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Onset of Semifluidization and Fluidization in Conical Vessels

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Semifluidization is a recent development in the field of fluid-solid contact techniques and is a two-phase phenomenon like the packed bed and the fluidized bed. A bed of this nature overcomes inherent disadvantages of packed and fluidized beds. Various aspects of semifluidization in cylindrical columns have been reported in literature. Liquid-solid semifluidization in conical vessels offers some more advantages like low pressure drop, less power consumption and smooth operation. In this paper an attempt has been made to predict the onset of semifluidization and fluidization for liquid-solid system in conical vessels.

NOTATIONS

d_p = particle size, m
D_c = diameter at the entrance of the cone, m
g_c = conversion factor, $\frac{gm}{gmf} \times \frac{cm}{sec^2}$
G = fluid mass velocity based on entrance cross section of the cone, gm/(cm^2 sec)
G_{osf} = fluid mass velocity at onset of semifluidization, gm/(cm^2 sec)
G_{of} = fluid velocity at onset of fluidization, gm/(cm^2 sec)
h_s = static bed height in the cone, m
Re = particle Reynolds number, d_pG/μ
V = linear velocity of the fluid based on the cross section at the entrance of cone, cm/sec
ΔP = pressure drop, gmf/cm^2
ΔP_{sf} = pressure drop in semifluidized bed, gmf/cm^2
α = apex angle of the cone, degree
ρ_s = density of the solid particle, gm/cm^3
ρ_f = density of the fluid, gm/cm^3
μ = viscosity of the fluid, gm/(cm sec)

INTRODUCTION

Semifluidization is a two-phase phenomenon suggested by Fan, *et al*[1] in 1959. A semifluidized bed can be viewed as a combination of a packed bed at the top and a fluidized bed at the bottom. A bed of this nature is obtained by putting a restraint on the top of a freely-fluidized bed. This type of bed overcomes various inherent disadvantages of fluidized and packed beds. Semifluidization operation finds application in chemical reactors, filtration, bioreactors, ion exchange columns etc. So far, this phenomenon has been studied in cylindrical columns only. Various aspects of this phenomenon in cylindrical columns dealing with momentum transfer studies (consisting of pressure drop, minimum and maximum semifluidization velocity, height of packed bed and residence time distribution) are reported in literature[2,3]. Semifluidization in cylindrical columns is associated with relatively high pressure drop and consumes more power than packed bed and fluidized bed operations. The fluidized section (especially in gas-solid) is quite non-uniform and slugging tendencies are not avoided. In contrast, semifluidization in conical vessels gives low pressure drop, consumes less power and offers smooth operation. So far, no work has been reported on semifluidization in conical vessels, although some work on flow through conical fixed beds and fluidization in conical vessels have been reported[4-9].

The conceptual development of semifluidization in cylindrical columns is shown in Fig 1. As seen from

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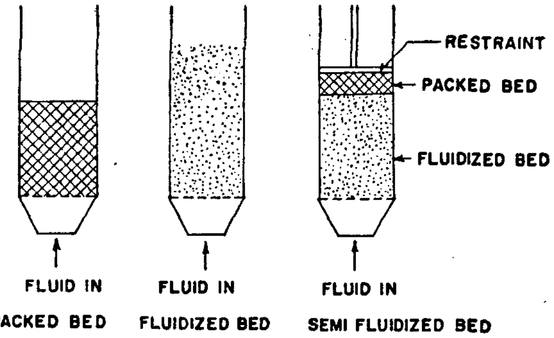

Fig 1 Development of semifluidization in cylindrical columns

the figure, the stages involved are (a) packed bed, (b) fluidized bed and (c) semifluidized bed. That is, to attain semifluidization in cylindrical columns, the bed has to go through the stage of fluidization. On the other hand, in the case of conical vessels, no restraint is necessary to obtain semifluidization. The phenomenon of semifluidization in conical vessels is shown in Fig 2. There are also three stages here as the fluid is passed through the bed, but in a different order. They are (a) packed bed or fixed bed stage, (b) semifluidization and (c) fluidization. Thus, it is possible to attain semifluidization in conical vessels without going through the process of fluidization.

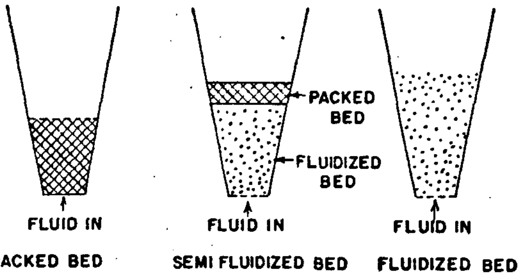

Fig 2 Semifluidization in conical vessels

The comparison of semifluidization phenomenon is best seen from pressure drop (ΔP) versus G plots in cylindrical and conical beds (Fig 3).

EXPERIMENTAL PROCEDURE

The schematic diagram of the experimental set-up is given elsewhere[5]. The cones were made from 2 mm thick perspex sheet. A screen of 60 mesh had been used as support-cum-distributor. Below this, a section packed with raschig rings was used as calming section. Water was used as the fluid medium and was supplied from a tank. Pressure drop across the bed was noted with the help of a U-tube manometer. A scale was provided on the wall of the cone to observe the solids' movement and also to measure the bed heights.

