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Prediction of the Height of the Lean-Bed Zone in Gas-Solid Semifluidized Beds

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It has been observed by many investigators that a lean-bed zone exists in between fluidized beds and packed beds. No attempt has been made however to predict it. Data have been obtained on the heights of the lean-bed zone in semi-fluidized beds using air-glass beads, air-ilmenite and air-chromite systems. Based on the lines of statistical design, the experiments were carried out at two levels. An equation is presented for predicting the heights of the lean-bed zone in terms of solid, fluid and bed properties. The equation has been, verified by carrying out additional independent experiments and has been found to hold good within ±15per cent.

THOUGH it has been observed by Fan, *et aL,*[1] Pandey, *et al.,*[2] and Sen Gupta, *et al.*[3] that there exists a lean-bed zone in between fluidized and packed beds, information is not available regarding its formation and prediction.

The prediction of this height helps in better understanding of transfer phenomena. In this paper the authors have attempted to formulate an equation to predict the height of the lean-bed zone in terms of the basic variables relating to gas, solid and bed.

The height of the lean-bed zone is dependent on gas, solid and bed properties. This can be expressed by the equation below

$$h_{lbz} = f\,(D_c,\ D_p,\ G_{sf},\ G_{msf},\ \rho_s,\ \rho_g,\ h_s,\ R) \qquad (1)$$

Dimensional analysis of the above equation gives us

$$\frac{h_{lbz}}{D_p} = f\left(\frac{D_c}{D_p},\ \frac{\rho_s}{\rho_g},\ \frac{G_{sf}}{G_{msf}},\ R,\ \frac{h_s}{D_p}\right) \qquad (2)$$

$$= f\,(x_1, x_2, x_3, x_4, x_5) \qquad (3)$$

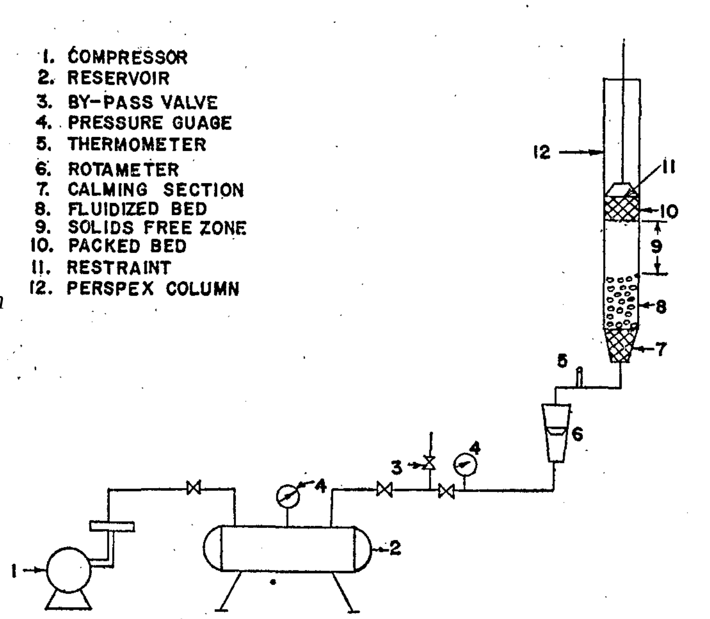

Fig. 1. Experimental set-up

Experimental

The schematic diagram of the experimental set-up is shown in *Figure 1.* The semifluidizer were made of Perspex. A 60-mesh stainless steel screen was used as bottom grid. A movable restraint, made also from a 60-mesh stainless steel screen and fixed to the bottom of a plastic cone, was rigidly fixed to a mild steel rod extending from the top of the semifluidizer.

Rotameters were used to measure the flow rate of air. The experiments were carried out in columns of sizes 2.5 cm and 5 cm inside diameter. The properties

TABLE I

PROPERTIES OF THE MATERIALS INVESTIGATED

Sl. no.	Material	Avg. size cm.	Density gm/cc	$^*G_{mst} \times 10^2$ gm/(cm sec^2)
1.	Glass beads	0·0486 (−28+36 B.S.S.)	2·62	37·70
2.	Glass beads	0·0928 (−16+18 B.S.S.)	2·62	61·00
3.	Chromite	0·0550 (−25+30 B.S.S.)	3·72	51·40
4.	Ilmenite	0·0486 (−28+36 B.S.S.)	4·20	62·05

