Prediction of onset semifluidization, maximum semifluidization velocities and the packed bed height

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Abstract

INVESTIGATIONS on semifluidization reported already have been briefly summarized. Experimental data for a few water-solid systems have been obtained. Correlations have been developed for the prediction of the onset of semifluidization velocity, the maximum semifluidization velocity and the height of packed bed formation from the properties of the liquid and solid particles and the position of restraining screen. The observed values are compared with the values calculated by the equations suggested.

Introduction

TILL recently the general method employed for solid fluid contacting was the fixed bed or packed bed. Batch and continuous fluidization techniques are advancements over the fixed bed. Considerable work on various aspects of these has already been made and published literature is available in the form of books[1-4].

Just a decade back a new type of fluid solid contacting method namely semifluidization was proposed by Fan et.a[5]. This can be viewed as combination of batch fluidized bed at bottom and fixed bed at the top. This is obtained by providing sufficient space available for free expansion of the bed and increasing the flow rate of fluid through the bed of particles sufficiently high to buoy the solid particles. A restraint provided at the top of the bed prevents the escape of the particles out of the system and helps the formation of a section of packed bed just below the restrain. Thus by control of the fluid velocity, known quantities of the solid particles can be distributed between the fluidized and fixed bed sections. Fan et al[6,7] studied both liquid and gas solid systems involving close size range particles. Equations for calculating the distribution of pressure drop as well as solid particles in the fluidized and packed bed sections were developed.

Baburao et al[8,9] also studied the mechanics of semi-fluidized bed in gas solid systems and their interest was to build up the packed bed in turbular bundle. A correlation has been proposed to predict semifluidization velocity in terms of Archimedes number and semifluidization number which was defined by them as

$$S_f = [(W_s - W_o)/(h - h_s)^3] \quad \rho_s$$

Poddar and Dutt[10,15] have recently reported data on semi-fluidization in liquid solid systems. Equations based on theoretical consideration have been presented by them to predict the minimum and maximum semifluidization velocities and height of packed bed formation. The experimental values were found to compare well with the values calculated by theoretical equation presented. Sunkoori and Kaparthi[11] have studied the dynamics of semifluidization in solid liquid systems. It was observed by them that the ratio of the total semifluidization height to static bed height has an exponential relation with the fluid mass velocity. Studies on wall to fluid heat transfer have also been made by these authors[12].

Object of present study

The object of the present work is two-fold: (i) to propose correlations for predicting the onset of semifluidization velocity, the maximum semifluidization velocity and the height of packed bed formed from the properties of the solids and fluid medium used, and (ii) to study the mechanics of semifluidization in liquid solid systems using different liquids and solids of close size ranges and mixed sizes.

Development of theoretical correlations

Onset of semifluidization, maximum semifluidization velocity: Poddar & Dutt (loc. at) presented equations of the following type for the prediction of minimum and maximum semifluidization velocities.

For minimum,

$$18Re_{osf} + 2.7Re_{osf}^{1.687} = 0.966\ \phi_s^{0.88}\ G_a\left[1 - \frac{h_s}{h}(1-\epsilon_{pa})\right]^{4.7} \qquad \dots (1)$$

Where $Re_{osf} = d_p\ G_{osf}/\mu$

For maximum,

$$19Re_{masf} + 2.7Re_{masf}^{1.687} = Ga \qquad \dots (2)$$

from which $G_{masf} = Re_{masf}\ x\ \mu/d_p$

The bases were shown to be the relation between the expanded bed voidage and the voidage function, proposed by Wen & Yu[13]. Based on their experimental data, Wilhelm & Kwauk[14] have presented relationships between $K \triangle\rho$ & particle Reynold's number with the expanded fluidized bed voidage as the parameter. Taking this as the basis, the expanded bed voidage can be expressed as a function of the Gallileo number and the particle Reynolds number. The exact relationship is given as follows:

$$\epsilon_f^{4.25} = 10.5 \times (Re^{1.48})/Ga \quad \dots (3)$$

Striking a material balance between the expanded bed and initial static bed the fluidized bed voidage (ϵ_f) can be related to-

$$\epsilon_f = 1 - (h_s/h_f)(1 - \epsilon_{pa}) \quad \dots (4)$$

So, equation 3 becomes

$$[1 - (h_s/h_f)(1 - \epsilon_{pa})]^{4.25} = 10.5\ Re^{1.48}/Ga \quad \dots (5)$$

For the onset of semifluidization, the limiting value of h_f/h_s will be h/h_s, which is the reciprocal of the bed expansion ratio. In terms of this ratio, the above equation will be

$$[1 - (1/R)(1 - \epsilon_{pa})]^{4.25} = 10.5\ Re_{osf}/Ga \quad \dots (6)$$

where, $Re_{osf} = d_p G_{osf}/\mu$

The onset of semifluidization on the minimum semi-fluidization velocity (G_{osf}) can be calculated by equation (6) from the value of Reynolds number. The above equation can also be simplified further for the direct prediction of the minimum semifluidization velocity and is given as-

$$G_{osf} = 0.2042\ G_a^{0.675}[1 - (1/R)(1 - \epsilon_{pa})]^{2.87}(\mu/d\rho) \quad \dots (7)$$

In the case of maximum semifluidization, the condition refers to the formation of total packed bed under the restraint thus leaving no particle in the fluidized bed state. This condition can be visualised as the fluidized bed voidage tending to unity. Substituting this limiting value in equation (3), we get expression for the prediction of the maximum semifluidization velocity either directly or from a knowledge of the Reynolds number as-

$$Re_{msf}^{1.48} = Ga/10.5 \quad \dots (8)$$

Where, $Re_{msf} = d_p\ G_{msf}/\mu$

In terms of velocity equation (8) will be

$$G_{msf} = 0.2042\ Ga^{0.675}(\mu/d_p) \quad \dots (9)$$

Packed bed height

While it is necessary to know the velocity at which semifluidization begins and also the velocity at which all the particles are transferred to the packed bed below the screen, it is also necessary to know the variation of the height of the packed bed with the change in velocity of the fluid, the limits of the velocity being the onset of semifluidization velocity and the maximum semi-fluidization velocity.

