Prediction of the Packed Bed Height in Gas-Solid Semifluidization

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Data on semifluidization of a few gas-solid systems are reported. Two correlations, one for spherical and another for nonspherical particles, have been obtained for the prediction of the packed bed formation by relating the ratio h_{pa}/h_s with the relevant system parameters.

The semifluidization phenomenon can be viewed as the combination of a batch fluidized bed at the bottom and a fixed bed at the top. Such a bed can be formed by providing sufficient space for the free expansion of a fluidized bed and then arresting the escape of the particles by means of a top restraint. A semifluidized bed overcomes the disadvantages of a fluidized bed, namely back-mixing of solids, attrition of particles, erosion of surfaces, etc., and at the same time, the inherent drawbacks of a packed bed such as nonuniformity in bed temperature, channel flow, and segregation tendency are absent. Babu Rao, *et al.* (1965), have shown that reactors involving fast exothermic reactions can be operated with steep temperature gradients in one section and a uniform temperature in the other section, with practically no elutriation of solids and a low pressure drop.

The pioneer investigators in the field of semifluidization are Fan, *et al.* (1959, 1961, 1963), who studied the mechanical and dynamical characteristics of semifluidized beds of single-sized particles both in liquid-solid and gas-solid systems. Additional studies dealing with the various aspects of liquid-liquid semifluidization have been reported by Poddar and Dutt (1969), Roy and Sarma (1970, 1971a,b) and Sunkoori, *et al.* (1969). Data on gas-solid semifluidization are relatively meager, the notable work being that of Fan, *et al.* (1963), and Roy (1971).

One important aspect in semifluidization is the prediction of the packed bed formation, which is closely related with the fluid velocity employed. Fan, *et al.* (1959, 1963), measured the packed bed formed in liquid-solid as well as gas-solid semifluidization. A plot of $(h - h_s)/(h - h_{pa})$ *vs.* $(G_{sf} - G_{mf})/(G_t - G_{mf})$ was given which can be used for the prediction of h_{pa}. An alternative method suggested by the same authors consists in the prediction of h_{pa} from bed porosity considerations. An identical equation valid for liquid-solid semifluidization was developed by Poddar and Dutt (1969). Roy and Sarma (1971a,b) modified the first approach of Fan, *et al.* (1963), and suggested the use of G_{osf} in place of G_{mf}. These authors proposed another dimensional equation for the prediction of h_{pa} by relating it with $(G_{sf} - G_{osf})$ only. In the work of Sunkoori, *et al.* (1969), the ratio of the free surfaces during free and restricted fluidizations (semifluidization) was related with the fluid mass velocity and the particle size.

Present Work

The experimental setup used consists of a Perspex semifluidization column 4.5 X 47.0 cm, an air compressor, **a** dehumidification tower packed with silica gel, an air reservoir, valves, and other fittings, and the details have been given by Roy and Sen Gupta (1973). The bottom grid for air distribution is made of 150 mesh screen. The movable top restraint is made of 80 mesh brass screen supported on a perforated brass plate. Pressure drop across the bed is noted with the help of a manometer and the flow rate measured by means of an orifice meter.

The materials investigated are spherical as well as nonspherical in shape. Table salt of size ranges 20/30, 30/40, 40/52, and 52/60 BSS has been thoroughly studied. Besides table salt, other nonspherical materials used are sand, ammonium sulfate, and magnesite having a particle size of 0.0442 cm. Two spherical materials, mustard seed and sago 0.1105 cm in diameter, were studied. The lowest and highest densities of solids used are 1.12 and 2.80 g/cm^3, respectively. The static bed height varied from 9 to 12 cm. Four bed expansion ratios being equal to 2.0, 2.5, 3.0, and 3.5 have been used.

