Gas Solid Fluidization

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Abstract

Studies in the expansion behavior of fluidized bed systems are important for specifying the height of the fluidized bed. The bed expansion takes place because of bubbles any excess gas passes in the form of bubbles. The expansion of a fluidized bed usually commences when it is beyond minimum fluidization velocity. The bubble hold up is responsible for the expansion of the fluidized bed. Therefore, the excess air ($U-U_{mf}$) is responsible for bed expansion. Other variables that may affect bed expansion are particles and fluid characteristics. Data have been obtained on the heights of fluidized bed for Air-salt, Air-Magnesite, Air-Ammonium Sulphate and Air-Sand system using different static bed height. In this paper a correlation has been established to predict directly the expanded bed heights as a function of particles Reduced Reynolds Numbers as well as fluid characteristics. It has been seen that the calculated values by correlation agree well with the experimental values.

Keywords: *Fluidized bed; minimum fluidization velocity; Reduced Reynolds Numbers.*

Introduction

The expansion of a fluidized bed usually commences when it is beyond minimum fluidization velocity. The gas solid fluidization is characterized by the formation of bubbles. The amount of gas in excess of what is required for minimum fluidization passes through the bed in the form of bubbles. The bubble hold up is responsible for the expansion of the fluidized bed. Therefore, the excess air ($U-U_{mf}$) is responsible for bed expansion. The bed expansion ratio (R) is defined as the ratio of expanded bed height (h) and the height corresponding to minimum fluidization velocity (h_0).

Therefore, the bed expansion (R) can be considered to be a function of reduced Reynolds number $\{d_p(U-U_{mf})\rho_f/\mu_f\}$. The other variables that may affect the bed expansion are particle and fluid characteristics. They include particle size (dp), particle density (ρ_p), fluid density (ρ_f) and fluid viscosity (μ_f). In this work, sphericity has been assumed equal to unity and the effect of particle shape has not been studied.

The bed can be visualized to consist of two sections, one being the bubble phase having very low concentration of particles and another being the homogeneous phase having same voidage as that of an incipiently fluidized bed. According to two-phase theory of fluidization, the velocity of flow in continuous phase remains constant at the minimum fluidization velocity and the voidage of the continuous phase remains constant. The bubble holds up and initial bed height determines the height of the expanded fluidized bed. There is an interchange between the bubble and homogenous phase.

The average bubble size increases quite rapidly with the height mainly as a result of coalescence. It also increases as a result of overall gas expansion as the pressure decreases with height. But, this is a small effect with very dense materials or in beds operated at very low overhead pressures. The average size can be doubled into a few centimeter heights (Rowe P.N. et al,1961). The walls of the column affect the bubble shape and size, once the bubble size exceeds half the bed column.

According to Leva , the dense phase voidage remains constant for a given material at any gas flow rate. However it may show deviations depending upon the nature, density, shape, granulometry, and surface state of the particle. In both two and three-dimensional analysis fluidized beds interstitials several times greater than the incipient value may be found particularly near the bottom of the bed (Pyle D.L et al,1967).

Here an attempt has been made to directly predict the expanded bed height, which can be, calculated the bed height by a designer.

Experimental procedure

The experimental set up consists of a glass column of *4.5* cm internal diameter and 150 cm length with a filter cloth, which supports the bed of the particles. A conical

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distributor filled with glass beads has been used for the uniform distribution of air. Other accessories include rotameter, valves and compressor. The pressure drop across the fluidized bed has been measured via manometer after deduction of grid pressure drop of fluidization column because manometer is connected below the grid. Materials investigated include salt, sand, magnesite and ammonium sulphate. The system salt has been studied for four closely sized fractions (of average diameter 0.0276, 0.0338, 0.0442 and 0.0751 cm). The other materials investigated have been of the same size (0.044 cm). The particle densities varied from 1.760 gm/cm^3 to 2.80 gm/cm^3. The static bed height has been varied from 4.0 cm to 5.3 cm. Air has been used as the fluidizing medium throughout the study.

Accurately weighed amount of the solid materials was feed into the column and air was allowed to pass through the bed. The air flow was slowly increased. The air inlet valve was closed and settled bed height was taken on the initial bed height. Then the initial bed height was measured thrice and the average of the same was noted. By increasing the flow rate, the bed was fluidized and the expansion of the bed with increased flow rate was studied. For this purpose the expanded bed height and corresponding flow rate was noted.

For this the column should be perfectly vertical. The surface of the fluidized bed has been fluctuating. Attempts were made to locate the bottom and the top layer height of the fluidized bed. In this work the expanded bed height has been taken as the mean of the bottom and top layer height of the fluidized bed. The average value has been obtained from four different sets of the observations.

