Semi-Fluidization

Design study

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Semi-fluidization techniques offer immense potential in processes involving heat and/or mass transfer

By partially restricting the free expansion of a fluidized bed. simultaneous formation of *a* packed section at the top and a hatch fluidized section at the bottom takes place. This technique offers immense potential in processes involving heat and/or mass transfer and can be employed in catalytic reactors [1], ion exchange columns, solvent extractors, driers, etc.

Studies have been reported for predicting maximum and minimum semi-fluidization velocities [1-5, 7-l0, 13-14] the packed bed fort-nation [3-4,7-9,12] and the pressure drop across the bed [3,11] although these cannot be regarded as comprehensive. The authors have carried out a series of experiments and details of the experimental set-up and materials used are available from the authors.

Maximum semi-fluidization velocity

The maximum semi-fluidization velocity (Gsmf) has been defined as the velocity at which the entire mass of solid particles is transferred to the lop and gives rise to a packed bed formation almost equal to the initial static bed. This velocity also corresponds to the terminal free fall velocity of the particles.

There are three methods for finding the maximum semi-fluidization velocity; (!) linear extrapolation of expanded bed voidage, *et* versus fluid mass velocity plot to the value of $\epsilon_f = 1.0$ (2) extrapolation of hpa/hs versus fluid mass velocity plot to the value of hpa/hn- 1.0 (3) by calculation of free-fall terminal velocity.

For gas-solid.systems, Fan et al[2-4] observed that values of Gmst calculated from free fall considerations are lower than those obtained by method (2).

For liquid-solid systems, Roy and Sarma[7-9] compared the G_{msf} values obtained by the above three methods and suggested a correlation in terms of the Archimedes number. The work of Poddar and Dutt[5] are similar in nature but, instead of the Archimedes number, the Galileo number was used.

The maximum semi-fluidization velocities in the author's work have been found by using the first two methods (Table 1) and it can be seen that comparitively higher values of G_{msf} are obtained by using the expanded bed voidage method. The correct evaluation of Ef offer is difficult &, so, far correlation purposes, this method cannot be considered very reliable.

Evidently, the parameters of importance in such an operation are the modified Reynolds number (Re_{msf}) containing the Gmsf term and the physical characteristic group, the Archimedes number (Ar), having the particle size, the densities of the solid and the fluid, and the viscosity of the fluid. In practice, a relationshio of the **$Re_{msf} = \psi (Ar)^n$ type has been found to** exist and, on evaluation of the constant and the exponent of the function (Fig. I) the following correlation has been obtained:

$$Re_{msf} = 1.15 \times 10^{-3} (Ar)^{0.676} \quad \ldots (1)$$

The maximum semi-fluidization velocity G_{msf} can be found from equation (1) as;

$$G_{msf} = \frac{3.46 \times 10^2 (d_p)^{1.03} [\rho_s(\rho_s - \rho_f)]^{0.676}}{\mu_f^{0.352}} \quad \ldots (1a)$$

In Table 1, the values of G_{msf} calculated by using equation (la) above have been compared with those obtained experimentally from h_{pa}/hs versus G plots; the percentage deviation being within 13 per cent exent in one case in which it was 23 per cent.

Minimum semi-fluidization velocity

The minimum semi-fluidization velocity (G_0sf) corresponds to the fluid velocity at which the first particle of the bed just touches the top restraint of the semi-fluidizer. In an experiment it is not possible to detect this precise moment so the value has to be obtained indirectly; either by plotting the fluid mass velocity against the pressure drop.

