Prediction of Bed Expansion Ratio for Gas-solid Fluidization in Cylindrical and Non-cylindrical Beds

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Based on dimensional analysis approach, equations have been developed for the prediction of bed expansion ratio for non-cylindrical (viz, semi-cylindrical, hexagonal and square) and cylindrical beds. A fairly good agreement has been obtained from calculated and"experimental values. Based on experiments, it is concluded that under similar operating conditions, fluidized bed height will be maximum in case of square bed and will be the least for hexagonal bed.

Keywords : Non-cylindrical conduits. Bed expansion ratio. Gas-solid fluidization.

NOTATION

a, b, c : exponents
D_c : equivalent diameter of column, L
d_p : particle diameter, L
G_f : fluid mass velocity, $ML^{-2}\,\theta^{-1}$
G_{mf} : fluid mass velocity at minimum fluidization, $ML^{-2}\,\theta^{-1}$
h_s : static bed height, L
K : coefficient
n : exponent
R : expansion ratio, dimensionless

INTRODUCTION

Gas-solid fluidized bed. generally of aggregative nature is marked by occurrence of bubbles of varied sizes and slugs. This results in non-uniform bed expansion and a poor fluidization phenomenon. Keeping in view, aforesaid inherent drawbacks of cylindrical conduit, non-cylindrical conduits can be employed in gas-solid fluidization with a view to smoothening the bed expansion behaviour and improve upon the fluidization quality.

BED EXPANSION RATIO

Bed expansion ratio is defined as the ratio of the average height of a fluidized bed to initial static bed height at a particular flow rate of the fluidizing medium above the minimum fluidizing velocity. It is an important parameter for fixing the height of fluidized bed required for a particular service.

The expansion ratio of a fluidized bed depends on excess gas velocity (G_f-G_{mf}), particle size (d_p), and initial bed height (h_s). Bed expansion is substantially greater in a two-dimensiona! bed than in a three-dimensional one. The bed expansion reported by different investigators have different meanings because of varied methods of measurement adopted.

Although some investigations have been made with respect to the prediction of bed expansion in cylindrical conduits[1-3], limited information is available for the. non-cylindrical ones[4,5]. In the present work, investigations have been carried out with respect to bed expansion behaviour of gas-solid fluidization in cylindrical and non-cylindrical conduits, *viz*, the semi-cylindrical, hexagonal and square ones for different materials of spherical and non-spherical shape (Table 1) and

Table 1 Properties of beds

Materials	Type of Bed	Voidage, ε
Dolomite	Cylindrical	0.515 – 0.550
Chromite ore	Cylindrical	0.522
Coal	Cylindrical	0.543
Sago	Cylindrical	0.437
Manganese ore	Cylindrical	0.568
Dolomite	Square	0.490 – 0.520
Chromite ore	Square	0.476
Coal	Square	0.516
Ramdana	Square	0.446
Manganese ore	Square	0.531
Dolomite	Semi-cylindrical	0.468 – 0.537
Chromite ore	Semi-cylindrical	0.546
Coal	Semi-cylindrical	0.563
Sago	Semi-cylindrical	0.467
Manganese ore	Semi-cylindrical	0.527
Urea	Semi-cylindrical	0.439 – 0.484
Dolomite	Hexagonal	0.502 – 0.547
Chromite ore	Hexagonal	0.498
Urea	Hexagonal	0.412 – 0.432
Coal	Hexagonal	0.520
Sago	Hexagonal	0.416
Manganese ore	Hexagonal	0.501

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the data have been computed in terms of correlations from dimensional analysis approach. The experimental set up is given elsewhere[6].

DEVELOPMENT OF CORRELATION

The correlations have been developed with the help of relevant dimensionless groups involving interacting parameters like, bed height, equivalent diameter of the column, particle diameter, fluid mass velocity at on-set of fluidization and the operating fluid mass velocity.