The methods available for the prediction of the height of the packed bed in semifluidization are: (1) experimental determination with the parameters such as the position of the screen, and (2) method of Fan et. al.[5] which is based on the material balance between the completely fluidized bed and packed bed under the assumption that the voidage of the packed bed is con stant and is equal to that of the least dense static bed. Fan and Wen[6,7] obtained the same relationship by assuming that the particles are uniformly distributed in the fluidized bed, the movement of particle in the suspension is completely independent and that each particle in the suspension is situated in the centre of a normal hexagon of fluid.

Packed bed height

Poddar and Dutt,[15] proposed a correlation for the calculation of the packed bed height which is on similar lines with the one proposed by the earlier authors. While the method proposed by Fan, Wen and Yang requires experimental data on fluidization, the above authors proposed an equation for evaluation of voidage of the fluidized bed in terms of dimensionless numbers. Fan and Wen (loc. cit) proposed a dimensionless correlation for the prediction of the packed bed height in terms of the initial packed height, of the fluidized column, fluid mass velocity, minimum fluidization velocity and the maximum semifluidization velocity.

It was felt that, since the formation of the packed bed begins at the onset of semifluidization and ends at the maximum semifluidization velocity, the introduction of the onset of semifluidization velocity (G_{osf}) instead of the minimum fluidization velocity in the derivation of Fan and Wen (loc. cit) should be more logical. So introducing G_{osf} in place of G_{mf} in the expression obtained by Beranek[16] and proceeding on similar lines of Fan and Wen the final relation can be written as-

$$f[(h - h_s)/(h - h_{pa})] \times [(G_f - G_{osf})/(G_{msf} - G_{osf})] = O \quad \dots (10)$$

The exact relationship can be evaluated from the experimental data. To apply this equation, a knowledge of the values of G_{osf} and G_{msf} are required and these can be readily obtained from the fluidization data of the concerned system or from the correlations proposed for evaluating the same.

Experimental set-up

The experimental set up used in the present study is described in Fig. 1. The fluidizer section proper is made of perspex column, 4.013 cms i.d. and height of 100 cms. A movable restraint made of 22 mesh screen (B.S) is fixed through a rubber stopper at the top. Pressure taps one above the bottom of screen and the other at the top of the column are provided. The pressure drop through the bottom and top re straints is found to be negligible. A rotameter is included in the liquid line and the fluid is recirculated by means of a pump. The inlet temperature of liquid is noted by a thermometer. Charging and removal of

Table I(A) *Properties of solid particles used in the experiments*

Sl. no.	*Particles & size range*	*Average particle size (d_p) ft.*	*Shape*	*Absolute density (ρ_s)*	*Porosity of least dense Static bed*
1.	Dolomite (—6+8)	0.008		172.2	.539
2.	Stonechip (—6+8)	,,	Broken	165.1	.5172
3.	Iron ore (—6+8)	,,	solids of irregular	315.2	.502
4.	Dolomite (—14+16)	0.00362	shapes	172.2	.452
5.	Stonechip (—14+16)	,,		165.1	.450
6.	Iron ore (—14+16)	,,		315.2	.490
7.	Coal (—14+16)	,,		98.5	.489
8.	Glass beads	0.0164	Spherical	151.8	.526

Table I(B) *Values of the dimensionless groups of the systems under study*

no.	*Systems*	*Size (ft)*	*Ga*	Ar	$(Re)_p$ *for* $(\epsilon_s = 1.0)$
1.	Glass beads-water	0.0164	2.74 x 10^6	6.65 x 10^6	2.645 x 10^3
2.	Dolomite ,,	0.008	0.391 x 10^6	1.08 x 10^5	0.934 x 10^3
3.	Stone-chips ,,	0.008	0.359 x 10^6	0.95 x 10^6	0.892 x 10^3
4.	Iron Ore ,,	0.008	0.901 x 10^6	4.55 x 10^6	1.257 x 10^3
5.	Dolomite ,,	0.00362	0.036 x 10^6	0.10 x 10^6	0.242 x 10^3
6.	Stone-chips ,,	0.00362	0.033 x 10^6	0.089 x 10^6	0.233 x 10^3
7.	Iron ore ,,	0.00362	0.083 x 10^6	0.421 x 10^6	0.389 x 10^3
8.	Coal ,,	0.00362	0.012 x 10^6	0.019 x 10^6	0.122 x 10^3

TABLE II B *Average values of the minimum semi-fluidization velocities* (G_{osf})

Systems	*Bed expansion ratio (R)*	G_{msf}* *lbs/hr. ft²*	G_{osf} *lbs/hr. ft²*	G_{osf} G_{msf} *lbs/hr. ft²*
1. Glass beads-water	2.0	3.12 x10^5	1.21 x10^5	.388
	2.5		1.37 x10^5	.439
	3.0		1.54 x10^5	.494
2. Dolomite-water	2.0	2.26 x10^5	0.840x10^5	.371
(D_p = .008′)	2.5		0.959x10^5	.4245
	3.0		1.08 x10^5	.477
3. Dolomite-water	2.0	1.292x10^5	0.470x10^5	.363
(CD_p = .00362)	2.5		0.536x10^5	.416
	3.0		0.606x10^5	.470
4. Stone chips-water	2.0	2.16x10^5	0.81 x10^5	.378
(CD_p = .008′)	2.5		0.925x10^5	.4285
	3.0		1.04 x10^5	.481
5. Stone chips-water	2.0	1.246x10^5	0.435x10^5	.350
(D_p = .00362′)	2.5		0.502x10^5	.401
	3.0		0.562x10^5	.451
6. Iron ore-water	2.0	3.04 x10^5	1.15 x10^5	.374
(D_p = .008′)	2.5		1.305x10^5	.427
	3.0		1.52 x10^5	.480
7. Iron ore-water	2.0	2.08 x10^5	0.745x10^5	.355
(D_p = .00362′)	2.5		0.855x10^5	.410
	3.0		0.96 x10^5	.460
8. Coal-water	2.0	0.65 x10^5	0.231x10^5	.355
(D_p = .00362′)	2.5		0.267x10^5	.411
	3.0		0.302x10^5	.465

