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Relationship between the Onset of Semi-fluidization Velocity & the Minimum Fluidization Velocity

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Data on the semi-fluidization characteristics of a few gas-solid systems have been obtained. The correlation, $G_{osf}/G_{mf} = A\left(\frac{D_c}{d_p}\right)^{a_1}\left(\frac{\rho_s}{\rho_f}\right)^{a_2}(R)^{a_3}$, relating the onset of semi-fluidization velocity (G_{osf}) with the minimum fluidization velocity (G_{mf}) has been developed in terms of various system parameters (D_c, column diameter; d_p, particle diameter; ρ_s, ρ_f, densities of solid and fluid respectively; and R, bed expansion ratio in state of semi-fluidization). The values of the constants A, a_1, a_2 and a_3 are $2{\cdot}66\times10^2$, 0·62, −1·0, 0·5 and $3{\cdot}4\times10^3$, 1·11, −1·78, 0·89 for non-spherical and spherical particles respectively.

SEMI-FLUIDIZATION, a recent development in the field of fluid-solid contact operations, is highly suitable for mixed and tubular reactors[1]. A semi-fluidized bed is a compromise between the packed and the fluidized bed conditions, eliminating certain drawbacks of both these operations[2]. The introduction of a porous disc or sieve in a conventional fluidizer arrests the free upward motion of the particles and results in the formation of a semi-fluidized bed consisting of a top packed section and a bottom fluidized portion.

Investigations dealing with the various aspects of liquid-solid semi-fluidization[3] have been reviewed by Roy and Sarma[4,5]. Very little information is available in the field of gas-solid semi-fluidization. In a recent communication[6], the present authors reported some data on gas-solid semi-fluidization. This paper presents a correlation, which relates the ratio of the minimum semi-fluidization velocity to the minimum fluidization velocity with the system parameters.

Experimental Procedure

The set-up used (Fig. 1) is a conventional semi-fluidizer made of perspex column of 4.5 cm int. diam. and 57 cm length. The bottom grid consists of a 150 mesh screen. The movable restraint is made of 80 mesh brass screen. The air flow rate was measured by an orificemeter. The bed pressure drops were measured with the help of two sets of manometers. While taking a run, a definite amount of material is charged into the column and the bed height noted. The movable restraint is adjusted for a fixed bed expansion ratio. With increase in air flow rate, pressure drops across the bed and the top bed formations are noted. The static and expanded bed porosities are determined in separate experiments. The surface area of the particles and the shape factor have been determined by the air permeability method[7].

Results and Discussion

Two spherical and four non-spherical materials of different size fractions were used (Table 1). In Fig. 2, a typical plot of bed pressure drop against fluid mass velocity is given. The onset velocities of semi-fluidization have been evaluated from similar plots and are given in Table 2.

Prediction of minimum semi-fluidization velocity from minimum fluidization velocity — The onset of fluidization and semi-fluidization represent the two consecutive sequences of operations of the semi-fluidization phenomena. While the former corresponds to the initiation of particle movement in a fluid-solid bed, the latter indicates the fluid velocity at which the first particle of the bed touches the top restraint of the semi-fluidizer. For finding the minimum fluidization velocity, several correlations are available in literature[8]. One of the most generalized equations is the one derived by Leva and coworkers[9], which is valid over a wide range of

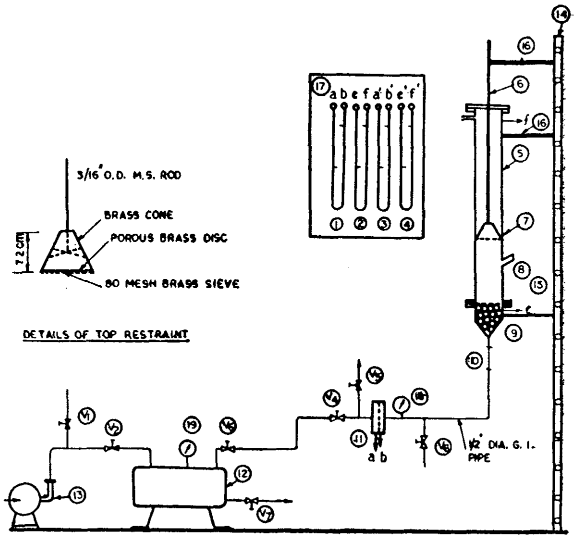

Fig. 1 — Experimental set-up: Schematic diagram [(1), (3) manometers for orificemeter; (2), (4) manometers for bed; (5) semi-fluidizer, (6) movable restraint assembly; (7) top restraint; (8) inclined feeder; (9) distributor; (10) flexible connection; (11) orificemeter; (12) reservoir; (13) compressor; (14) structure; (15) base plate support; (16) clamp; (17) manometer panel board; (18) line pressure gauge; (19) reservoir pressure gauge; V_1 V_5, V_7 bypass valves; V_2, V_3, V_4 control valves; and V_6 solid valve]