From dimensional analysis, the bed expansion ratio can be related to the system parameters as follows:

$$R = f\left(\frac{d_p}{D_c}, \frac{D_c}{h_s}, \frac{G_f - G_{mf}}{G_{mf}}\right) \tag{1}$$

Equation (1) can be written as

$$R = K\left[\left(\frac{d_p}{D_c}\right)^a \left(\frac{D_c}{h_s}\right)^b \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^c\right]^n \tag{2}$$

where K is the coefficient and *a, b, c* arc the exponents.

The effects of the individual groups on bed-expansion ratio have been separately evaluated for different conduits fluidizing non-spherical particles and the values of the exponents have been determined. Effect of the groups on bed expansion ratio has also been established for fluidizing a few spherical particles in hexagonal and semi-cylindrical conduits.

NON-SPHERICAL PARTICLES

(A) Cylindrical Bed

The exponents obtained are as follows:

a = 0.25, b = 0.727 and c = 0.433. Putting these values, equation (2) becomes,

$$R = K\left[\left(\frac{d_p}{D_c}\right)^{0.25} \left(\frac{D_c}{h_s}\right)^{0.727} \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.433}\right]^n \tag{3}$$

The values of K and n have been obtained by plotting the correlation factor against the expansion ratio, with the values of K and n, equation (3) becomes,

$$R = 2.55\left(\frac{d_p}{D_c}\right)^{0.11} \left(\frac{D_c}{h_s}\right)^{0.31} \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.18} \tag{4}$$

(B) Non-cylindrical Conduits

In a similar procedure as above, the values K and n have been obtained for semi-cylindrical, hexagonal and square conduits and the correlations developed are as under:

For semi-cylindrical bed,

$$R = 5.46\left(\frac{d_p}{D_c}\right)^{0.26} \left(\frac{D_c}{h_s}\right)^{0.03} \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.21} \tag{5}$$

For hexagonal bed,

$$R = 2.422\left(\frac{d_p}{D_c}\right)^{0.12} \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.35} \tag{6}$$

For square bed.

$$R = 6.09\left(\frac{d_p}{D_c}\right)^{0.24} \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.27} \tag{7}$$

SPHERICAL PARTICLES

With dimensional analysis approach, the effects of relevant groups on bed expansion ratio for fluidization of spherical particles have also been established.

By an identical approach as adopted for non-spherical particles, the values of K and n have been obtained for semi-cylindrical and hexagonal beds and the correlations developed are as follows:

For semi-cylindrical bed.

$$R = 2.92\left(\frac{d_p}{D_c}\right)^{0.14} \left(\frac{d_c}{h_s}\right)^{0.36} \left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.16} \tag{8}$$