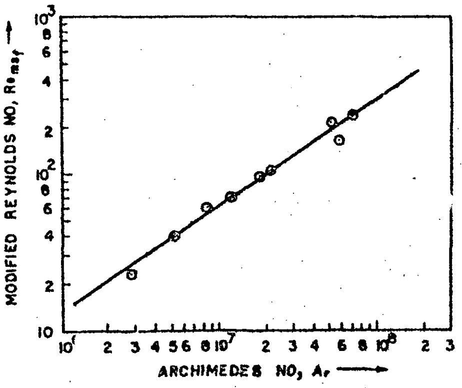

Fig. 1—Correlation for maximum semi-fluidization velocity

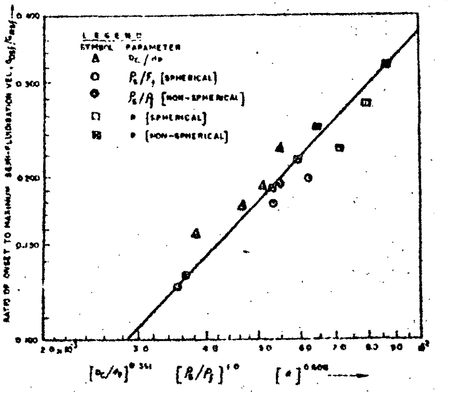

Fig. 2—Relationsl › between G_{osf}/G_{msf} and system variables

Table 1 Data on maximum semi-fluidization velocity for gas-solid systems

Characteristics of materials					Maximum semi-fluidization velocity, G_{msf}, kg/h.m²			Percentage deviation of G_{msf} from
Material	*Size mx10⁴*	*Density gm/cm³*	*Sphericity*	*Surface area cm²/cm³*	*From h_{pa}/h_s vs. G plot*	*From ϵ_f vs. G. plot*	*Calculated from equation (1a)*	*those found using h_{pa}/h_s vs. G plot*
Non-spherical								
Table salt	7·51	2·10	0·33?	241·0	14,000	15,000	17,250	+23·20
Table salt	4·42	2·10	0·452	300·5	10,500	12,000	10,180	− 3·05
Table salt	3·38	2·10	0 587	302·0	7,500	9,700	7,690	+ 2·53
Table salt	2·74	2·10	0 654	335·0	5,500	9,200	6,160	+ 12·00
Ammonium sulphate	4·42	1·76	0 832	133·0	9,000	14,000	7,990	−11·20
Sand	4·42	2·65	0·798	170·5	14,000	15,500	14,400	+ 2·86
Magnesite	4·42	2·80	0·770	177·0	15,000	16,000	14,500	− 3·34
Spherical								
Mustard seed	11·05	1·12	1·000	54·2	12,400	14,200	10,840	−12·60
Sago	11·05	1·30	1·000	54·2	14,000	15,500	13,320	− 4·85

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List of symbols

A	constant
Ar	Archimedes number, $d_p^3 g_c \rho_f(\rho_s - \rho_f)/\mu_f^2$
a_1, a_2, a_3	constants
B	constant
D_c	diameter of column, m
d_p	diameter of particle, m
G	fluid mass velocity, kg/h. m²; subscript $_{msf}$ for maximum semi-fluidization and $_{osf}$ for onset (or minimum) of semi-fluidization
g_c	gravitational constant, m/h²
h	height, m; subscript $_f$ for fluidization, $_{pa}$ for packed bed and $_s$ for static bed
R	bed expansion ratio, h_f/h_s
Re_{msf}	Reynolds number corresponding to maximum semi-fluidization, $d_p G_{msf}/\mu_f$
ϕ	function
ψ	function
ϵ	porosity of bed; subscript $_f$ for fluidized bed
ρ	density, kg/m³; subscript $_f$ for fluid and $_s$ for solid
μ	viscosity, kg/m.h; subscript $_f$ for fluid

Table 2 Effect of static bed height on minimum semi-fluidization velocity

Material	Size $m \cdot 10^4$	Static bed height h_s, cm.	Minimum semi fluidization velocity G_{osf}, kg/h.m² R = 2·0	R = 2·5	R = 3·0	R = 3·5
Table salt	7·51	9·00	2200	2600	2900	3300
		10·00	2200	2700	3000	3300
		11·00	2200	2700	2800	3200
		12·00	2200	2600	2800	3200

Table 3 Comparison of experimental and calculated velocities

Material	D_c/d_p	$\rho_s\rho_f$	G_{osf}	G_{msf}	G_{osf}/G_{msf} Experimental	Calculated	Percentage deviation
Non-spherical							
Table salt	59·9	1,750	2,200	14,000	0·157	0·141	—10·20
Table salt	101·8	1,750	1,850	10,500	0·176	0·165	— 6·25
Table salt	133·0	1,750	1,462	7·500	0·192	0·190	— 1·04
Table salt	164·0	1,750	1,250	5,500	0·227	0·207	— 8·80
Ammonium sulphate	101·8	1,470	1,750	9,000	0·195	0·207	+ 6·15
Sand	101·8	2,206	1,850	14,000	0·132	0·134	+ 1·51
Magnesite	101·8	2,330	1,875	15,000	0·128	0·128	+ 2·40
Spherical							
Mustard seed	40·7	933	2,450	12,400	0·198	0·234	+ 18·20
Sago	40·7	1,082	2,500	14,000	0·179	0·196	+10·60

on log-log paper (two distinct breaks are observed, the first corresponding to the minimum fluidization velocity and the second to Gosf or. from the plot 'of h_f/h_s against fluid mass velocity G (wherein the velocity of the fluid corresponding to h_f/h_s equal to R represents G,osf).

Fan studied the dynamic characteristics of semi-flnidied beds of single-sized particles for both liquid-solid and gas-solid systems and observed that G_{osf} was dependent on the physical properties of the system and the bed expansion ratio.

For liquid-solid systems, two correlations have been reported; the first by Poddar and Dutt', relates the Reynolds number corresponding to the onset of semi-fluidisation with the Galileo number the bed expansion ratio R, the sphericity *of* particles and the packed bed porosity, while the other, by Roy and Sarma ". relates the ratio of G_{osf} to Gmsf with R and Archimedes number. No correlation has. however, been suggested for gas-solid systems.

