Statistical Analysis of Bed Fluctuation Ratio in Gas-solid Fluidized Bed with Rod Promoter

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A model equation for the prediction of bed fluctuation ratio in rod promoted gas-solid fluidized (condition above quicksand) bed has been developed using statistical design of experiments approach. Four rod promoters of varying volume blockage together with bed materials of four densities and four initials static bed heights have been used in the investigation. A comparison has been presented between the predicted values of bed fluctuation ratio using proposed model equation and the corresponding experimental ones for the test data. The mean and standard deviations of the predicted values of bed fluctuation ratio from the corresponding experimental ones show fair agreement.

Keywords: Fluidization; Rod promoter; Bed fluctuation ratio; Statistical design

NOTATION

A_o	:	open area in promoted bed, m^2
D_c	:	column diameter, m
D_e	:	equivalent diameter of promoted bed, $4A_o/P$, m
G_f	:	fluidization mass velocity, kg (m^2/h)
G_{mf}	:	minimum fluidization mass velocity, kg/m^2h
G_R	:	mass velocity ratio, $(G_f - G_{mf})/G_{mf}$
h_{av}	:	average bed height, $(h_{max} + h_{min})/2$, m
h_{max}, h_{min}	:	maximum and minimum heights of fluidized bed, respectively, m
h_s	:	initial static bed height, m
P	:	total perimeter, m
R	:	bed expansion ratio, h_{av}/h_s
$X_1 - X_4, x_1 - x_4$	:	decoded and coded (levelled) values of variables, respectively
ρ_s, ρ_f	:	density of solid and of fluidizing medium, respectively, kg/m^3

INTRODUCTION

Statistical design of experiments[1,2] is a method with the help of which experiments are planned in advance to achieve maximum benefit for minimum efforts. Statistical design results in an organized approach to the collection and analysis of information. Also, method of experimentation based on statistical design of experiments (factorial design analysis) enables study of interaction effects of variables, which would not be possible by conventional experimentation. This explicitly finds out the effect of each variable quantitatively on the response (output result). In addition, the number of experimental runs required is much less as compared to the conventional experimentation.

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The efficiency and the quality of gas-solid fluidized beds suffer seriously due to certain drawbacks such as channeling, bubbling and slugging. For the gas flow more than the minimum fluidization velocity, the top of the fluidized bed fluctuates considerably. The formation of bubbles and their ultimate growth to form slugs and the collapsing of bubbles cause erratic bed expansion with intense bed fluctuation. It becomes important to specify the extent of fluctuation and its estimation for the design of a fluidizer. Out of the two methods available to quantify fluctuation, fluctuation ratio method has been used widely because of more exact quantification of fluidization quality. Several techniques such as vibration and rotation of the bed, use of promoter, and application of conical and non-cylindrical conduits in place of the columnar ones have been recommended by investigators[3-7] to dampen fluctuation and to improve fluidization quality. The use of promoter has been found to be more effective in controlling fluidization quality as compared to other methods. In the present case the effect of rod promoters on bed fluctuation has been investigated and a model equation has been proposed to predict the values of bed fluctuation ratio.

EXPERIMENTATION

The experimental set-up (Figure 1) consists of an air compressor, rotameter, silica gel column, clamps for the proper placement of promoters, 50.8 mm inner φ perspex column (fluidizer) with two pressure tappings and a differential U-tube manometer. Figure 2 presents details of rod promoters used in the investigation. The fluidizing medium (compressed and dried air) from the rotameter has been passed through a conical