(* By method — 2)

TABLE II (A)

Experimental values of the minimum semi-fluidization velocities (G_{osf}) for different bed heights with restraint positions

Systems	Initial static bed ht. hs	Bed expansion ratio (R)	G_{osf} from graph lbs/hr. ft^2
A. Glass beads-water (Size-. .0164)	5″	2.0	1.22 x10^5
		2.5	1.36 x10^5
		3.0	1.52 x10^5
	6″	2.0	1.17 x10^5
		2.5	1.37 x10^5
		3.0	1.56 x10^5
	7″	2.0	1.20 x10^5
		2.5	1.36 x10^5
		3.0	1.52 x10^5
	8″	2.0	1.24 x10^5
		2.5	1.40 x10^5
		3.0	1.60 x10^5
B. Dolcmite-water (Size-. 008′)	5″	2.0	0.79 x10^5
		2.5	0.910x10^5
		3.0	1.07 x10^5
	6″	2.0	0.85 x10^5
		2.5	0.96 x10^5
		3.0	1.08 x10^5
	7″	2.0	0.37 x10^5
		2.5	1.0 x10^5
		3.0	1.05 x10^5
	8″	2.0	1.85 x10^5
		2.5	0.965x10^5
		3.0	1.12 x10^5
Size-. 00362′	5″	2.0	0.430x10^5
		2.5	0.515x10^5
		3.0	0.575x10^5
	6″	2.0	0.5 x10^5
		2.5	0.55 x10^5
		3.0	0.62 x10^5
	7″	2.0	0.43 x10^5
		2.5	0.5 x10^5
		3.0	0.6 x10^5
	8″	2.0	0.52 x10^5
		2.5	0.58 x10^5
		3.0	0.63 x10^5
C. Stone Chips (Size=.008)	5″	2.0	1.85 x10^5
		2.5	1.0 x10^5
		3.0	1.07 x10^5
	6″	2.0	0.86 x10^5
		2.5	0.925x10^5
		3.0	1.05 x10^5
	7″	2.0	0.75 x10^5
		2.5	0.86 x10^5
		3.0	1.0 x10^5
	8″	2.0	0.81 x10^5
		2.5	0.915x10^5
		3.0	1.05 x10^5
Systems	*hs*	*(R)*	G_{osf}
(Size=.00362′)	5″	2.0	0.42 x10^5
		2.5	0.490x10^5
		3.0	0.565x10^5
	6″	2.0	0.43 x10^5
		2.5	0.48 x10^5
		3.0	0.545x10^5
	7″	2.0	0.45 x10^5
		2.5	0.52 x10^5
		3.0	0.56 x10^5
	8″	2.0	0.44 x10^5
		2.5	0.52 x10^5
		3.0	0.58 x10^5
D. Iron ore (Size = .008′)	5″	2.0	1.146x10^5
		2.5	1.30 x10^5
		3.0	1.54 x10^5
	6″	2.0	1.10 x10^5
		2.5	1.30 x10^5
		3.0	1.54 x10^5
	7″	2.0	1.17 x10^5
		2.5	1.31 x10^5
		3.0	1.48 x10^5
	8″	2.0	1.2 x10^5
		2.5	1.31 x10^5
		3.0	1.50 x10^5
Size= .00362′	5″	2.0	0.70 x10^5
		2.5	0.85 x10^5
		3.0	0.95 x10^5
	6″	2.0	0.76 x10^5
		2.5	0.85 x10^5
		3.0	0.96 x10^5
	7″	2.0	0.75 x10^5
		2.5	0.85 x10^5
		3.0	0.97 x10^5
	8″	2.0	0.77 x10^5
		2.5	0.86 x10^5
		3.0	0.95 x10^5
E. Coal (Size=.00362′)	5″	2.0	0.27 x10^5
		2.5	0.32 x10^5
		3.0	0.332x10^5
	6″	2.0	0.180x10^5
		2.5	0.192x10^5
		3.0	0.265x10^5
	7″	2.0	0.265x10^5
		2.5	0.308x10^5
		3.0	0.316x10^5
	8″	2.0	0.21 x10^5
		2.5	0.25 x10^5
		3.0	0.295x10^5

solid are done by taking out the column by removing flanges. Initially some amount of solid particles are charged into the fluidizer and the bed is allowed to come back to static position. The height of the bed (h_s) is then measured. Then expanded bed fluidization data is obtained by increments and measuring the

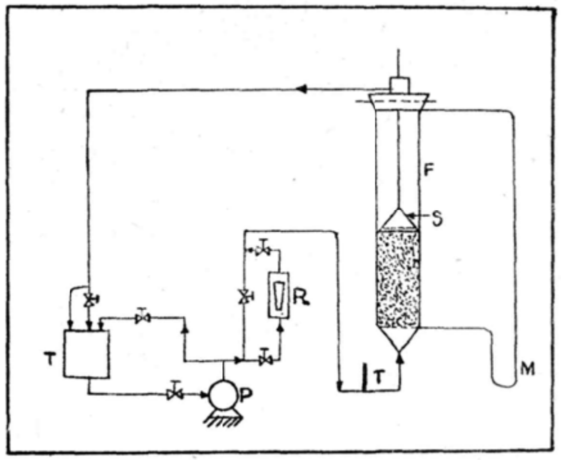


fig. 1.

