Prediction of Maximum and Minimum Semi-fluidization Velocities for Liquid-Solid Systems from Dimensional Analysis Approach

G. K. **Roy,** *B. Sc. Chem. Engg. (B. H. U.), M. Tech. (I. I. T.), A. M. I. I. Ch. E., A. M. I. E., Senior Lecturer,*
Dr. K. J. R. Sharma, *M. Sc. Tech. (Andhra), Ph. D. (I. I. T.), A. M. I I. Ch. E., A. M. A. I. Ch. E., Professor,*
—Department of Chemical Engineering, Regional Engineering College, Rourkela-8.

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In an earlier communication[3], the authors have given theoretical equations for the prediction of maximum and minimum semi-fluidization velocities for liquid-solid systems based on the expanded bed voidage and voidage unction, proposed by Wen and Yu[5] and Wilhelm and Kwauk[4]. Here, however, an attempt has been made to give correlations for the prediction of maximum and minimum semi-fluidization velocities from a dimensional approach.

Experimental

The set-up and the methods of investigation are as given in an earlier paper[3].

Results and Discussions

(A) Predication of maximum semi-fluidization velocity—two suggested methods[1,2] for finding the maximum semi-fluidization velocity from semi-fluidization experiments are :

(1) Linear extrapolation of expanded bed voidage vs. fluid mass velocity plot to the value of e_f = 1.0.

(2) Extrapolation of h p_a/h_s vs. fluid mass velocity plot to the value of h p_a/h_s = 1.0.

In the present case, the values have been calculated by the second method (Table 1).

TABLE I

Comparison of the values of maximum semi-fluidization velocity

System	d_p ft	ϱ_s lb/ft^3	G_{msf}, lbs/hr. ft^2 From expt. (by method 2)	G_{msf}, lbs/hr. ft^2 From correlation	% deviation calculated values from experimental
1. Glass bed-water	0.0164	151.8	3.00 × 10^5	2.840 × 10^5	− 5.33
2. Dolomite water	0.0080	172.2	1.80 × 10^5	2.020 × 10^5	+ 12.20
3. Stone chips-water	0.0080	165.1	1.80 × 10^5	1.950 × 10^5	+ 8.34
4. Iron ore-water	0.0080	315.2	2.60 × 10^5	3.180 × 10^5	+ 22.30
5. Dolomite water	0.0036	172.2	1.15 × 10^5	1.250 × 10^5	+ 8.70
6. Stone chips water	0.0036	165.1	1.10 × 10^5	1.210 × 10^5	+ 10.00
7. Iron ore water	0.0036	315.2	1.75 × 10^5	1.970 × 80^5	+ 12.60
8. Coal water	0.0036	98.5	0.84 × 10^5	0.686 × 10^5	− 18.35

Development of Correlation

For liquid-solid systems under investigation, it has been found that the effects of the initial static bed height and the position of movable restraint on maximum semi-fluidization velocity, were not appreciable. So the variables of importance are particle size and density. Hence a relationship can be written in terms of dimensionless group as :

$Re_{msf} = G_a$ .... (1)

Re_{msf} takes into consideration the effect of velocity, whereas the latter contains terms involving the physical characteristics of the fluid and the solid. In Fig. 1, Re_{msf} has been plotted against G_a ona log-log paper and a straight line has been obtained, the equation for which is

$Re_{msf} = 0.815\ G_a^{\ 0.54}$ .... (2)

Writing in terms of mass velocity, the maximum semi-fluidization velocity for water solid system becomes,

$G_{msf} = 3.20 \times 10^5_{\ } (d_p)^{0.62}_{\ } (\rho_s - \rho_f)^{0.54}$ .... (3)

The values calculated with the help of the above equation have been found to be in good agreement with the experimental ones. The deviations along with the values are given in Table 1.

(B) Prediction of minimum semi-fluidization velocity— The methods for the prediction of minimum semi-fluidization velocity are :

(1) From Δp vs. G curve.

(2) From h_f/h_s vs. G curve for $h_f/h_s = R$.

The values calculated by both these methods have been presented earlier[8].