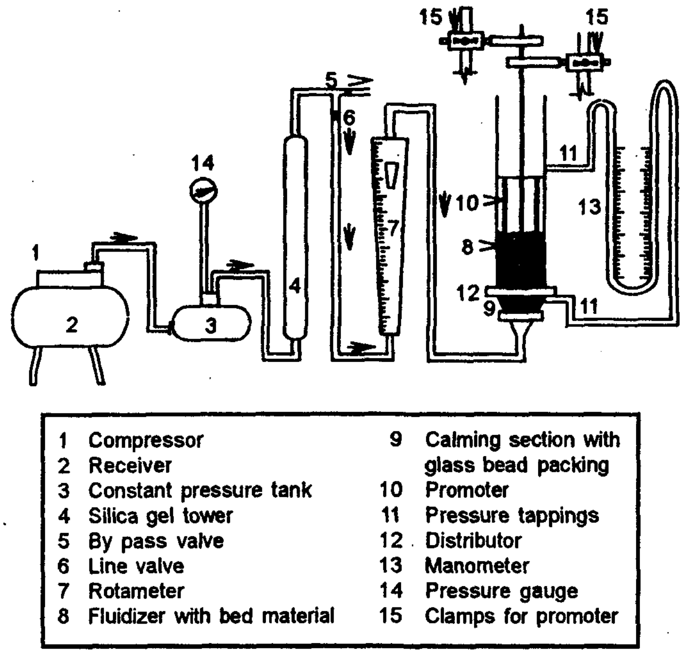

Figure 1 Experimental set-up

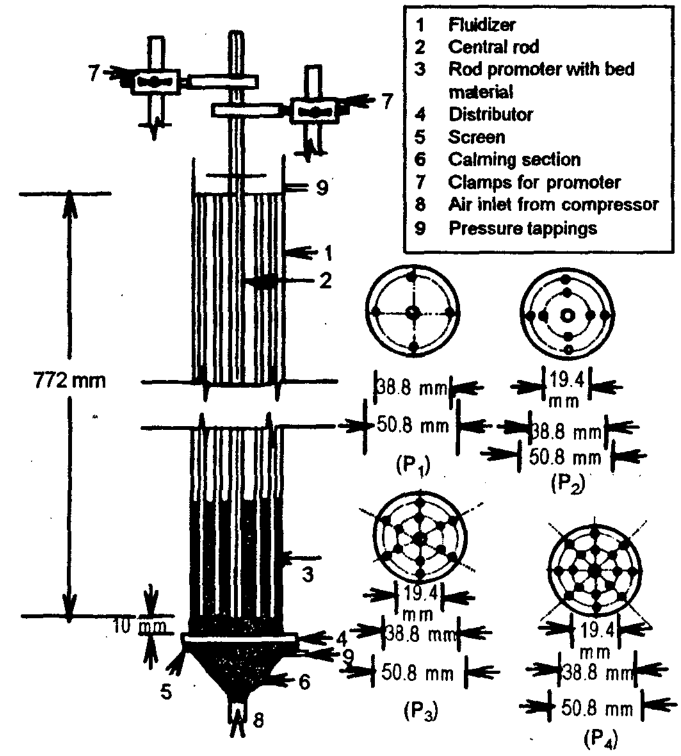

Figure 2 Details of rod promoter

section with 5 mm φ glass beads, supported on a coarse screen which serves as the calming section. A GI plate of 1.00 mm thickness having 37 orifices (2.5 mm ϕ) placed in an equilateral pattern at a pitch of 7.5 mm centre-to-centre has been used as distributor. The rod promoters each having a 6.1 mm central rod and 4, 8, 12 and 16 numbers of 4 mm radial rods placed in concentric circles have been used in the investigation. The

Table 1 Scope of the experiment

A. Properties of bed material, $d_p \times 10^3$, m = 0.7250					
Materials		$\rho_s \times 10^{-3}$, kg/m^3			
Dolomite		2.817			
Alum		1.691			
Iron ore		3.895			
Mangnese ore		4.880			
B. Bed parameter					
Initial static bed height, $h_s \times 10^2$, m		8	12	16	20
C. Details of rod promoter					
Promoter specification		Number of 4 mm ϕ radial rods			
Rod :	P_1	4			
	P_2	8			
	P_3	12			
	P_4	16			
E. Flow properties					
Maximum, kg/h-m^2		Minimum, kg/h-m^2			
5500		200			

experimental data for bed pressure drop with varying flow rate have been noted and the same have been repeated for different bed materials of varying particle size, initial static bed height and promoters blockage volume. The values of minimum fluidization velocity used in the analysis have been obtained by using correlation developed by Kumar and Roy[8]. The scope of the present experiment has been given in Table 1.

DESIGN OF EXPERIMENT

The independent variables affecting the bed fluctuation ratio expressed in dimensionless forms are: (i) flow parameter *(G_R)*, *(ii)* density parar $\left(\frac{\rho_s}{\rho_f}\right)$, (iii) bed height parameter $\left(\frac{h_s}{D_c}\right)$, and (iv) promoter parameter $\left(\frac{D_e}{D_c}\right)$. The total number of experiments required at two levels for four parameters is $2^4 = 16$ for response as bed fluctuation ratio. To test the developed model equation, some more experimentation has been carried out at values of parameters in between low and high levels. The scope of the factors for the study has been presented in Table 2.