Results

The semifluidization velocity, G_{sf}, ranges between the onset of semifluidization velocity, G_{osfs} i.e, the velocity at which the first particle touches the top restraint and the. maximum semifluidization velocity, $G_{mS}f$, corresponding to the accumulation of all the particles in the bed below the top restraint. The values of $G_{mS}f$ have been found by using the following methods: (i) extrapolation of an h_{pa}/hs *vs.* G plot to a value of h_{pa}/h_sequal to unity, and (ii) extrapolation of the Ef value equal to unity from the plot of E_f *us.* G.

It can be seen from Table I that comparatively higher values of G_{msf} are obtained by the second method. This is possibly due to the difficulty experienced in finding the expanded bed voidage accurately. Consequently, the first method has been preferred in processing the data. The onset of semifluidization velocity, G_{osf}, has been experimentally determined from a pressure drop *vs.* fluid velocity plot. For the sake of comparison, the minimum fluidization velocities, G_{mf}, have been calculated by using Leva's (1959) generalized equation and are given in the table.

Correlation

It is evident that the formation of a packed bed below the top restraint will depend on a number of factors, namely the semifluidization velocity, the particle size, the density of the material, the static bed height, the column diameter, and the bed expansion ratio. Consequently, the ratio, G_{Sf}/G_{msf} may be related with the system variables expressed as dimensionless groups in the following manner

$$G_{sf}/G_{msf} = \phi(D_c/d_p, \rho_s/\rho_f, h_s/D_c, R, h_{pa}/h_s)$$

or

$$G_{sf}/G_{msf} = A[(D_c/d_p)^{a_1}(\rho_s/\rho_f)^{a_2}(h_s/D_c)^{a_3}(R)^{a_4}(h_{pa}/h_s)^{a_5}]^B \quad (1)$$

where A is the coefficient, B is the overall exponent, and a_1, a_2, 0_3, a4, and 05 are the respective exponents of the system variables. The exponents a_1, a_2, a_3, a_4, and a_5 were evaluated from the slopes, of straight lines obtained by plotting G_{Sf}/G_{rnsf} values against the respective parameters.

Since the exponents were known, the products of the groups within the parentheses were calculated and plotted

Table I. Data on Semifluidization Characteristics of Gas–Solid Systems

Material	Size mesh, BSS	Sphericity, ϕ_s	Density, g/cm³	G_{mf}, kg/hr m² (calcd)	G_{osf}, kg/hr m² (from ΔP vs. G plot)	G_{msf}, kg/hr m² From h_{pa}/h_s vs. G plot	G_{msf}, kg/hr m² From ϵ_f vs. G plot
Table salt	20/30	0.331	2.100	804	2200	14,000	15,000
Table salt	30/40	0.452	2.100	491	1850	10,500	12,000
Table salt	40/52	0.587	2.100	390	1462	7,500	9,700
Table salt	52/60	0.654	2.100	258	1250	5,500	9,200
Ammonium sulfate	30/40	0.832	1.763	349	1750	9,000	14,000
Sand	30/40	0.798	2.650	653	1850	14,000	15,500
Magnesite	30/40	0.770	2.800	596	1875	15,000	16,000
Mustard seed	14/20	1.000	1.120	1200	2450	12,400	14,200
Sago	14/20	1.000	1.304	1665	2500	14,000	15,500

