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Dynamics of Gas-Solid Semi-Fluidization of Binary Homogeneous and Heterogeneous Mixtures

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The necessity of generalized correlations relating to the dynamics of gas-solid semi-fluidization of homogeneous and heterogeneous mixtures has been emphasized. Based on dimensional analysis approach, equations have been developed for the prediction of minimum and maximum semi-fluidization velocity and semi-fluidized bed pressure drop for the above-mentioned systems. Equations have also been proposed for minimum fluidization velocity. A fairly good agreement has been obtained from the various calculated and experimental values.

NOTATION

d_p = particle diameter, L

D_c = column diameter, L

$d_{p_{avg}}$ = average diameter of particle in case of mixture, L

G_{mf} = fluid mass velocity for minimum fluidization condition, $M L^{-2} \theta^{-1}$

G_{msf} = fluid mass velocity for maximum semi-fluidization condition, $M L^{-2} \theta^{-1}$

G_{osf} = fluid mass velocity for onset of semi-fluidization, $M L^{-2} \theta^{-1}$

Δp_{of} = pressure drop across the bed for minimum fluidization condition, $F L^{-2}$

Δp_{sf} = pressure drop across the bed for semi-fluidization condition, $F L^{-2}$

R = bed expansion ratio

W = weight of semi-fluidized material, M

ρ_f = density of semi-fluidizing medium, $M L^{-3}$

ρ_s = density of semi-fluidized particles, $M L^{-3}$

$\rho_{s_{avg}}$ = average density of semi-fluidized particles in case of a mixture, $M L^{-3}$

μ = viscosity of semi-fluidizing medium, $M L^{-1} \theta^{-1}$

INTRODUCTION

Of late, the concept of mixed particle fluidization and semi-fluidization has generated considerable interest in the context of several gas-solid chemical and metallurgical processes namely, the combustion and gasification of solid fuels, solid catalysed reactions and ore reduction, etc dealing with solids either of mixed size (a homogeneous system) or of mixed density (a heterogeneous system). For practical applicability of the concept, it is imperative that the dynamics of the phenomena should be exhaustively investigated and correlations with relevant process parameters be developed. Various aspects of gas-solid semi-fluidization for single-sized (close-cut) particles have been reported in literature[1,2]. Though some studies have been made for the semi-fluidization characteristics of binary mixtures for liquid-solid system[3-6] little information on similar lines is available for gas-solid systems[7].

In this paper an attempt has been made to study the dynamics of semi-fluidization for binary homogeneous and heterogeneous mixtures and develop correlations for the prediction of minimum and maximum semi-fluidization velocity and semi-fluidized bed pressure drop. Equations have also been proposed for the prediction of minimum fluidization velocity for such systems.

EXPERIMENTAL PROCEDURE

The experimental set-up used in this study consisted of a semi-fluidizer, and orifice, a compressor, a constant pressure tank, a silica-gel tower and two sets of manometers. The semi-fluidizer was a perspex column 4.4 cm in internal diameter and 100 cm long. The bottom was a 60-mesh stainless steel screen. A movable restraint made up of 60 mesh brass screen and fitted to a truncated plastic cone was fixed rigidly to a mild steel rod 6.4 mm in diameter extending from the top to near bottom of the semi-fluidizer. The rod can be fixed with respect to a particular position of the movable restraint by means of a clamp at the top. Two sets of manometers were provided, one for the measurement of pressure, drop across orifice meter to measure the flow rate and the other for the bed pressure drop. Air from the compressor was stored in the constant pressure tank, from where it was admitted to the semi-fluidizer after stripped of its moisture in the silica-gel tower.

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Experimental variables included in the investigations are given in Table 1. Seven different combinations of glass beads of 36/44 and 44/52 BSS constitute the homogeneous mixtures while three 50:50 mixtures of CMC, sugar and dolomite with glass beads all of 44/52 BSS are the heterogeneous ones. Experimental values for minimum fluidization and semi-fluidization velocities have been obtained from the plots of fluid mass velocity and bed pressure drop while the packed bed height and fluid mass velocity plots provided with the experimental values for maximum semi-fluidization velocity.

From a dimensional analysis approach, the following correlations have been developed.