DEVELOPMENT OF MODEL EQUATION

The model equation is assumed to be linear and can be presented in the general form as:

$$r = b_0 + b_1x_1 + b_2x_2 + \ldots + b_{12}x_1x_2 + b_{13}x_1x_3 + \ldots + b_{123}x_1x_2x_3 + \ldots + b_{1234}x_1x_2x_3x_4 \qquad (1)$$

Table 2 Scope of the factors (factorial design analysis)

Variables (general) symbol	Factorial design symbol	Minimum level coded	Minimum level decoded	Maximum level coded	Maximum level decoded	Magnitude of variables
$\left(\frac{G_f - G_{mf}}{G_{mf}}\right)$	x_1	− 1	0.300	+ 1	2.900	0.30-2.90
$\left(\frac{\rho_s}{\rho_f}\right)$	x_2	− 1	1409.170	+ 1	4066.670	1409.17, 2347.5, 3245.83, 4066.67
$\left(\frac{h_s}{D_c}\right)$	x_3	− 1	1.580	+ 1	3.940	1.58, 2.36, 3.15, 3.94
$\left(\frac{D_e}{D_c}\right)$	x_4	− 1	0.372	+ 1	0.670	0.372, 0.441, 0.535, 0.670

The values of the coefficients (Table 3) have been calculated by using the experimental data of bed fluctuation ratio collected for the runs planned according to the Yate's standard order and treatment combinations of the design of experiments.

Thus

$$b_i = \sum \alpha_i r_i / N \qquad (2)$$

where b is the coefficient, r_i is the response (corresponding bed fluctuation ratio), a_i is the level of the parameters; and N is the total number of the treatments. The value of the coefficients indicates the effect of the parameters and the sign of the coefficient gives the direction of the effect of the parameters. Thus, a positive value of the coefficient indicates an increase and negative value indicates a decrease in the value of response with increase in the value of the parameters. Ranking the values of the coefficient of the parameters for their effects, the effect of all the four parameters have been found significant. The effects of first, second and third order interactions between the respective parameters have been found inappreciable except for one, *ie*, first order interaction between x_1 and x_2

Table 3 Values of coefficients of equation (1)

Coefficients	Values	Coefficients	Values
b_0	1.668	b_{23}	− 0.029
b_1	0.309	b_{24}	0.029
b_2	0.173	b_{34}	− 0.018
b_3	− 0.114	b_{123}	− 0.013
b_4	0.112	b_{124}	0.013
b_{12}	0.079	b_{134}	− 0.009
b_{13}	− 0.053	b_{234}	− 0.006
b_{14}	0.051	b_{1234}	− 0.002

Considering the significant effects of the main variables and interactions between parameters and neglecting other insignificant parameters, the final model equation (1) becomes:

$$r = 1.668 + 0.309\,x_1 + 0.173\,x_2 - 0.114\,x_3 + 0.112\,x_4 + 0.079\,x_1x_2 \qquad (3)$$

The level of the system parameters can be obtained as:

$$\text{Level of } x_1 = \left(\frac{X_1 - 1.6}{1.3}\right)$$

$$\text{Level of } x_2 = \left(\frac{X_2 - 2737.92}{1328.75}\right)$$

$$\text{Level of } x_3 = \left(\frac{X_3 - 2.76}{1.18}\right)$$

$$\text{Level of } x_4 = \left(\frac{X_4 - 0.521}{0.149}\right)$$

RESULT AND DISCUSSIONS

The positive values of coefficients of parameters x_1, x_2, x_4, indicate that bed fluctuation ratio increases with increase in flow parameter, density and equivalent diameter of the promoted bed. In other words, the bed fluctuation ratio reduces with increase in blockage volume of the rod promoter, *ie,* with increase in number of rods in the fluidized bed. The negative value of the coefficient of x_3 shows reduction in bed fluctuation ratio with increase in bed height. First order interaction between x_1 and x_2 also show increasing trend of bed fluctuation ratio. The response plot between the predicted values of bed fluctuation ratio using developed model equation (3) and the system parameters (Figures 3 and 4) also indicate these observations. The reduction in bed fluctuation ratio can be