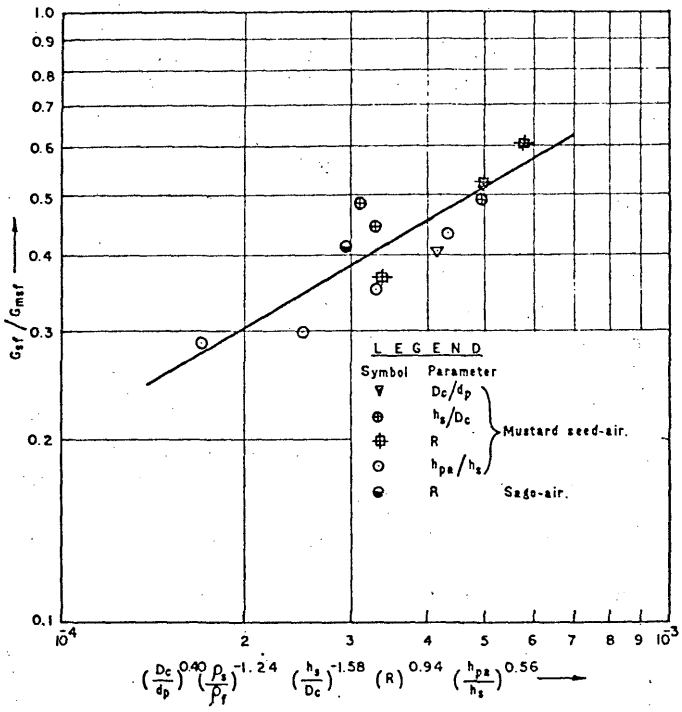

Figure 1. Correlation for packed bed formation of spherical particles.

in Figures 1 and 2 with G_{sf}/G_{msf} as the ordinate (Figure 1 for spherical and Figure 2 for nonspherical particles).

The least-square values of A and B in Figure 1 have been found to be $A \simeq 37.07$ and $B \simeq 0.5648$.

Substituting the values of A and B in eq 1 and simplifying, the correlation for spherical particles becomes

$$G_{sf}/G_{msf} = 37.0.7(D_c/d_p)^{0.23}(\rho_s/\rho_f)^{-0.70}(h_s/D_c)^{-0.89}(R)^{0.53}(h_{pa}/h_s)^{0.32} \quad (2)$$

In terms of h_{pa}/h_s

$$h_{pa}/h_s = 1.25 \times 10^{-5}(G_{sf}/G_{msf})^{3.13} \times (D_c/d_p)^{-0.72}(\rho_s/\rho_f)^{2.19}(h_s/D_c)^{2.79}(R)^{-1.66} \quad (2a)$$

The correlation coefficient for eq 2a has been found as 0.81.

In a similar manner, the values of A and B for nonspherical particles have been obtained as $A \simeq 35.16$ and $B \simeq 0.5460$. Accordingly, the correlation for nonspherical particles can be written as

$$G_{sf}/G_{msf} = 35.16(D_c/d_p)^{0.22}(\rho_s/\rho_f)^{-0.68}(h_s/D_c)^{-0.86}(R)^{0.51}(h_{pa}/h_s)^{0.31} \quad (3)$$

or, in terms of h_{pa}/h_s, eq 3 takes the form

Table II. Deviation of Predicted Values from Experimental Data

Run no.	Prod[a] × 10⁴	G_{sf}/G_{msf} From experiment	G_{sf}/G_{msf} From least-square line	% Dev
		Spherical		
1	4.17	0.404	0.460	13.80
2	2.94	0.415	0.380	−8.40
3	4.93	0.494	0.510	3.24
4	3.30	0.444	0.405	−8.80
5	3.13	0.484	0.390	−19.40
6	3.39	0.366	0.408	11.50
7	4.96	0.524	0.510	−5.90
8	5.74	0.605	0.560	−7.44
9	1.70	0.286	0.295	3.14
10	2.50	0.299	0.342	14.40
11	3.31	0.351	0.404	15.10
12	4.36	0.435	0.474	8.95
		Nonspherical		
1	2.26	0.357	0.360	0.84
2	2.79	0.415	0.408	−1.69
3	3.11	0.479	0.432	−9.80
4	3.38	0.589	0.450	−23.60
5	3.43	0.485	0.460	−5.15
6	2.08	0.254	0.343	35.00
7	1.93	0.302	0.330	9.26
8	3.30	0.372	0.445	19.60
9	2.20	0.344	0.355	3.20
10	2.10	0.348	0.348	0.00
11	2.27	0.314	0.360	14.55
12	3.32	0.436	0.448	−2.75
13	3.84	0.579	0.486	−16.10
14	0.52	0.226	0.159	−29.70
15	1.42	0.240	0.277	15.40
16	2.10	0.270	0.346	28.20
17	2.43	0.316	0.374	18.40
18	3.09	0.484	0.428	−11.50
19	3.37	0.556	0.450	−19.10