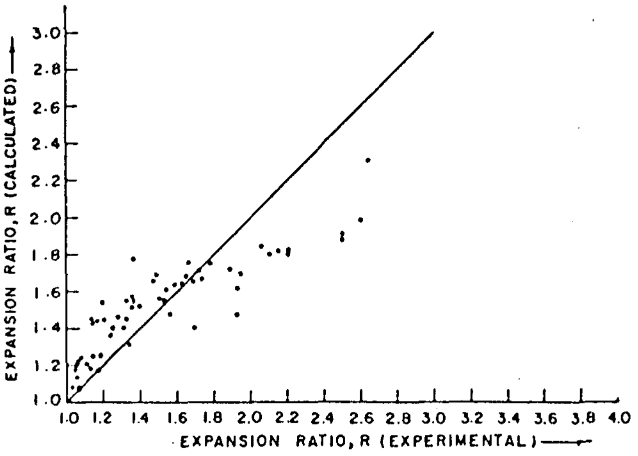

Fig 1 Cylindrical bed, non-spherical particles

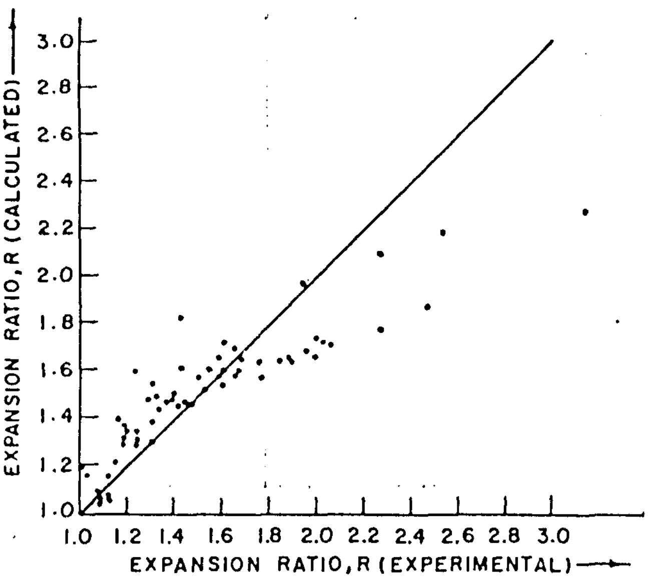

Fig 2 Semi-cylindrical bed, non-spherical particles

Table 2 Mean and standard deviations

Type of Conduits	Particle Shape	No of Readings	Mean Deviation, %	Standard Deviation, %
Cylindrical	Non-spherical	62	15.55	24.93
Semi-cylindrical	Spherical	63	10.81	14.45
Semi-cylindrical	Non-spherical	62	10.04	16.65
Hexagonal	Spherical	66	11.19	18.02
Hexagonal	Non-spherical	81	13.37	12.80
Square	Non-spherical	69	18.33	30.71

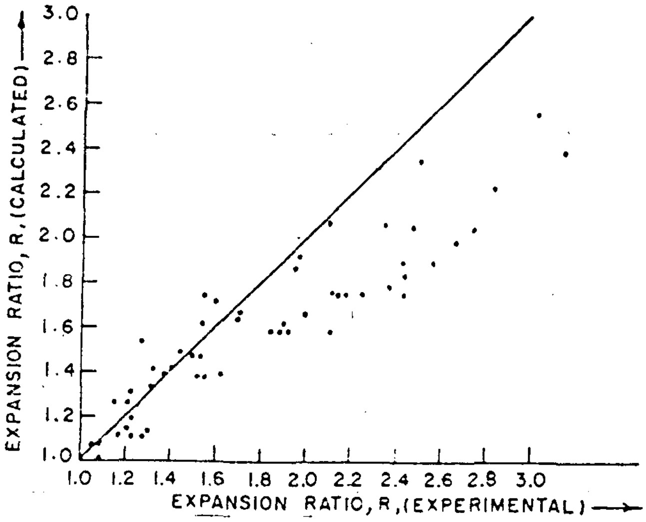

Fig 3 Hexagonal bed, non-spherical particles

For hexagonal bed,

$$R = 2.82\left(\frac{d_p}{D_c}\right)^{0.13}\left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.22} \qquad (9)$$

RESULTS AND DISCUSSION

Values of bed expansion ratio calculated with the help of equations (4) to (9) have been compared with their respective experimental values as shown in Fig 1-6. The mean and standard deviations for the above cases are given in Table 2.