Results & discussions

Based on two-phase theory, the voidage of homogeneous phase remains constant at minimum fluidization velocity and bubble is normally devoid of the particles. As a result the bed expansion takes place because of hold up of bubbles.

In this section an attempt has been made to directly predict bed expansion as a function of particle reduced Reynolds number (R_{ep}-R_{emf}), particle size (d_p), particle density (ρ_p), fluid density (ρ_f) column diameter (D_t). Based on the work of Lewis and Bohmann (5) and Richardson and Zaky (6) the following functionality for bed expansion ratio has been postulated.

$$R=\Phi\left(d_p,\rho_p,\rho_f,\mu_f,U_{mf}\left(U_f-U_{mf}\right),D_t\right) \tag{1}$$

Using Buckingham π theorem following dimensionless groups are obtained.

$$R=\Phi\left[\left(\left(R_{ep}-R_{emf}\right)/R_{emf}\right)^p,\left(dp/D_t\right)^q,\left(\rho_p/\rho_f\right)^r\right] \tag{2}$$

The bed expansion data have been plotted on log-log graph in Fig. 1 (A-G). For materials differing in size and density these graph shows the effect of reduced Reynolds number on the bed expansion. The Fig. 2 and Fig. 3 show the effect of the particle density and particle size on the bed expansion.

The entire bed expansion curve has been divided into two parts and one equation for each part has been suggested as

$$R_{lower}=76.13\left[\left(\left(R_{ep}-R_{emf}\right)/R_{emf}\right)^{0.246}*\left(dp/D_t\right)^{0.359}*\left(\rho_p/\rho_f\right)^{-0.315}\right] \tag{3}$$

$$R_{upper}=952.64\left[\left(\left(R_{ep}-R_{emf}\right)/R_{emf}\right)^{0.50}*\left(dp/D_t\right)^{0.46}*\left(\rho_p/\rho_f\right)^{-0.609}\right] \tag{4}$$

The above equation (3) has the coefficient of determination, coefficient of multiplication and standard error of estimate of 0.631, 0.704 and 0.0399 respectively. The above equation (4) has the coefficient of determination, coefficient of multiplication and standard error of estimate of 0.863, 0.929 and 0.043 respectively.

Limits

Both the equations (for lower and upper sections) have been equated to give the limit of applicability of equations after equations (3) and (4) we get,

$$\left[\left(\left(R_{ep}-R_{emf}\right)/R_{emf}\right)^{-0.254}*\left(dp/D_t\right)^{0.101}*\left(\rho_p/\rho_f\right)^{0.294}\right]=12.513 \tag{5}$$

The equation (5) gives the limit of applicability if the value of equation (5) is greater than 12.513, the equation (3) is valid if the value of equation (5) is less than 12.513 the equation (4) is valid. Singh S.P. & Singh A.N (7) have studied fluidization of solid particles by means of air in 4.5 cm dia column, data reported in their work cover particles diameter from 0.0276 cm - 0.0751 cm and particle density from 1.760 g/cm^3 to 2.80 g/cm^3. The static bed height covers from 4.0 cm to 5.3 cm.

Table 1 and 2 give a comparison of bed expansion data observed by Singh & Singh with the height predicted by Equation (3) and Equation (4) respectively. The maximum deviation is limited to 10%.

Table 1.
Comparison of Expanded Bed Height observed by Singh & Singh with Expanded Bed Height predicted by eq. (3)

Material	d_p	ρ_p	h_{exp}	h_{cl}	$\frac{h_{cl}*h_{exp}}{h_{exp}}*100$
Salt	0.027	2.10	5.324	5.40	+1.5
			6.048	5.96	-1.32
			6.644	6.44	00
			7.700	6.92	-10.13
			8.20	7.16	+12.68
Salt	0.0338	2.10	6.952	6.996	+0.63
			7.836	7.480	-4.54
			8.544	7.832	-8.34
Salt	0.0442	2.10	5.58	5.98	+7.2
			5.98	6.42	+7.35
			6.51	6.86	+5.41
Salt	0.0751	2.10	5.736	6.48	+12.97
			7.492	8.256	+10.19
			7.824	8.688	+11.04

			8.544	8.976	+5.05
Ammonium Sulphate	0.0442	1.76	6.916	6.864	-0.75
			7.592	7.436	-2.06
			7.824	8.060	-4.37
			8.996	8.476	-5.78
Sand	0.0442	2.65	6.264	5.936	-5.24
			7.107	6.731	-5.29
			7.372	7.102	-3.66
			8.003	7.42	-7.28
			8.597	7.844	-8.75
			9.074	8.215	-9.46
Magnesite	0.0442	2.80	6.35	6.20	-2.36
			6.85	6.65	-2.92
			7.20	7.05	-2.08
			7.55	7.35	-2.65
			8.05	7.65	-4.97