Liquid-solid semifluidization set-up T — Liquid reservoir, F = fluidization column, P = Pump, R = Rotameter, T — Thermometer, M = Manometer, S = Adjustable restraint (with screen).

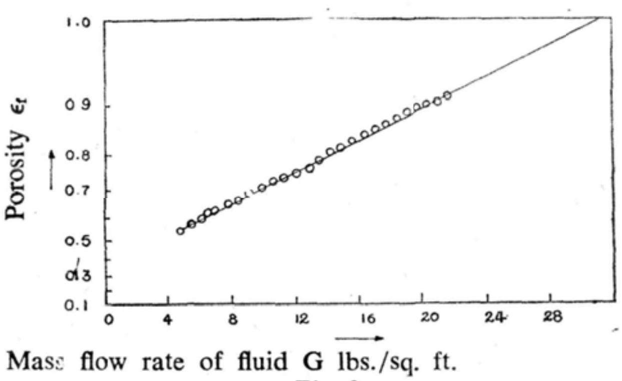


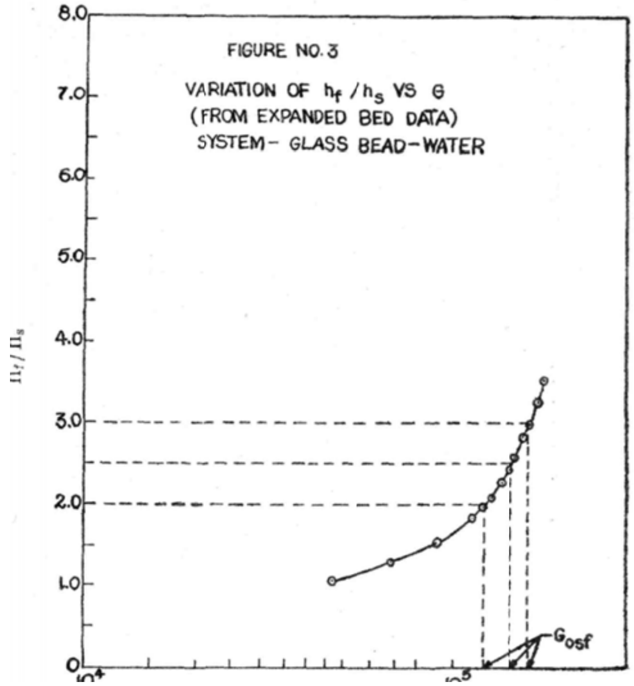
Fig. 2

Porosity of fully fluidized bed System: Glass beads-water

height of the expanded bed height after the steady state conditions are reached. While obtaining semifluidization data at various restraint positions the height of the packed bed formed below the restraining screening for the various fluid velocities is also noted accurately

Observations and results Onset of semifluidization *(G_{osf})*

The properties of the solid particles used in the ex-periment and the values of the dimensionless groups of the systems under study are given in Tables IA and TB respectively. The expanded bed fluidization data for the system glass beads-water are presented in Figs. 2 and 3. The semifluidization data obtained for a solid liquid system (glass-beads-water) are presented in Figs. 4A, 4B, 4C and 4D. In these figures two points corresponding to the change of slopes indicate the onset of fluidization (G_{mf}) and onset Semifluidization (G_{osf}) in the order of occurrence. While the onset of fluidization velocity is dependent only on the



G -----> lbs/hr. sq. ft.

properties of system, the onset of semifluidization is dependent upon the bed expansion ratio also.

Values of G_{osf} are read from the graph and arc tabulated in Table II A for analysis later on.

The average values of minimum semifluidization velocities (G_{osf}) for solid particles at different values of 'R' are listed in Table II B. The maximum semifluidization velocities are read from Fig. 2 by extrapolating the e_f vs G curve to $e_f = 1.0$ and are included in Table IIB.

The onset of semifluidization velocities can also be read directly from the graph between h_f/h_s and G (shown in Fig. 3). Values of G_{osf} corresponding to various bed expansion ratios are given in Table III along with the values read from Figs. 4A, 4B etc. and values calculated from equation (6). On comparision it can be seen that the percentage deviation in both the cases is less than 30% for smaller size particles and more in case of the bigger ones.

Maximum semifluidization velocity ($G_{ms/}$):