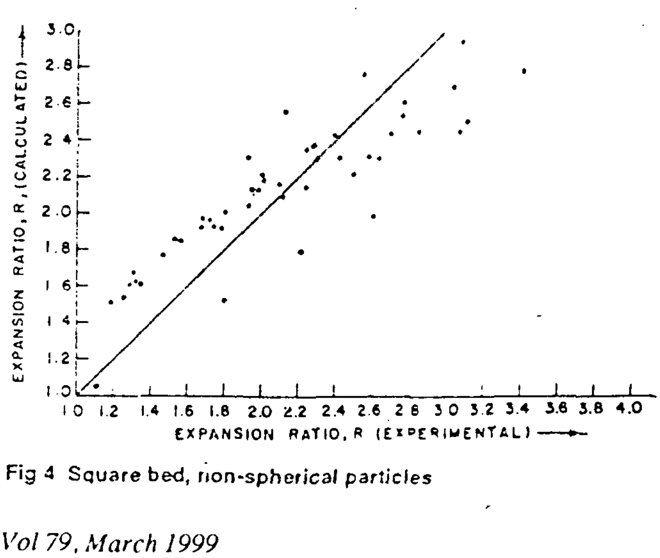

Fig 4 Square bed, non-spherical particles

Table 3 Comparison of bed expansion ratio in different conduits

$\frac{d_p}{D_c}$	$\frac{D_c}{h_s}$	$\frac{G_f - G_{mf}}{G_{mf}}$	Expansion Ratio, R			
			Cylindrical Bed	Semi-cylindrical Bed	Hexagonal Bed	Square Bed
0.0059	1.069	0.50	1.3065	1.2453	1.0260	1.4734
0.0059	1.069	0.75	1.4055	1.3560	1.1829	1.6439
0.0059	1.069	1.00	1.4802	1.4404	1.3082	1.7769
0.0059	1.069	1.25	1.5408	1.5095	1.4145	1.8870
0.0059	1.069	1.50	1.5923	1.5684	1.5076	1.9823

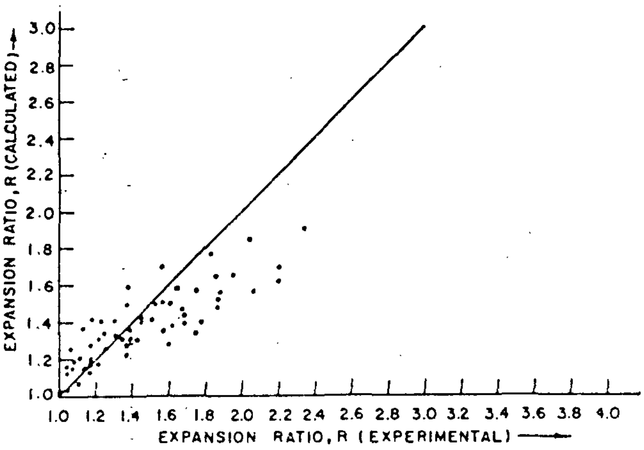

Fig 5 Semi-cylindrical bed, spherical particles

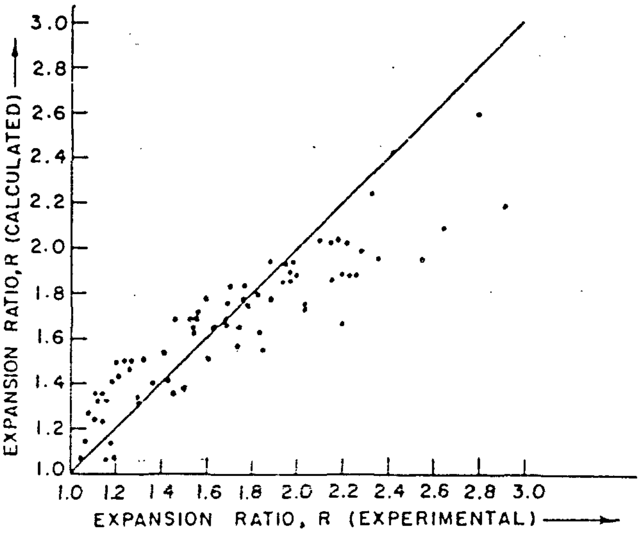

Fig 6 Hexagonal bed, spherical particles

It is evident from the developed correlations that bed expansion ratio is a function of the three -dimensionless groups, *viz*, the excess velocity ratio, wall effect (reciprocal) and aspect ratio (reciprocal). Further, it is revealed that bed expansion ratio is a strong function of the above groups for cylindrical and semi-cylindrical beds while the effect of aspect ratio is insignificant in case of hexagonal and square beds. This is due to the fact that, the range of variables studied in these two conduits results in an aspect ratio value nearly equal to unity which was due to operational constraints.

Bed expansion ratios have also been compared for all the conduits with identical excess velocity ratio and wall effect for an aspect ratio value of nearly unity in case of non-spherical particles (Table 3). Under similar operating conditions, fluidized bed height will be the maximum in case of a square bed and will be the least for a hexagonal bed.

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