The onset of semifluidzation velocit has beer, determined by the authors from a pressure drop versus fluid mass velocity plot and it.is observed (Table 2) that the static bed height has no appreciable effect on G_{osf}. Consequently an average value of G_{osf} at a particular bed expansion ratio has been used irrespective of the static bed height, lis.

In Table 3, the values of Gosf a bed expansion ratio *of 2* are given. It can be seen that, for a given material (table salt), the 'bigger the particle size, the greater is the value of G_{osf}

Derivation of design equation

The bed expansion ratio, R is of great importance. The position of the movable restraint in a semi-fluidizer will give a quantitative idea of the upward lift of the particle by the fluid. From the trend of the data it can be concluded that with an increase in the bed expansion ratio, the onset of semi-fluidization velocity increases.

For a particular fluid-solid system of fixed particle size, the maximum semi-fluidization velocity remains constant, so the velocity ratio G_{osf}/G_{mst} becomes a direct function of the bed expansion ratio.

Apart from bed expansion ratio R, the other parameters (expressed as dimensionless groups) affecting the velocity ratio G_{osf}/G_{msf}, are h_s/D_c, D_c/d_p, and ρ_s/ρ_f. Since the column diameter was not altered in the authors' study, the ratio h_s/D_c becomes irrelevant and the relationship can be expressed as:

$$G_{osf}/G_{msf} = \phi\,(D_c/d_p,\ \rho_s/\rho_f,\ R) \text{ or}$$

$$G_{osf}/G_{msf} = A\,[(D_c/d_p)^{a1}\,(\rho_s/\rho_f)^{a_2}\,(R)^{a_3}]^{B} \quad \ldots (2)$$

where A is the coefficient, a_1, a_2, and a_3 are exponents of the variable groups respectively and B the overall exponent.

From plots of the velocity ratio against the individual groups, the exponents a_1, a_2 and a_3 were evaluated as 0.361, −1.0 and 0.608 respectively.

Using these values, equation (2) was then plotted on log-log paper (Fig. 2) and the values A ≃ 48.0 and B ≃ 1.045 obtained from the plot.

After substitution of the values of A and B, and on simplification, equation (2) becomes;

$$G_{osf}/G_{msf} = 48.0\,(D_c/d_p)^{0.38}\,(\rho_f/\rho_s)^{1.05}\,(R)^{0.61} \quad \ldots (3)$$

In Table 3, the percentage deviations of G_{osf}/G_{msf} values calculated by using equation (3) from the experimental data are given for one set of runs for a bed expansion ratio of 2.

Considering the entire data, the maximum deviation was observed to be 20 per cent and equation (1a) with equation (3) provides a method for predicting G_{osf} with reasonable accuracy. It should, however, be noted that sphericity does not seem to have any appreciable effect on G_{msf} or G_{osf} but, since the data are confined to two spherical materials only, more work is recommended.

References

1 Babu Rao, K., Mukherjee, S.P., Doraiswamy, L.K., *A.I.Ch.E.J.*, 1965, **11**, 741.

2 Fan, L.T., Yang, Y.C., Wen, C.Y., *A.I.Ch.E.J.*, 1959, **5**, 407

3 Fan, L.T., Wen, C.Y., *A.I.Ch.E.J.*, 1961, **7**, 606.

4 Fan, L.T., Wang, S.C., Wen, C.Y., *A.I.Ch.E.J.*, 1963, **9**, 316

5 Poddar, S.K., Dutt, D.K., *Ind. Chem. Eng.*, 1969, **11**, (No. 3), 30

6 Roy, G.K., M. Tech. thesis, I.I.T., Kharagpur, India, 1971

7 Roy, G.K., Sarma, K.J.R., *Ind. Chem. Manfr.*, 1970, **12**, (No. 12), 14

8 Roy, G.K., Sarma, K.J.R., *Chem. Proc. Eng.*, 1971, **5**, (No. 3), 11

9 Roy, G.K., Sarma, K.J.R., *Chem. Proc. Eng.*, 1971, **5**, (No. 6), 23

10 Roy, G.K., Sen Gupta, P., *Ind. J. of Tech.*, 1972, **10**, 337

11 Roy, Sen Gupta, P., *Chem. Eng. J.*, 1973, **5** (No. 2), [illegible]

12 Roy, G.K., Sen Gupta, P., *Ind. Eng. Chem. Proc. Res. and Dev.*, July, 1974

13 Roy, G.K., Sen Gupta, P., *Proc. of I.I.Ch.E.*, Silver Jubilee Session, December, 1972, 33

14 [illegible], N.R., Moinuddin, S., Kaparthi, R., *Ind. Chem. Eng.*, 1969, **11**, (No. 3) 89.