Minimum Semi-fluidization Velocity (G_{osf})

For homogeneous mixtures,

$$\frac{d_{p\,avg} G_{osf}}{\mu} = 3.9 \times 10^5 \left(\frac{D_c}{d_{p\,avg}}\right)^{-2.19} \left(\frac{\rho_s}{\rho_f}\right)^{0.74} (R)^{0.55} \tag{1}$$

For heterogeneous mixtures,

$$\frac{d_p G_{osf}}{\mu} = 7.0 \times 10^5 \left(\frac{D_c}{d_p}\right)^{-2.19} \left(\frac{\rho_{s\,avg}}{\rho_f}\right)^{0.74} (R)^{0.55} \tag{2}$$

Maximum Semi-fluidization Velocity (G_{msf})

For homogeneous mixtures,

$$\frac{d_{p\,avg} G_{msf}}{\mu} = 3.13 \times 10^7 \left(\frac{D_c}{d_{p\,avg}}\right)^{-1.95} \left(\frac{\rho_s}{\rho_f}\right)^{0.22} \tag{3}$$

For heterogeneous mixtures,

$$\frac{d_p G_{msf}}{\mu} = 2.30 \times 10^7 \left(\frac{D_c}{d_p}\right)^{-1.95} \left(\frac{\rho_{s\,avg}}{\rho_f}\right)^{0.22} \tag{4}$$

Minimum Fluidization Velocity (G_{mf})

For homogeneous mixtures,

$$\frac{d_{p\,avg} G_{mf}}{\mu} = 2.23 \times 10^6 \left(\frac{D_c}{d_{p\,avg}}\right)^{-1.79} \left(\frac{\rho_s}{\rho_f}\right)^{0.20} \tag{5}$$

For heterogeneous mixtures,

$$\frac{d_p G_{mf}}{\mu} = 1.28 \times 10^6 \left(\frac{D_c}{d_p}\right)^{-1.79} \left(\frac{\rho_{s\,avg}}{\rho_f}\right)^{0.20} \tag{6}$$

Semi-fluidized Bed Pressure Drop (Δp_{sf})

For homogeneous mixtures,

$$\frac{\Delta p_{sf}}{\Delta p_{of}} = 1.3 \times 10^9 \left(\frac{D_c}{d_p}\right)^{4.05} \left(\frac{h_{pa}}{h_s}\right)^{0.75} \left(\frac{h_s}{D_c}\right)^{1.25} (R)^{1.4} \tag{7}$$

For heterogeneous mixtures,

$$\frac{\Delta p_{sf}}{\Delta p_{of}} = 1.5 \times 10^{-2} \left(\frac{h_{pa}}{h_s}\right)^{0.88} (R)^{1.8} \left(\frac{\rho_{s\,avg}}{\rho_f}\right)^{0.73} \tag{8}$$

For the above equations $(d_{p_{avg}})$ and $(\rho_{s_{avg}})$ are calculated as under

$$\frac{1}{d_{p_{avg}}} = \sum \frac{X}{d_p} \tag{9}$$

and

$$(\rho_{s_{avg}}) = \frac{\Sigma\, W}{\Sigma\, W/\rho_s} \tag{10}$$

TABLE 1 SCOPE OF EXPERIMENTAL DATA

Material	Average Density, kg/m^3	Mixture Characteristics, % Course 36/44 BSS	Fine 44/52 BSS	$d_{p_{avg}}$, m$\times10^4$	h_s, m$\times10^2$	R
Homogeneous systems						
Glass beads	2600	100	0	4.20	6	2, 2.5, 3
Glass beads	2600	80	20	4.10	6	2, 2.5, 3
Glass beads	2600	60	40	3.82	6	2, 2.5, 3
Glass beads	2600	50	50	3.72	4,5,6,7	2, 2.5, 3
Glass beads	2600	40	60	3.62	6	2, 2.5, 3
Glass beads	2600	20	80	3.43	6	2, 2.5, 3
Glass beads	2600	0	100	3.24	6	2, 2.5, 3
Heterogeneous systems						
CMC + glass beads	1566	100		3.24	6	2, 2.5, 3
Sugar + glass beads	1972	100		3.24	6	2, 2.5, 3
Dolomite + glass beads	2710	100		3.24	6	R. 2, 2.5, 3

RESULTS AND CONCLUSIONS

Values calculated with the help of equations (1) to (8) have been compared with the experimental ones in Figs 1—5, respectively. A fairly good agreement has been found in most of the cases.

Hence, the developed equations can be used to predict the dynamics of semi-fluidization for unknown homogeneous and heterogeneous mixtures with variation of properties within the range of investigations conducted. The work on heterogeneous systems is in progress to study the effect of parameters like particle size, height of the static bed and also to cover a wider range of the parameters.