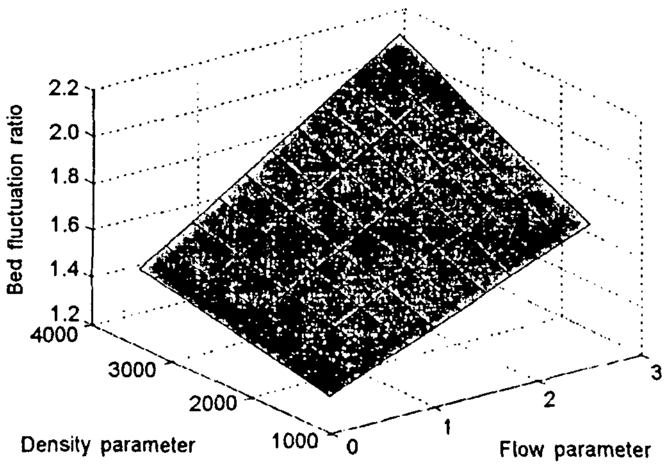

Figure 3 Variation (response surface) of bed fluctuation ratio with flow and density parameters at constant bed height and promoter parameter

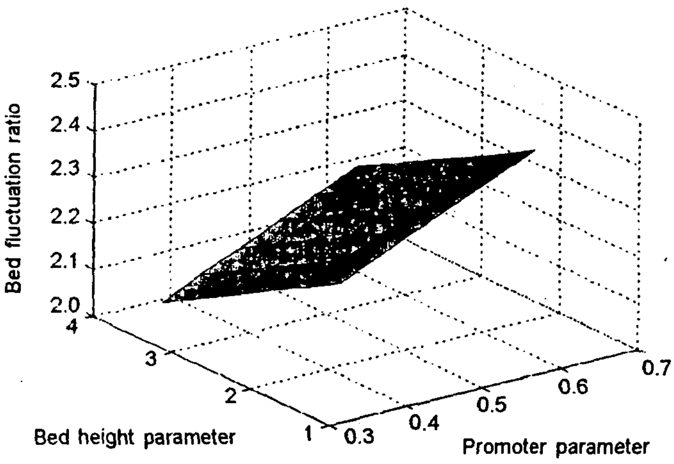

Figure 4 Variation (response surface) of bed fluctuation ratio with rod promoter and bed height parameters at constant mass flow rate and for same material

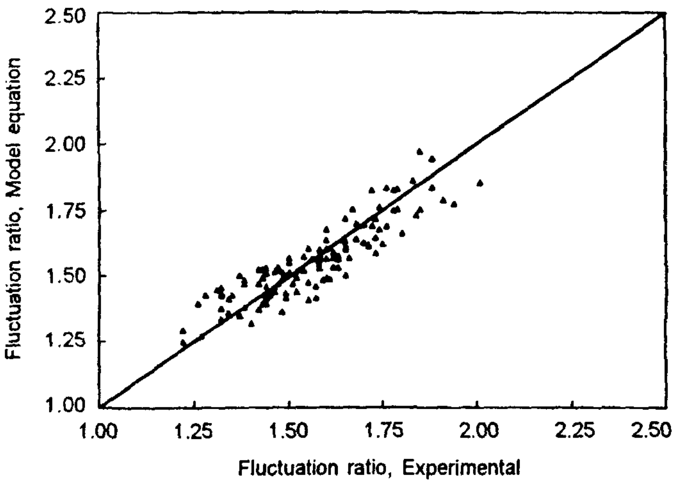

Figure 5 Comparison between experimental and predicted values of bed fluctuation ratio using developed model equation

attributed to the effectiveness of the promoter in breaking up of the bubbles. Further, the calculated values of bed fluctuation ratio using developed model equation (3) has been compared with the corresponding experimental ones (Figure 5) for the data different from minimum and maximum levels used in the development of model equation. The mean and the standard deviations of the predicted values of bed fluctuation ratio from the corresponding experimental ones have been obtained as 4.77 and 3.02, respectively.

CONCLUSION

The use of rod type promoter in gas-solid fluidized bed has been found effective in reducing the bed fluctuation. This helps in reducing the overall size of a fluidizer and the operation becomes economical. Also, the number of experimental runs required to develop a model equation from statistical design is considerably less in comparison to conventional experimentation. In addition to present the effect of different variables explicitly and quantitatively, statistical design method also brings out interactions between the variables, thereby more accurate predictions can be obtained. Further, the comparison plot (Figure 5) and the mean and standard deviations show that the calculated values of bed fluctuation ratio using developed equation (3) are in close agreement with the corresponding experimental ones. Hence, the developed model equation can be satisfactorily used for the prediction of the bed fluctuation ratio in the range of the present system variables.

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