**Values determined by plotting the packed bed height below the restraint against flow rate and then extrapolating the curve to* $h_{pa} = h_s$

of the materials and experimental conditions are given in *Table I.*

The semifluidizer was charged with a sample of solid material to a desired static bed height and the movable restraint was adjusted for a particular bed expansion ratio. Air was admitted at values higher than the minimum semifluidization velocity, and the heights of the lean bed zone in each of the above cases were noted for steady state conditions. The values of the variables in the investigations were fixed by the experimental design method.[4]

Experimental Design

It is assumed here that the response Y can be expressed as a linear function of the main effects and interactions of the independent variables x_1, x_2, x_3, x_4 and x_5. That is, the equation could be expressed in the form

$$Y = \text{constant} + \beta_{11}x_1^2 + \beta_{22}x_2^2 + \beta_{33}x_3^2 + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \ldots \quad (4)$$

where $/_{11}$, etc., are the coefficients which are to be determined.

As is seen from dimensional analysis, the response Y ($=h_{ibz}/D_p$) is dependent on five dimensionless variables. These are D_c/D_p; ps/pgj G_{Sf}/G_{msf}; and R and (5) hs/Dp. The experiments were carried out keeping the variables at two levels which are presented in *Table II.*

TABLE II

LEVELS OF VARIABLES

Sl. no.	Dimensionless variable	Higher level (+1 level)	Lower level (−1 level)
1.	D_c/D_p	102·88	51·44
2.	ρ_s/ρ_g	$3{\cdot}64 \times 10^3$	$2{\cdot}25 \times 10^3$
3.	G_{sf}/G_{mst}	0·75	0·45
4.	R	4·00	3·00
5.	h_s/D_p	164·60	123·50

The number of experiments required for the five factors, keeping each at two levels, is 32. These experiments were carried out in columns of 2.5 and 5.0 cms with glass beads and ilmenite of particle size 0.0486 cm. The bed heights used were 6 and 8.0 cm. The expansion ratios maintained were 3 and 4. The G_{Sf} to G_{mSf} were 0.45 and 0.75. The average temperature maintained during the experiment was 35°C.

After carrying out the 2^5 factorial experiments, the data were tested by Yates' technique for the importance of the main effects and interactions of the variables.

Using Yates' technique, it was noted that the following variables were statistically significant at a 5 per cent level. They are x_1, x_4, x_5, x_1x_3, x_3x_4, x_3x_5, x_2x_3 and x_4x_5. Treating these as independent variables and denoting higher levels by +1 and lower levels by —1, a least square fit of these variables with 32 observations was made and the following equation obtained

$$Y = 160 - 16{\cdot}1\, X_1 + 26{\cdot}3\, X_4 + 19{\cdot}5\, X_5 + 10{\cdot}3\, X_4X_5 + X_3(16{\cdot}8\, X_1 - 17{\cdot}4\, X_4 - 16{\cdot}9\, X_5 - 10{\cdot}2\, X_2) \quad (5)$$

The constant 160 includes the square terms of the five main effects, i.e. X_1^2, X_2^2, X_3^2, X_4^2, and X_5^2 and another constant term.

To determine the coefficients of these five square terms and constant, six additional runs at varying con-