Development of Correlation

In liquid-solid semi-fluidization, the properties of the fluid and the solid as well as the geometry of the system will determine the velocity at which onset of semi-fluidization occurs. The parameters of importance in this case are :

$$\frac{G_{osf}}{G_{msf}},\ \frac{h_s}{D_c},\ \frac{D_c}{d_p},\ \frac{\rho_s}{\rho_f},\ \text{and R.}$$

The relation between the group, G_{osf}/G_{msf} and the other parameters can be written in the following manner :

$$\frac{G_{osf}}{G_{msf}} = (h_s/D_c,\ D_c/d_p, \rho_s/\rho_f, R) \quad ....(4)$$

It has been observed in course of investigations that the static bed height has no appreciable effect on G_{osf}. Also the column diameter has not been altered in the present study. The effect of h_s/D_c group is, therefore, not relevant. Consequently, the above expression reduces to—

$$\frac{G_{osf}}{G_{msf}} = A(D_c/d_p)^{a_1} (\rho_s/\rho_f)^{a_2} (R)^{a_3} \quad ....(5)$$

where, A is a constant and a_1, a_2, a_3 are respective exponents of the system variables.

The effects of various parameters on C_{osf}/G_{msf} has been studied and the values of the exponents have been determined. On substitution of exponents, the correlation becomes—

$$\frac{G_{osf}}{G_{msf}} \quad A\ [(D_c/d_p)^{-0.2} (\rho_s/\rho_f)^{0.392} (R)^{0.681}]^B \ ...(6)$$

Where, A is the coefficient and B is the exponent of the over all product. In Fig. 2, the ratio of G_{osf}/G_{msf} is plotted on a log-log paper against the product $(D_c/d_p)^{-0.2} (\rho_s - \rho_f)^{0.392} (R)^{0.681}$. All the data have fitted well and an equation of the following type has been obtained—

$$\frac{G_{osf}}{G_{msf}} = 0.30\ (D_c/d_p)^{-0.21} (\rho_s/\rho_f)^{0.41} \ (R)^{0.66} \quad ......(7)$$

The calculated values have been compared with the experimental in Table II. It has been found that except for iron ore and coal, where densities are either too large or too small, the deviations lie within ±10%.

Nomenclature

A	=	Constant.
D_c	=	Diameter of column (semi-fluidizer), L.
d_p	=	Particle diameter, L.
g_c	=	Gravitational constant, $L\theta^{-2}$
G	=	Mass velocity of fluid $M\theta^{-1} L^{-2}$.
G_a	=	Galileo number, dimensionless group, $d_p^3 \rho_f(\rho_s - \rho_f)g_c/\mu^2$
G_{osf}	=	Minimum semi-fluidization velocsty, $M\theta^{-1}L^{-2}$
G_{msf}	=	Maximum semi-fluidization velocity, $M\theta^{-1} L^{-2}$.
h	=	Height of semi-fluidized bed, L.
h_f	=	Height of fully fluidized bed, L.
h_{pa}	=	Height of packed section in semi-fluidization, L.
h_s	=	Height of initial static bed, L.
R	=	Bed expansion ratio in semi-fluidization, dimensionless, h/h_s.
Re_{msf}	=	Reynolds number at maximum semi-fluidization velocity, $\frac{d_p G_{msf}}{\mu}$

Greek Letters

ψ	=	Function.
μ	=	Viscocity, $M\theta^{-1} L^{-1}$
ρ	=	Density, ML^{-3}
ϵ	=	Bed porosity