[a] Refers to the product of dimensionless groups as abscissa in Figures 1 and 2.

$$h_{pa}/h_s = 1.07 \times 10^{-5}(G_{sf}/G_{msf})^{3.22} \times (D_c/d_p)^{-0.71}(\rho_s/\rho_f)^{2.18}(h_s/D_c)^{2.78}(R)^{-1.66} \quad (3a)$$

The last equation has a correlation coefficient of 0.66.

Table II contains the per cent deviations of G_{sf}/G_{msf} values, obtained by using the least-square line, from the experimental data. It can be seen that the maximum deviation in case of spherical particles is about 19.4% as against 35% in case of nonspherical particles. This is also evident from a higher value of the correlation coefficient in case of spherical particles. As can be seen, the two equations are nearly identical. Since sphericity of particles is important for packing orientation, a separate equa-

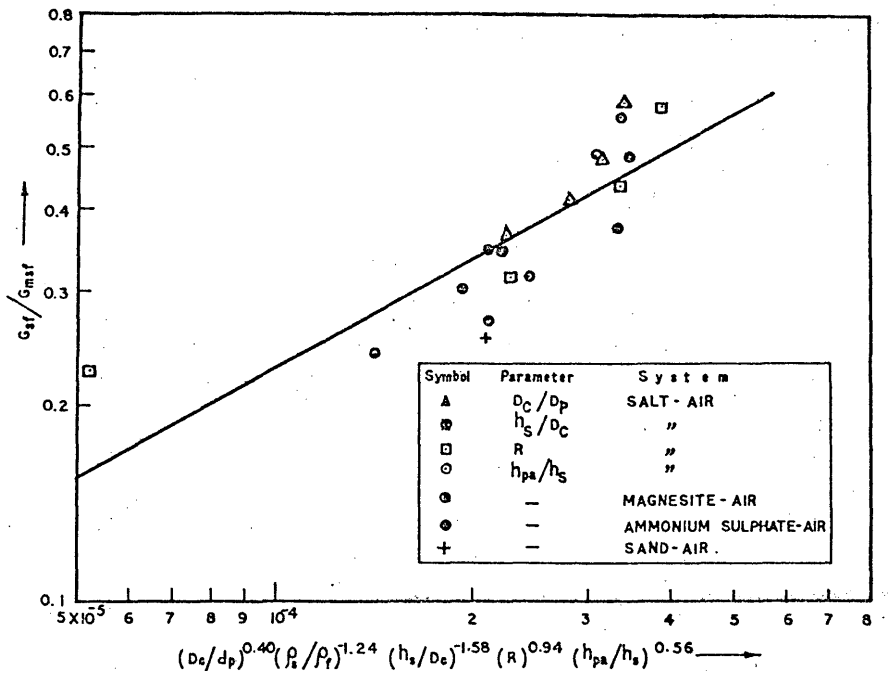

Figure 2. Correlation for packed bed formation of nonspherical particles.

tion is proposed for the two spherical materials investigated. The equations suggested have limitations, and so more work in this field is recommended.

Nomenclature

A = constant
$a_1, a_2, \ldots, a_5$ = constants
B = constant
D_c = diameter of column, L
d_p = particle diameter, L
G = fluid mass velocity, $ML^{-2}T^{-1}$
h = height of fluidized section, L
R = bed expansion ratio, h/h_s

Greek Letters

ϕ = function
ρ = density, ML^{-3}
ϵ = bed porosity
ϕ_s = sphericity

Subscripts

f = fluid or fluidized bed
mf = minimum fluidization condition
msf = maximum semifluidization condition
osf = onset (or minimum) of semifluidization condition
pa = packed condition
s = static or solid
sf = semifluidization condition .
f = free-fall terminal condition

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