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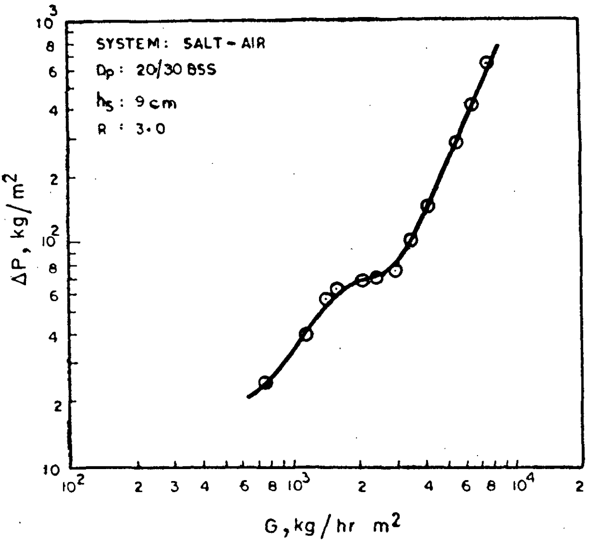
TABLE 1 — PHYSICAL CHARACTERISTICS OF MATERIALS USED

Material	Particle size		Density (ρ_s) g/cc	Packed bed porosity (ϵ_{pa})	Surface area (S_v) cm^2/m^3	Sphericity (ϕ_s)
	Mesh No. BSS	Size (d_p) m×10^4				
NON-SPHERICAL						
Table salt	20/30	7·51	2·100	0·596	241·0	0·331
do	30/40	4·42	2·100	0·588	300·5	0·452
do	40/52	3·38	2·100	0·560	302·0	0·587
do	52/60	2·74	2·100	0·533	335·0	0·654
Ammonium sulphate	30/40	4·42	1·763	0·377	136·0	1·000
Sand	30/40	4·42	2·650	0·451	170·5	0·798
Magnesite	30/40	4·42	2·800	0·443	177·0	0·770
SPHERICAL						
Mustard seed	14/20	11·05	1·120	0·362	54·2	1·000
Sago	14/20	11·05	1·304	0·380	54·2	1·000

TABLE 2 — CALCULATED AND EXPERIMENTAL MINIMUM SEMI-FLUIDIZATION VELOCITY DATA

System	d_p m×10^4	G_{mf} kg/hr m^2	R	G_{osf} kg/hr m^2 (exp.)	$\frac{G_{osf}}{G_{mf}}$	G_{osf} kg/hr m^2 [from Eq. (4)]	Deviation of calc. from exp. value %
NON-SPHERICAL							
Table salt-air	7·51	804	2·0	2200	2·74	2215	+0·70
			2·5	2650	3·30	2480	−6·40
			3·0	2900	3·61	2715	−6·38
			3·5	3250	4·05	2925	−10·00
do	4·42	491	2·0	1350	3·76	1887	+2·00
			2·5	2000	4·07	2115	+5·75
			3·0	2275	4·64	2310	+1·27
			3·5	2600	5·30	2500	−3·84
do	3·38	390	2·0	1462	3·75	1770	+21·00
			2·5	1675	4·30	1970	+17·60
			3·0	2025	5·20	2165	+6·90
			3·5	2225	5·71	2340	+5·16
do	2·74	258	2·0	1250	4·85	1330	+6·40
			2·5	1550	6·00	1490	−3·87
			3·0	1850	7·16	1630	−11·90
			3·5	1950	7·55	1760	−9·75
Ammonium sulphate-air	4·42	349	2·0	1750	5·01	1592	−9·04
			2·5	2050	5·87	1785	−12·90
			3·0	2550	7·30	1955	−23·40
			3·5	2850	8·16	2106	−26·10
Sand-air	4·42	653	2·0	1850	2·38	1985	+7·30
			2·5	2050	3·14	2220	+8·30
			3·0	2450	3·75	2428	−0·90
			3·5	2750	4·21	2625	−4·55
Magnesite-air	4·42	596	2·0	1875	3·14	1720	−8·38
			2·5	2100	3·52	1924	−8·38
			3·0	2500	4·20	2106	−15·75
			3·5	2900	4·86	2275	−21·50
SPHERICAL							
Mustard seed-air	11·05	1200	2·0	2450	2·04	2375	−3·06
			2·5	2800	2·33	2900	+3·57
			3·0	3400	2·83	3405	+0·15
			3·5	4000	3·33	3910	−2·25
Sago-air	11·05	1665	2·0	2500	1·50	2530	+1·20
			2·5	2900	1·74	3080	+6·20
			3·0	3500	2·10	3600	+2·86
			3·5	4100	2·46	4160	+1·46



variables. Thus, G_{mf} is given as

$$G_{mf} = \frac{0{\cdot}005\ g_c\rho_f(\rho_s-\rho_f)d_p^2\phi_s^2}{\mu}\ \frac{\epsilon_{pa}^3}{(1-\epsilon_{pa})^2} \qquad \ldots(1)$$

The calculated values of G_{mf} and the ratios of G_{osf}/G_{mf} for the systems studied are given in Table 2.