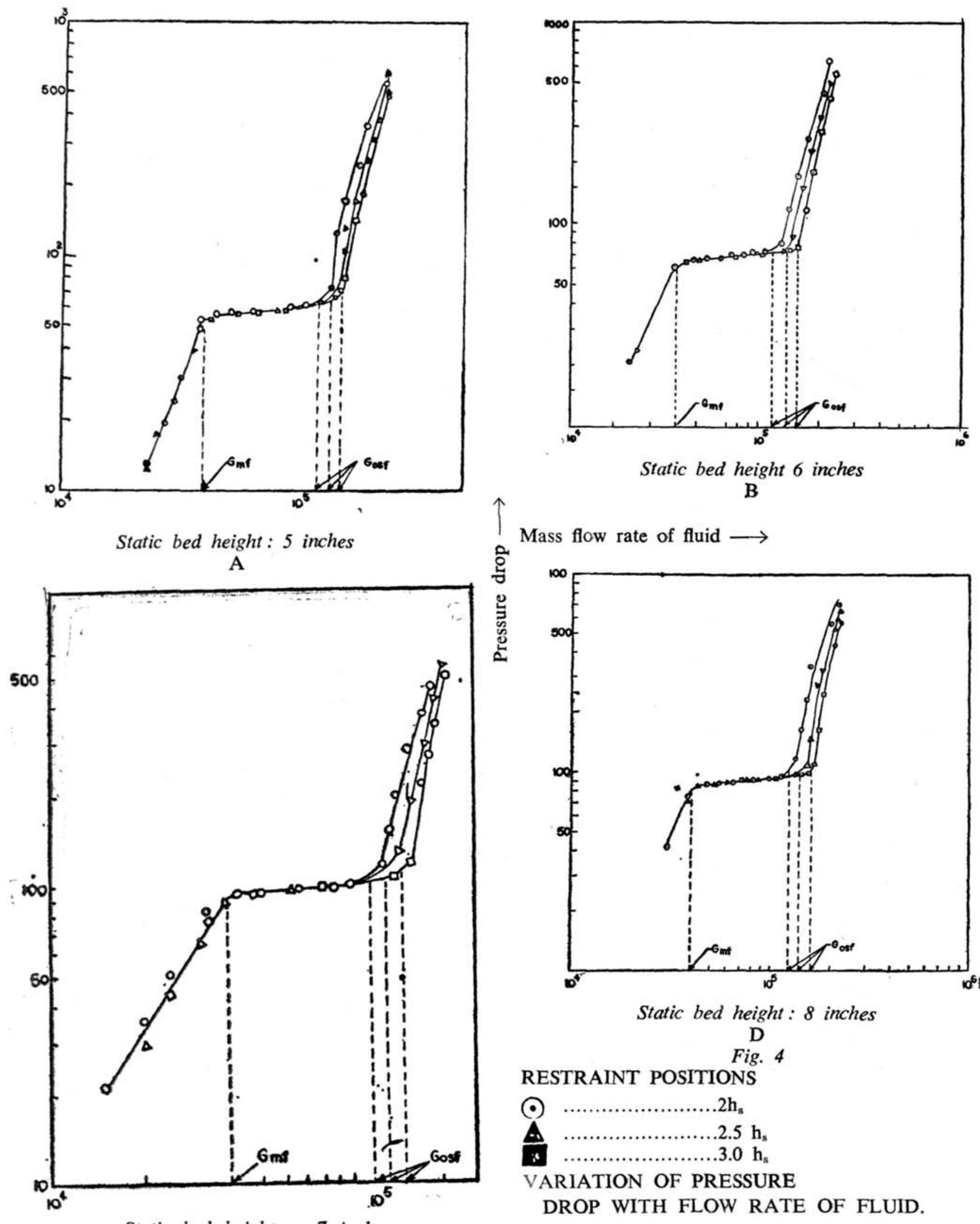
The various methods for the prediction of the maximum semifluidization velocities are (1) extrapolation of h_{pa}/h_s values equation to unity from the graphs of h_{pa}/h_s vs. G (Figs. 5A 5B, 5C & 5D).

(2) From Fig. 2 by extrapolation of $\epsilon_f = 1$.

(3) By calculation from the equation (8). The values are tabulated and compared in Table IV.

Proposed correlation

Values of G_{osf}/G_{msf} vs. bed expansion ratio are plotted (Fig. 6) and it can be seen that the above ratios vary linearly with bed expansion ratio on semi-



Static bed height : 5 inches
A

Static bed height 6 inches
B

Static bed height = 7 inches
C

Static bed height : 8 inches
D

Fig. 4

RESTRAINT POSITIONS

- ⊙ ....$2h_s$
- ▲ ....$2.5\ h_s$
- ■ ....$3.0\ h_s$

VARIATION OF PRESSURE DROP WITH FLOW RATE OF FLUID.

SYSTEM-GLASS BEAD-WATER

TABLE III *Comparision of the experimental and calculated values of the onset of semi-fluidization* (G_{osf})

System	Particle Size (ft.)	Bed expansion ratio (R)	G_{osf} lbs/hr. ft² by method (1)*	by method (2)**	By calculation	Percentage deviation from calculated value method 1	method 2
Dolomite-water	.088	2.0	0.84 x10^5	0.88 x10^5	1.367x10^5	38.6	35.7
		2.5	0.959x10^5	1.05 x10^5	1.65 x10^5	41.9	36.4
		3.0	1.08 x10^5	1.17 x10^5	1.855x10^5	41.7	36.9
	.00362	2.0	0.47 x10^5	0.45 x10^5	0.524x10^5	10.3	14.1
		2.5	0.536x10^5	0.56 x10^5	0.646x10^5	17.0	13.3
		3.0	0.606x10^5	0.64 x10^5	0.737x10^5	17.8	13.2
Stone-chip-water	.008	2.0	0.81 x10^5	0.84 x10^5	1.27 x10^5	36.2	33.8
		2.5	0.925x10^5	0.98 x10^5	1.488x10^5	37.9	34.2
		3.0	1.04 x10^5	1.10 x10^5	1.694x10^5	38.6	35.0
	.00362	2.0	0.435x10^5	0.44 x10^5	0.497x10^5	12.5	11.5
		2.5	0.502x10^5	0.52 x10^5	0.615x10^5	18.4	15.4
		3.0	0.562x10^5	0.60 x10^5	0.70 x10^5	19.7	14.3
Iron-ore-water	.008	2.0	1.15 x10^5	1.20 x10^5	2.275x10^5	49.5	47.3
		2.5	1.305x10^5	1.43 x10^5	2.76 x10^5	52.6	48.1
		3.0	1.52 x10^5	1.60 x10^5	3.10 x10^5	51.0	48.4
	.00362	2.0	0.745x10^5	0.78 x10^5	0.984x10^5	24.3	20.7
		2.5	0.855x10^5	0.94 x10^5	1.212x10^5	29.4	22.4
		3.0	0.96 x10^5	1.05 x10^5	1.352x10^5	29.0	22.3
Coal-water	.00362	2.0	0.231x10^5	0.243x10^5	0.275x10^5	16.1	11.8
		2.5	0.267x10^5	0.285x10^5	0.332x10^5	19.5	14.2
		3.0	0.302x10^5	0.322x10^5	0.374x10^5	19.2	13.9
Glass-beads-water	.0164	2.0	1.21 x10^5	1.22 x10^5	2.46 x10^5	50.8	50.4
		2.5	1.37 x10^5	1.45 x10^5	2.935x10^5	53.3	50.0
		3.0	1.54 x10^5	1.62 x10^5	3.42 x10^5	55.0	52.6