Table 2.
Comparison of Expanded Bed Height observed by Singh & Singh with Expanded Bed Height predicted by eq. (4)

Material	d_p	ρ_p	h_{exp}	h_{cl}	$\frac{h_{cl}*h_{exp}}{h_{exp}}*100$
Salt	0.027	2.10	12.04	12.48	+3.65
			13.0	14.04	+8.0
			15.0	14.80	-1.33
			16.08	16.28	-1.21
			19.00	17.04	-10.31
Salt	0.0338	2.10	9.328	10.252	+9.09
			10.252	11.131	+8.58
			11.198	12.364	+10.41
			12.408	12892	+3.90
			13.990	14.564	+4.10
			15.090	15.444	+2.34
			16.760	16.28	-2.86-
			18.120	17.952	0.93
			19.840	18.744	-5.54
Salt	0.0442	2.10	7.08	7.744	+9.37
			10.20	11.00	+7.84
			11.08	12.10	+9.20
			12.496	12.892	+3.16
			12.84	13.728	+6.91
			14.12	14.564	+3.14
			15.00	15.444	+2.96
			16.36	16.28	-0.49
Salt	0.0751	2.10	8.83	9.504	+7.60
			9.31	9.984	+7.20
			10.08	10.704	+6.19
			10.56	11.184	+5.90
			11.28	12.144	+7.65
			12.24	13.104	+7.05
			12.96	13.392	+3.33
Ammonium Sulphate	0.0442	1.76	10.19	9.828	-3.56
			11.80	11.024	-6.60
			13.52	12.116	-10.38
			15.49	14.196	-8.35-
			20.48	17.212	15.96
			22.98	19.240	-16.27
Sand	0.0442	2.65	9.33	8.586	-7.97
			10.505	9.858	-6.15
			11.87	10.918	-8.02
			13.48	12.349	-9.96
			16.49	14.469	-12.25
			19.19	17.384	-9.40
Magnesite	0.0442	2.80	8.25	8.00	-3.03
			9.05	8.65	-4.41
			9.60	9.15	-4.68
			11.80	11.15	-5.50
			12.35	11.45	-7.28

A bubbling fluidized bed can be regarded as consisting of two phases, a continuous phase and a bubble phase. The voidage of continuous phase may be change depending upon its composition (large and dense particles). Excess gas passes through the bed in the form of bubbles. The bubbles hold up in the bed accounts for the bed expansion at any stage the interchange of gas between the phases exists but can be neglected for the calculation of expanded bed height.