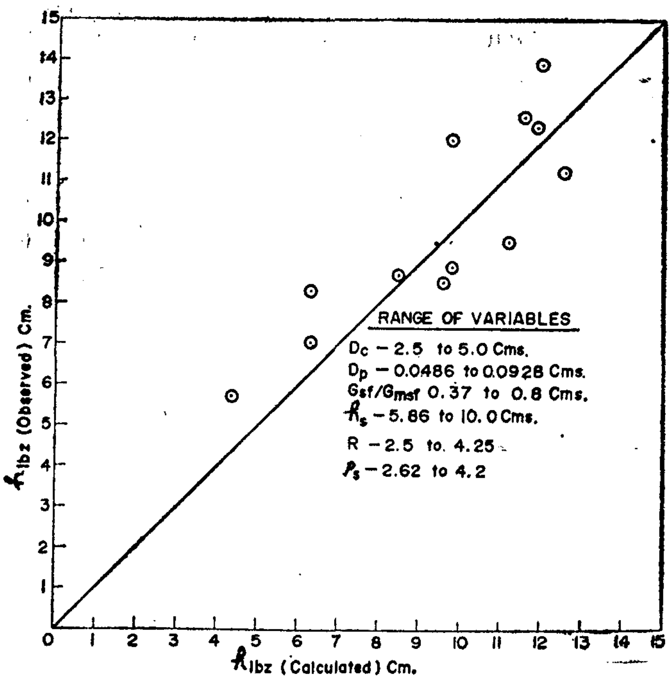

Fig. 2. Comparison of heights of the lean-bed zone

TABLE III

OBSERVATION FOR CHECKING THE EQUATION

Sl. no.	Material	D_c (cm)	D_p (cm)	G_{sf}/G_{msf}	R	h_s (cm)	ρ_s (gm/cc)	h_{lbz}(cm) calculated	h_{lbz}(cm) observed	% deviation
1.	Ilmenite	2·5	0·0486	0·370	3·50	8·00	4·20	11·60	12·6	– 7·9
2.	-do-	2·5	0·0486	0·600	4·25	8·00	4·20	11·90	12·4	– 4·0
3.	-do-	2·5	0·0486	0·600	3·50	10·00	4·20	12·00	13·9	–13·7
4.	-do-	5·0	0·0486	0·375	3·50	8·00	4·20	9·80	12·0	–18·3
5.	Glass beads	5·0	0·0486	0·490	4·00	8·00	2·62	9·80	8·8	+11·4
6.	-do-	5·0	0·0928	0·500	2·50	7·40	2·62	9·60	8·5	+12·9
7.	-do-	5·0	0·0928	0·320	2·50	7·40	2·62	6·30	7·0	–10·0
8.	-do-	5·0	0·0928	0·320	3·00	7·40	2·62	12·60	11·2	+12·5
9.	Ilmenite	5·0	0·0486	0·288	2·50	8·00	4·20	11·20	9·5	+17·9
10.	Chromite	5·0	0·0550	0·570	4·00	5·80	3·72	6·30	8·3	–24·2
11.	-do-	5·0	0·0550	0·520	3·00	5·80	3·72	4·40	5·7	–22·8
12.	-do-	5·0	0·0550	0·800	3·00	5·80	3·72	8·51	8·7	– 2·2

ditions of these variables were taken. After substitution of these coefficients equation (5) becomes

$$Y = 138{\cdot}7+2{\cdot}5\,X_1^2+5{\cdot}1\,X_2^2+20{\cdot}6\,X_3^2+6{\cdot}0\,X_4^2+2{\cdot}5\,X_5^2-16{\cdot}1\,X_1+26{\cdot}3\,X_4+19{\cdot}5\,X_5+10{\cdot}3\,X_4X_5+X_3\,(16{\cdot}8\,X_1-17{\cdot}4\,X_4-16{\cdot}9\,X_5-10{\cdot}2\,X_2). \quad (6)$$

Conclusion

The final equation as obtained above has been tested for various conditions of the independent variables and compared with the response obtained from experiments in *Figure 2.* It was found to hold good for all the data within reasonable limits, and the mean and standard deviations were found to be 13.1 per cent and 14.7 per cent respectively. In the case of gas-solid semifluidization, the height of the fluidized bed fluctuates continuously due to the aggregative nature as well as the periodic formation of bubbles and their eruption, thereby throwing up the solids. These are found to influence the accurate measurement of the height of the lean-bed zone to some extent.

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NOMENCLATURE

D_c column diameter, cm
Dp particle diameter, cm
G_{sf} semifluidization mass velocity, gm/(cm^2 sec)
G_{mSf} maximum semifluidization velocity, gm/(cm^2 sec)
h_{pa} packed bed height below restraint, cm
h_s static bed height, cm
h_{lbz} height of the lean-bed zone, cm
h_{sf} height of the semifluidized bed, cm
R expansion ratio ($=h_{sf}/h_s$), dimensionless

$x_1 = D_c/D_p$ $\quad X_1 = \dfrac{x_1 - 77{\cdot}16}{25{\cdot}72}$

$x_2 = \rho_s/\rho_g$ $\quad X_2 = \dfrac{x_2 - 2{\cdot}9\,45\,10^3}{0{\cdot}695\times10^3}$

$x_3 = G_{sf}/G_{msf}$ $\quad X_3 = \dfrac{x_3 - 0\,6}{0{\cdot}15}$

$x_4 = R$ $\quad X_4 = \dfrac{x_4 - 3{\cdot}5}{0{\cdot}5}$

$x_5 = h_s/D_p$ $\quad X_5 = \dfrac{x_5 - 144\,05}{20{\cdot}55}$

$Y = h_{lbz}/D_p$

Greek letters

ps density of the solid material, gm/cc
pg density of fluid, gm/cc
fi constant

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