* From G vs. $\triangle$P curve ** From G vs. h_f/h_s curve

TABLE IV

Comparison of the experimental and calculated values of the maximum semi-fluidization velocities (G_{msf}).

System	Size (ft)	$(Re)_p$ at $\epsilon_f=1$	G_{msf} lbs/hr. ft₂ Experimental by method 1	by method 2	By calculation	% deviation from calculated values in case of Method A	Method B
Dolomite-water	.008	1210	1.8 x10^5	2.26 x10^5	2.925x10^5	38.5	22.75
,,	.00362	245	1.15x10^5	1.292x10^5	1.31 x10^5	12.2	1.37
Stone chips-water	.008	1165	1.8 x10^5	2.16 x10^5	2.82 x10^5	36.15	23.4
,,	.00362	233	1.1 x10^5	1.246x10^5	1.248x10^5	11.86	0.16
Iron ore-water	.008	2165	2.6 x10^5	3.04 x10^5	5.24 x10^5	50.4	42.0
,,	.00362	433	1.75x10^5	2.08 x10^5	2.315x10^5	24.4	10.14
Coal-water	.00362	120	0.84x10^5	0.65 x10^5	0.642x10^5	30.8	- 1.245
Glassbeads-water	.0164	4545	3.0 x10^5	3.12 x10^5	5.35 x10^5	43.9	41.6

log coordinates and the shift is also parallel in nature. The variation of the constants with the properties of the system (namely Archimedes group) are plotted in Fig. 7. The following equation has been formulated with the help of the above plots.

$G_{osf}/G_{msf}=0.015\ (R) + (\log Ar. + 2.456)/52$ ... (11)

In order to estimate the maximum semifluidization velocities directly from the physical properties of the system, the values of G_{msf} obtained (from extropolation of $\epsilon_f = 1$ in. Fig. 2) are plotted against Archimedes number (Fig. 8) it is found that the following equation represents the data very well —

$$G_{msf} = 0.3\ (Ar)^{0.58}\ (\mu/d_p) \qquad ...\ (12)$$

The functional relationship of equation (10) shows that if the two dimensionless factors are plotted on a log-log plot a straight line should result.

In Figure 9 is plotted the relationship between $(h - h_s)/(h - h_{pa})$ and $(G_f - G_{osf})/(G_{msf} - G_{osf})$ The data can be well represented by a straight line.

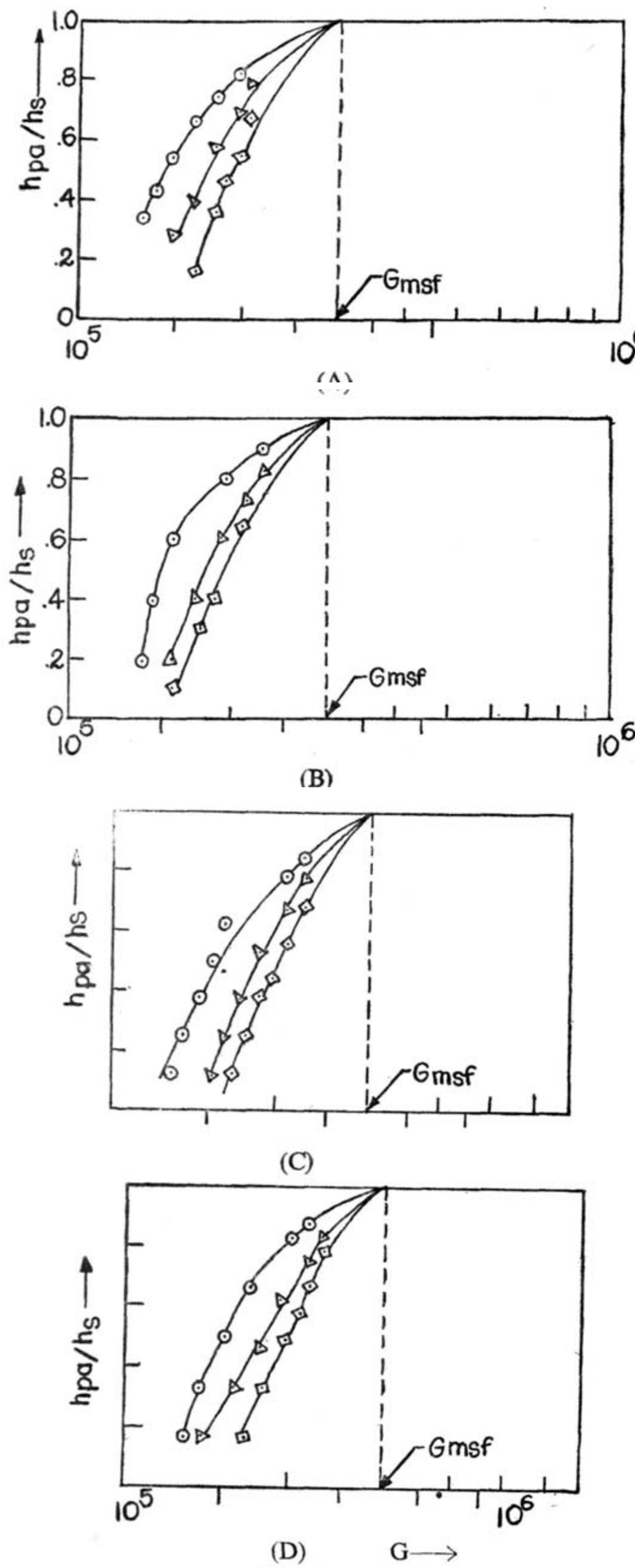
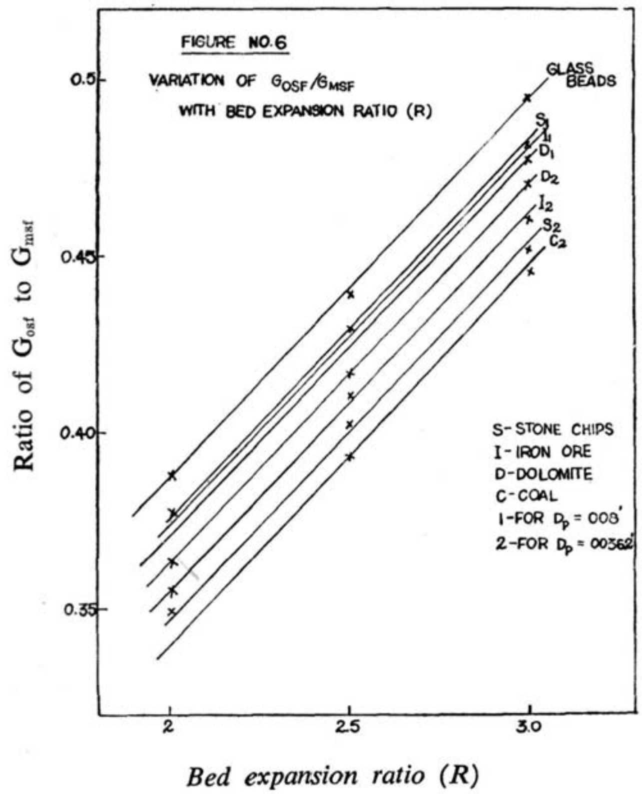