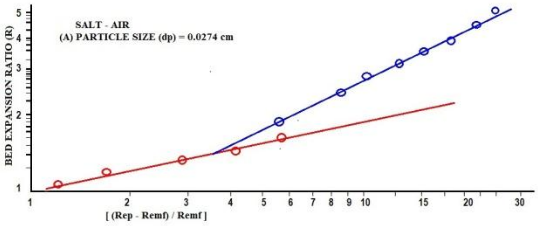

Fig.1 (a): Expansion of gas - solid fluidized bed

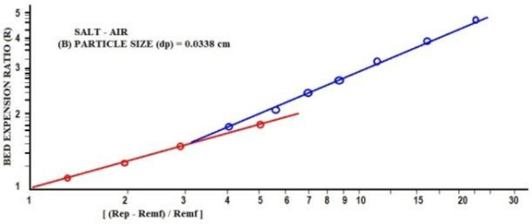

Fig.1 (b): Expansion of gas - solid fluidized bed

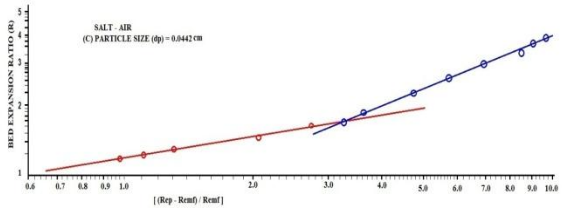

Fig.1 (c): Expansion of gas - solid fluidized bed

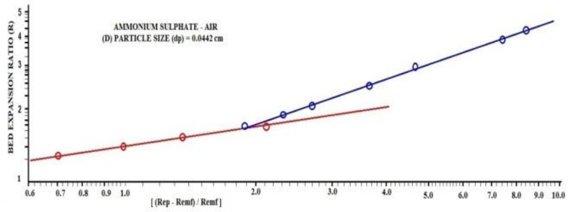

Fig.1 (d): Expansion of gas - solid fluidized bed

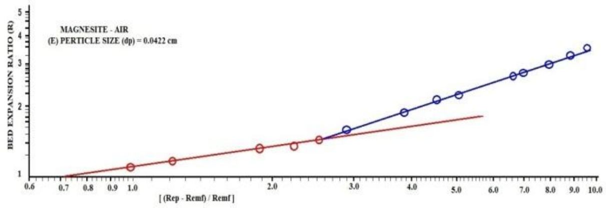

Fig.1 (e): Expansion of gas - solid fluidized bed

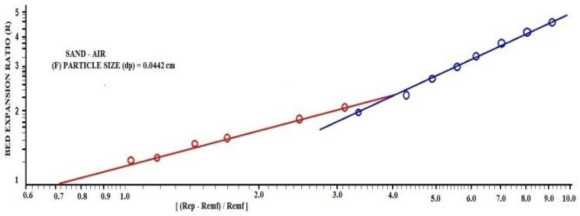

Fig.1 (f): Expansion of gas - solid fluidized bed

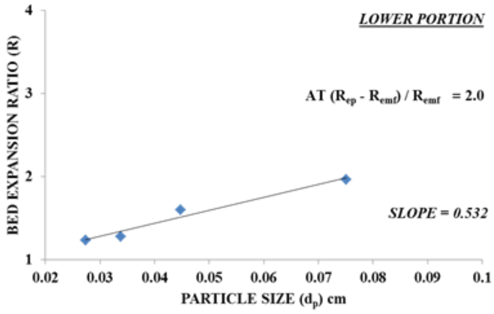

Fig. 2(a): Effect of particle size on bed expansion

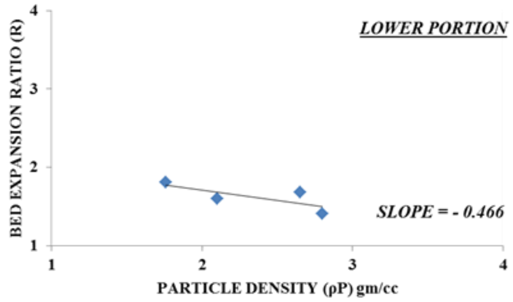

Fig. 2(b): Effect of particle density on bed expansion

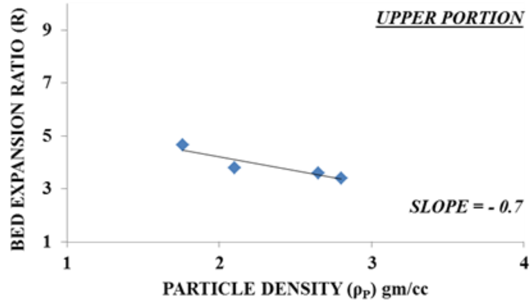

Fig. 3(a): Effect of particle size on bed expansion

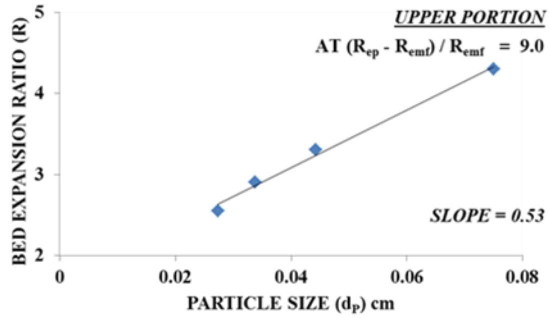

Fig. 3(b): Effect of particle density on bed expansion

Conclusion

Gas solid fluidization is characterized by the formation of bubbles and the expansion beyond the point of incipient fluidization is due to gas bubbles, which increases the bed volume.

The entire bed expansion curve has been divided into two parts and one equation for each part has been suggested. The experimental results are excellent with the predicted one within the range of ± 10%.

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Nomenclature

(dp) Diameter of Particles
(ρ_f) Density of Fluid
(D_t) Diameter of Column
(h_0) Height of initial static bed
(h_f) Height of the expanded bed
(R) Bed expansion ratio, dimensionless
$R_{ep}(d_p \rho u / \mu_f)$ Reynolds number,dimensionless
μ_f Superficial velocity through a bed of solids, m/s
(U_{mf}) Minimum fluidization velocity
(R_{emf}) Reynolds number at min. fluidization velocity
(h_{cl}) Expanded Bed Height Calculated
(h_{exp}) Expanded Bed Height Observed
$\frac{h_{cl} * h_{exp}}{h_{exp}} * 100$ Percentage Deviation

Greek Symbols
(ρ_p) Density of Particles
(ρ_t) Density of Air
Φ Functional Relationship
μ_f Viscosity of Fluid

Subscripts

f fluidization condition
p particle
(o) initial condition
t tube
f Fluidizing medium