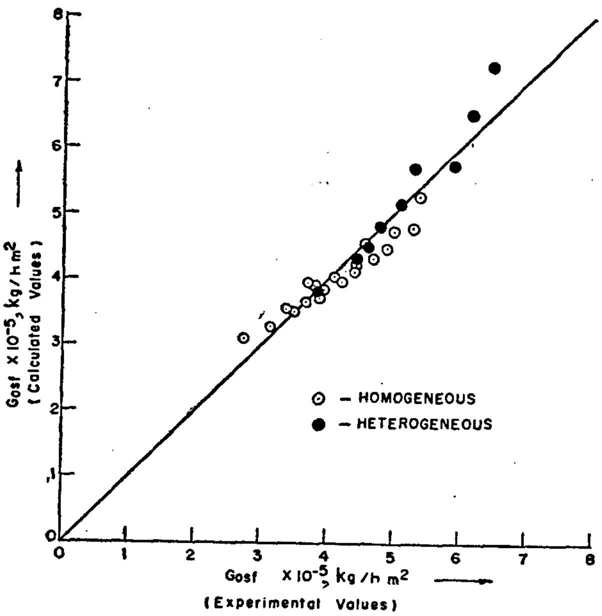

Fig. 1 Comparison of G_{osf} values

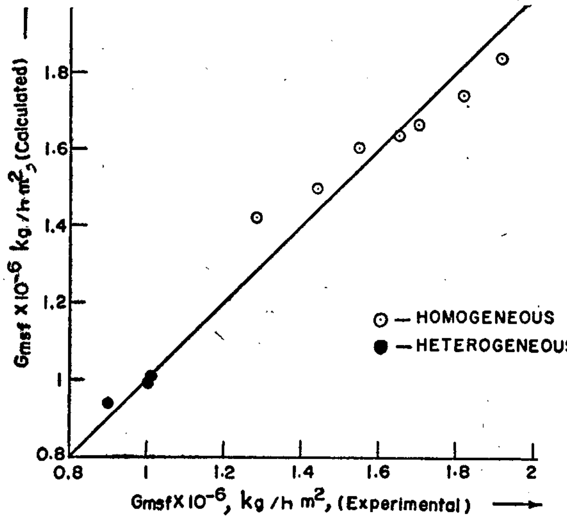

Fig 2 Comparison of G_{msf} values

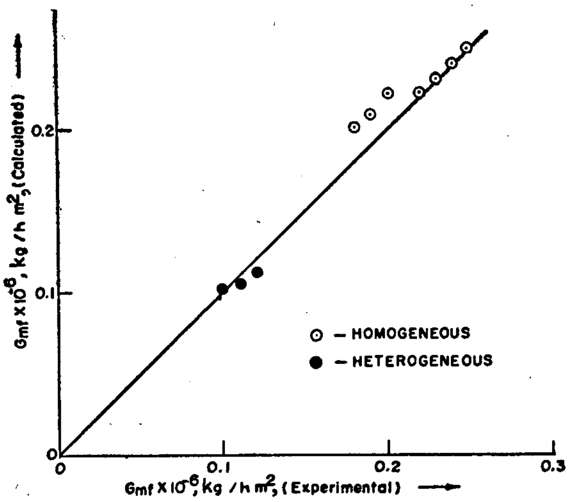

Fig 3 Comparison of G_{mf} values

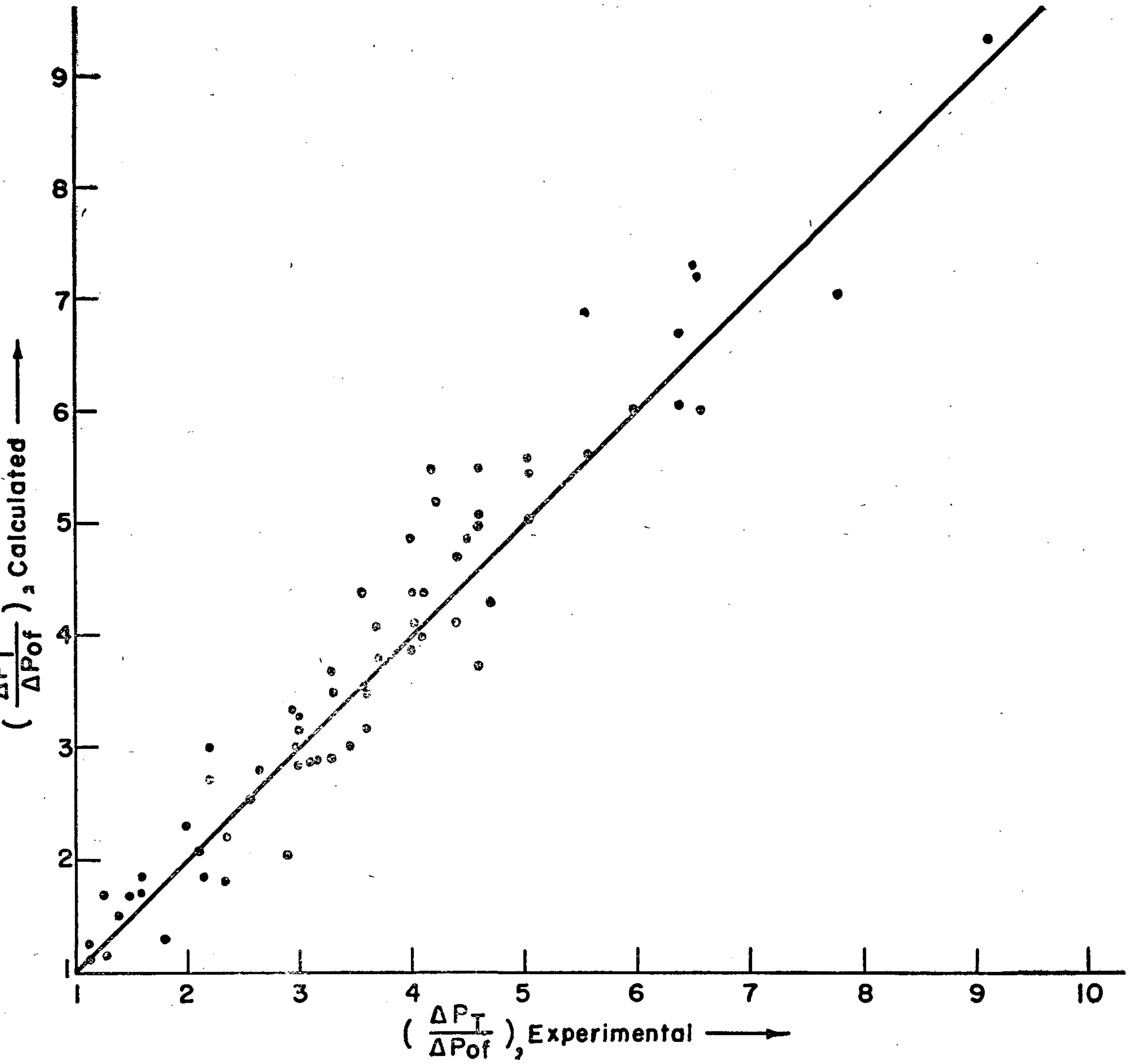

Fig 4 Comparison of $\frac{\Delta P_T}{\Delta P_{of}}$ for homogeneous systems

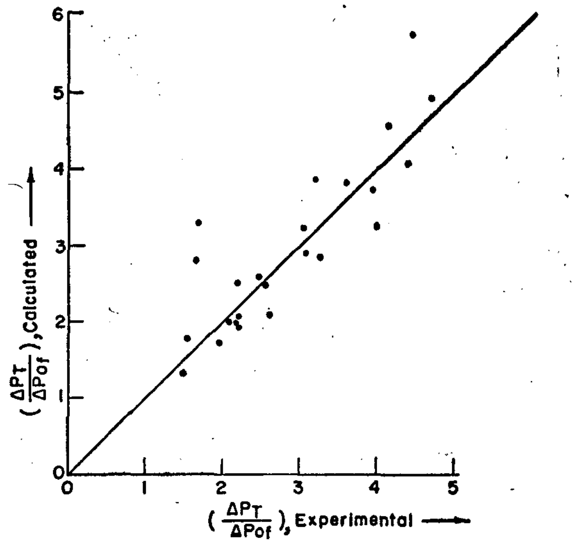

Fig 5 Comparison of $\frac{\Delta P_T}{\Delta P_{of}}$ *for heterogeneous systems*

It is also proposed to formulate a mathematical model so as to make the results applicable over a broad range of the parameters.

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