Fig. 5

Variation of h_{pa}/h_s with G. System Glass beads-water



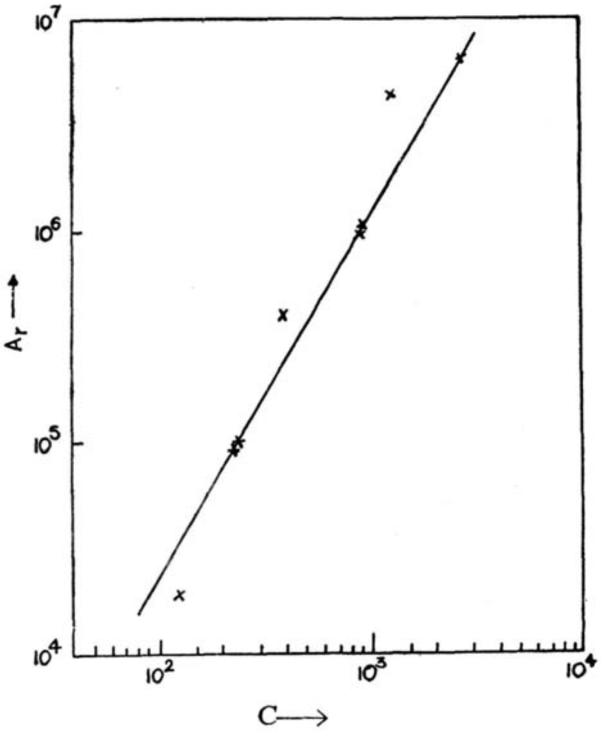


Fig. 7

Variation of constant C with Archimedes number

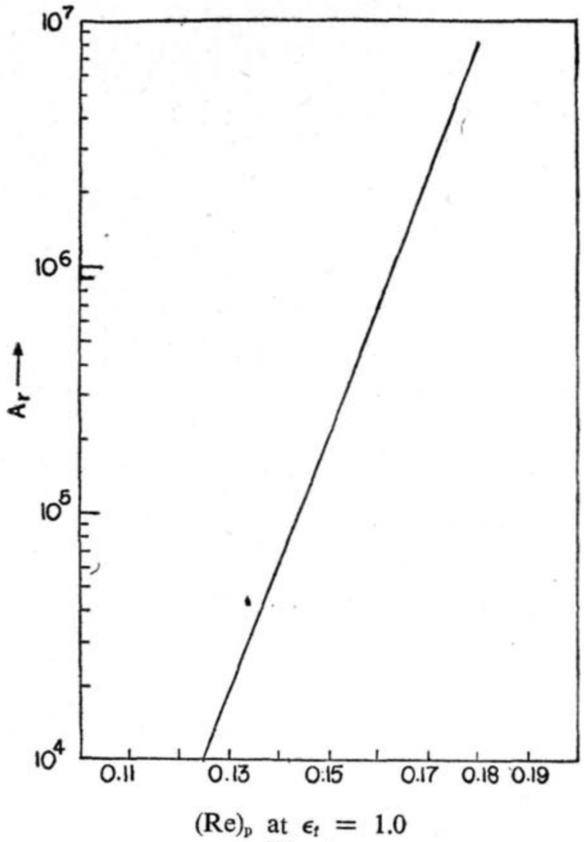


Fig. 8

Reynolds no. vs. archimedes no. The equation for the straight line can be evaluated and the following expression can be written $(h - h_s)/(h - h_{pa}) = [(G, - G_{osf})/(G_{msf}G_{osf})3^{0.2}$ (13) while calculating the factor $(G - G_{0Sf})/(G_{mf} - G_{osf})$ the values of G_{osf} and G_{msf} are obtained from the experimental data. Conclusions

(1) It can be seen from the present work that the maximum and minimum semifluidization velocities and also the packed bed height can be predicted from the properties and flow conditions of the system.