Comparison of the values of minimum semi-fluidization velocity

Sl. No.	System	d_p ft	$\rho_{s}/_{f}\rho$	R	G_{osf}/G_{msf}	G_{msf} lbs/hr.ft^2	G_{osf}, lbs/hr. ft^2 Calculated	Expt.	% deviation of calculated value from experimental
1.	Glass bed-water	0.0164	2.43	2.0	0.440	2.84×10^5	1.250×10^5	1.218×10^5	+ 3.31
				2.5	0.510		1.450×10^5	1.370×10^5	+ 5.84
				3.0	0.575		1.635×10^5	1.540×10^5	+ 6.06
2.	Dolomite-water	0.0080	2.76	2.0	0.398	2.02×10^5	0.805×10^5	0.840×10^5	− 4.17
				2.5	0.461		0.931×10^5	0.959×10^5	− 2.92
				3.0	0.521		1.052×10^5	1.080×10^5	− 2.59
3.	Dolomite-water	0.0036	2.76	2.0	0.338	1.25×10^5	0.442×10^5	0.470×10^5	− 5.59
				2.5	0.391		0.489×10^5	0.536×10^5	− 8.75
				3.0	0.441		0.551×10^5	0.606×10^5	− 8.40
4.	Stone chips-water	0.0080	2.65	2.0	0.392	1.95×10^5	0.765×10^5	0.810×10^5	− 5.55
				2.5	0.455		0.886×10^5	0.925×10^5	− 4.22
				3.0	0.513		1.000×10^5	1.040×10^5	− 36.5
5.	Stone chips-water	0.0036	2.65	2.0	0.332	1.21×10^5	0.402×10^5	0.435×10^5	− 7.80
				2.5	0.385		0.466×10^5	0.502×10^5	− 7.16
				3.0	0.435		0.526×10^5	0.562×10^5	− 6.40
6.	Iron ore-water	0.0080	5.05	2.0	0.510	3.18×10^5	1.620×10^5	1.150×10^5	+ 40.80
				2.5	0.590		1.875×10^5	1.305×10^5	+ 43.70
				3.0	0.666		2.120×10^5	1.520×10^5	+ 39.50
7.	Iron ore-water	0.0036	5.05	2.0	0.432	1.97×10^5	0.850×13^5	0.745×10^5	+ 14.10
				2.5	0.501		0.986×10^5	0.855×10^5	+ 15.30
				3.0	0.565		1.112×10^5	0.960×11^5	+ 15.85
8.	Coal-water	0.0036	1.58	2.0	0.268	0.686×10^5	0.184×10^5	0.231×10^5	− 20.40
				2.5	3.311		0.214×10^5	0.297×10^5	− 19.85
				3.0	0.351		0.241×10^5	0.332×10^5	− 20.20

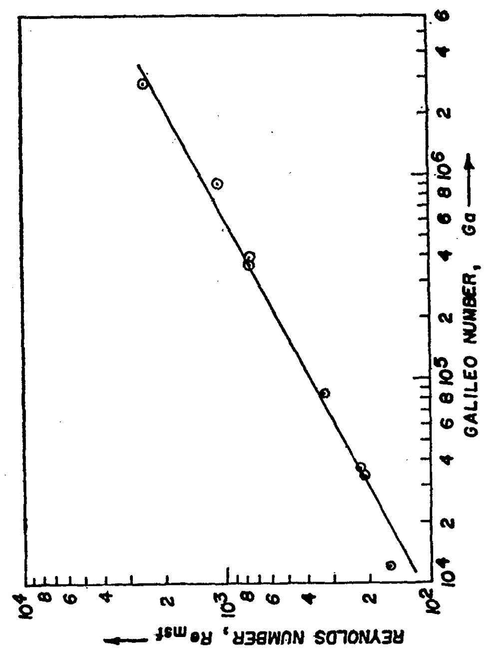

Fig. I
Prediction ot Maximum Semi-Fluidization Velocity from Physical Properties of the System

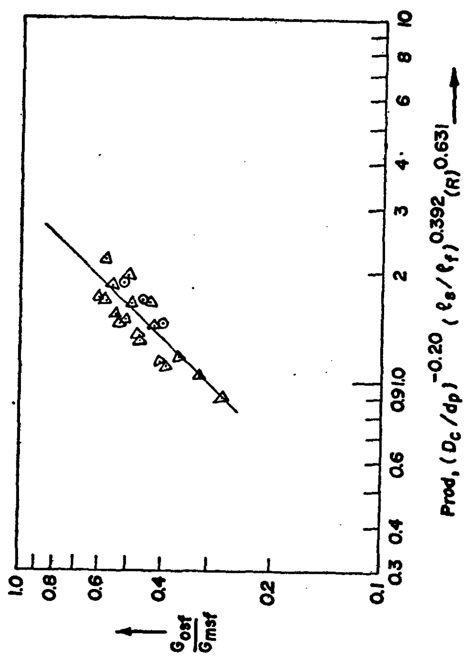

Fig. II
Retation of G_{osf}/G_{msf} with System Variables

Subscripts

c = Column.

f = Fluid or fluidized.

msf = Maximum semi-fluidization condition.

p_s = Packed bed

s = Solid or initial static bed.

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