It is intuitive that both in fluidization and semi-fluidization, the properties of the fluid and the solid as well as the geometry of the system will influence the onset conditions. Among the variables encountered, the important ones are: h_s, D_c, d_p, ρ_s, ρ_f and R. Writing in the form of dimensionless groups

$$\frac{G_{osf}}{G_{mf}} = \phi\left[\frac{h_s}{D_c}, \frac{D_c}{d_p}, \frac{\rho_s}{\rho_f}, R\right] \qquad \ldots(2)$$

It has been observed in the course of investigations that variation in bed height does not appreciably affect the velocity of onset of semi-fluidization. Ignoring the effect of h_s/D_c, the expression reduces to

$$\frac{G_{osf}}{G_{mf}} = A\,\{(D_c/d_p)^{a_1}(\rho_s/\rho_f)^{a_2}(R)^{a_3}\} \qquad \ldots(3)$$

The exponents a_1, a_2 and a_3 have been evaluated experimentally. In Fig. 3 the values of the ratio G_{osf}/G_{mf} are plotted on a log-log paper against the product $\{(D_c/d_p)^{0{\cdot}623}(\rho_s/\rho_f)^{-1{\cdot}0}(R)^{0{\cdot}5}\}$. Two different straight lines, one for the spherical and the other for the non-spherical particles, have been obtained. For the non-spherical particles, the slope of the line was 1·0 and for the spherical ones it was 1·78. The final correlations can be given as:

For non-spherical particles:

$$\frac{G_{osf}}{G_{mf}} = 2{\cdot}66\times10^2(D_c/d_p)^{0{\cdot}62}(\rho_s/\rho_f)^{-1{\cdot}0}(R)^{0{\cdot}5} \qquad \ldots(4a)$$

For spherical particles:

$$\frac{G_{osf}}{G_{mf}} = 3{\cdot}4\times10^3(D_c/d_p)^{1{\cdot}11}(\rho_s/\rho_f)^{-1{\cdot}78}(R)^{0{\cdot}89} \qquad \ldots(4b)$$

The values of G_{osf} calculated from Eqs. (4a) and (4b) have been found to be in good agreement with

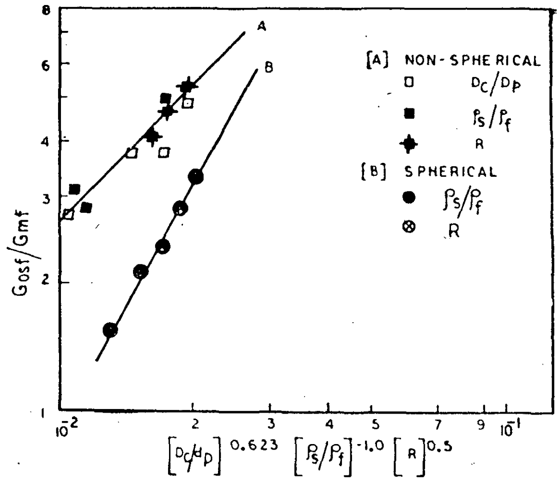


Fig. 3 — Correlation plot of G_{osf}/G_{mf} with system variables

the experimental data. The deviations are given in Table 2, and it is seen that the spherical materials show lesser deviation.

It should, however, be noted that the present study was confined only to two spherical materials and as such, the effect of sphericity, if any, could not be properly ascertained. Further work to study this aspect is necessary.

Nomenclature

D_c = diam. of column, L
d_p = particle diam., L
g_c = gravitational constant, $L\theta^{-2}$
G = mass velocity of fluid, $M\theta^{-1}L^{-2}$; subscript mf for minimum fluidization and osf for onset of semi-fluidization
h = height of column, L; subscript pa for packed bed and s for static bed
ΔP = pressure drop across semi-fluidized bed, FL^{-2}
R = bed expansion ratio in semi-fluidization, dimensionless
S_v = surface area of particles per unit volume of solid, L^2/L^3
ϕ = function
ϕ_s = sphericity of particles
μ = viscosity, $M\theta^{-1}L^{-1}$
ρ = density, ML^{-3}
ϵ = bed porosity

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