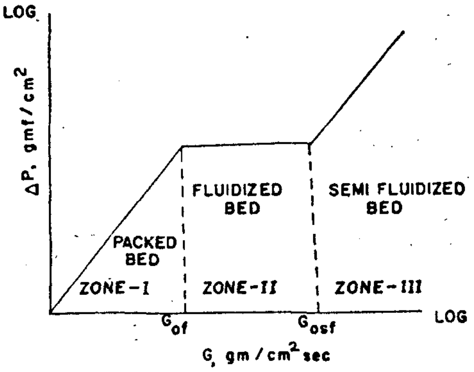

Fig 3 (a) Semifluidization in cylindrical columns

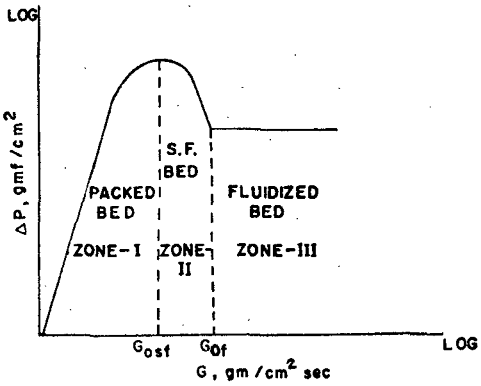

Fig 3 (b) Semifluidization in conical beds

A weighed amounat of material was charged into the cone and the static bed height was noted. Water was pumped at a low flow rate initially and gradually the flow rate was increased. At each flow rate the pressure drop was noted. Flow rate was increased gradually till complete fluidization was attained. The above procedure was repeated for different bed heights, particle sizes, materials and cone angles. The scope of the experimental data is given in Table 1.

TABLE 1 SCOPE OF EXPERIMENTAL DATA

MATERIAL	SPECIFIC GRAVITY	PARTICLE SIZE, $m \times 10^3$	BED HEIGHT, $m \times 10^2$	α DEGREE
Glass beads	2.76	0.950	20.6	10
Glass beads	2.76	0.950	15.2	10
Glass beads	2.76	0.950	10.0	10
Glass beads	2.76	1.000	22.0	10
Glass beads	2.76	1.000	18.0	10
Glass beads	2.76	1.000	12.6	10
Glass beads	2.76	0.290	26.4	10
Glass beads	2.76	1.500	17.7	10
Glass beads	2.76	1.500	26.5	10
Coal	1.27	0.950	21.5	10
Chromite	3.20	1.080	10.7	10
Ferrosilicon	2.69	0.850	18.2	10
Glass beads	2.76	1.1035	18.0	15
Chromite	3.20	1.080	9.9	15
Glass beads	2.76	1.000	16.3	21
Glass beads	2.76	1.500	14.3	21

RESULTS

From the experimental data, plots of pressure drop (ΔP) versus mass velocity (G) were drawn. From these plots, the values of mass velocity at onsets of semifluidization (G_{osf}), and fluidization (G_{of}) were noted. Onsets of semifluidization (G_{osf}) and fluidization (G_{0f}) depended, on properties of solid material (density and particle size), fluid properties (density and viscosity), bed properties (apex angle of the cone and initial static bed height) and mass velocity of the fluid. The following correlations were obtained through dimensional analysis and experimental data.

TABLE 2 OBSERVATION FOR CHECKING EQUATION FOR ONSET OF SEMIFLUIDIZATION

MATERIAL	PARTICLE SIZE, m × 10³	BED HEIGHT, m × 10²	∢ DEGREE	G_{osf} (OBSERVED)	G_{osf} (CALCULATED)
Glass beads	0.95	15.2	10	0.560	0.690
Glass beads	0.95	10.0	10	0.410	0.510
Coal	0.95	21.5	10	0.200	0.235
Chromite	1.08	10.7	10	0.660	0.750
Perrosilicon	0.85	18.2	10	0.580	0.700
Glass beads	0.29	15.0	21	1.460	1.180
Glass beads	1.10	18.0	15	2.780	2.440
Glass beads	0.29	16.9	15	0.780	0.960
Coal	2.20	19.7	15	0.950	1.110
Glass beads	1.50	26.5	10	0.167	0.127
Glass beads	0.95	20.6	10	0.600	0.700

TABLE 3 OBSERVATIONS FOR CHECKING THE EQUATION FOR ONSET OF FLUIDIZATION

MATERIAL	PARTICLE SIZE, m×10³	BED HEIGHT, l(cm×10²)	∢ DEGREE	G_{of} (OBSERVED)	G_{of} (CALCULATED)
Glass beads	0.95	20.6	10	0.811	0.640
Glass beads	0.95	15.2	10	0.680	0.490
Glass beads	0.95	10.0	10	0.450	0.340
Glass beads	1.00	22.0	10	0.550	0.730
Glass beads	1.00	12.6	10	0.320	0.220
Glass beads	0.29	26.4	10	0.093	0.106
Coal	0.95	21.5	10	0.242	0.185
Chromite	1.08	10.7	10	0.700	0.570
Ferrosilicon	0.85	18.2	10	0.620	0.460
Glass beads	1.50	26.5	10	2.170	2.500
Glass beads	1.11	18.0	15	3.370	2.500

For onset of semifluidization,

$$\frac{d_p\, G_{osf}}{\mu} = 2.32 \times 10^4 \left(\frac{h_s}{D_c}\right)^{0.73} \left(\frac{D_c}{d_p}\right)^{-1.68} \cdot \left(\frac{\rho_s}{\rho_f}\right)^{1.70} \left(\tan\frac{\sphericalangle}{2}\right)^{1.78} \qquad (1)$$

For onset of fluidization

$$\frac{d_p\, G_{of}}{\eta} = 1.65 \times 10^6 \left(\frac{h_s}{D_c}\right)^{0.89} \left(\frac{D_c}{d_p}\right)^{-2.70} \cdot \left(\frac{\rho_s}{\rho_f}\right)^{1.65} \left(\tan\frac{\sphericalangle}{2}\right)^{2.13} \qquad (2)$$

The above correlations were verified and found to fit the data satisfactorily (Tables 2 and 3) with mean deviations of ± 25 %.

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