(2) The deviation between the experimental and calculated values of the maximum and minimum semifluidization velocities, was wider in cases, where particle Reynolds number was greater than 500 and less in other cases. The equations proposed can satisfactorily be used for the calculation of the maximum and minimum semifluidization velocities knowing the properties of solids and the medium of fluidization.

(3) Valces of h_{pa} can be fairly/accurately predicted from the known values of G_{osf}, G_{msf} and h_s. The values of G_{osf}, and G_{msf} to be used are to be obtained from expanded bed fluidization data.

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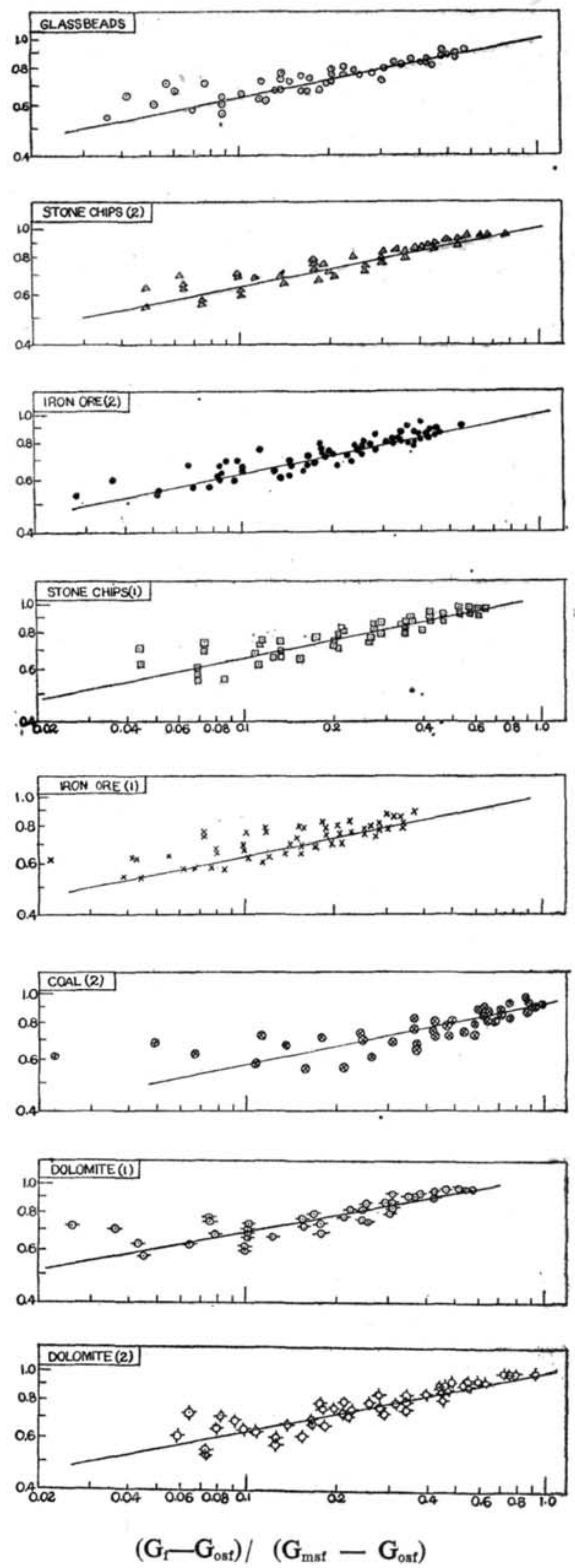

Fig. 9

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Nomenclature

A_r = Archimedes number, dimensionless group. $d^3_p \, \rho_s(\rho_s - \rho_f) \, g/\mu^2$

d_p = Particle diameter, L.

G_a = Galileo number, dimensionless group = $d^3_p \, \rho_f(\rho_s - \rho_f) \, g/\mu^2$

G_f = Mass velocity of fluid, M. O^{-1} L^{-2}

G_{mf} = Onset velocity of fluidization, M. O^{-1} L^{-2}

G_{osf} = Onset velocity of semi-fluidization or minimum semifluidization velocity, M $O^{-1}L^{-2}$

G_{msf} = Maximum semi-fluidization velocity, M O^{-1} L^{-2}

h = Overall height of column (or semi-fluidized bed) L.

h_f = Height of fully fluidized bed L.

h_s = Height of initial static bed, at least dense condition, L.

h_{pa} = Height of packed section in semi-fluidization bed. L.

R = Bed expansion ratio in case of semi-fluidization. (h/h_s)

Re_{osf} = Particle Reynolds number corresponding to the onset of semi-fluidization $d_p \, G_{osf}/\mu$

Re_{msf} = Particle Reynolds number corresponding to the onset of semi-fluidization, $d_p \, G_{msf}/\mu$.

S_f = Semi-fluidization group, dimensionless group.

W_p = Packed bed weight, M.

W_s = Initial weight of the static bed, M.

Greek letters:

ϵ_f = Porosity of fluidized section or porosity of fully fluidized bed.

ϵ_{pa} = Porosity of packed section.

μ = Viscosity of fluid, ML^{-1} O^{-1}.

ρ_f = Density of fluid, ML^{-3}.

ρ_s = Density of solid particle, ML^{-3}.

ϕ_s = Shape factor defined as the ratio of the surface area of a sphere having the same volume as an arbitrary shaped particle to that of the particle of arbitrary shape.