Effect of Coaxial Rod, Disk and Blade Type Promoters on Bed Fluctuation in a Gas-solid Fluidized Bed with Varying Distributor Open Area

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Experiments have been carried out extensively to study the effectiveness of promoters in reducing bedfluctuation in solid fluidized beds with distributors of varying open area. Four type of rod promoters, seven types of disk promote along with one blade promoter have been used in beds supported respectively on five distributors with open area of 12.9%, 8.96%, 5.74%, 3.23% and 1.43% of the column cross-sectional area. Correlations for bed fluctuation ratio been developed for unpromoted and the promoted beds with rod, disk and blade type of promoters. The values of be fluctuation ratio obtained from the developed correlations compare fairly well with the experimental values. It is al observed that there is reduction in fluctuation of the bed in case of all the promoted beds as against the unpromoted for identical bed and operating parameters, which may be attributed to the combined effect of promoter and distributor.

Keywords: **Fluidization; Promoter; Distributor; Bed fluctuation ratio.**

NOTATION

A_A	:	distributor annular area [reference equation (5)], m^2
A_c	:	area of column, m^2
A_{do}	:	open area of distributor, m^2
A_o	:	open area in promoted bed with rod promoters, m^2
BP	:	bed with blade type of promoter
d_o	:	orifice dia, m
d_p	:	particle size, m
D_c	:	column dia, m
D_e	:	equivalent dia of promoter ($4A_o/P$), m
DP	:	bed with disk promoter
D_k	:	disk dia, m
G_f	:	fluidization mass velocity, kg/(m^2-h)
G_{mf}	:	minimum fluidization mass velocity in promoted beds, kg/(m^2-h)
G_R	:	mass velocity ratio, $(G_f - G_{mf})/(G_t - G_{mf})$
G_t	:	terminal mass velocity, kg/(m^2-h)
h_{max}	:	maximum height of fluidized bed, m
h_{min}	:	minimum height of fluidized bed, m
P	:	total rod perimeter, m
RP	:	bed with rod promoter
r	:	bed fluctuation ratio, h_{max}/h_{min}
t	:	disk thickness, m
UP	:	unpromoted bed
ρ_f	:	density of fluid, kg/m^3
ρ_s	:	density of solid, kg/m^3

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INTRODUCTION

Gas flow in a gas-solid fluidized bed is characterized by the predominance of bubbles. Under gas flow more than minimum fluidization velocity, the top of the fluidized bed may fluctuate considerably leading to an unstability in operation. Bed fluctuation and fluidization quality are inter-related. The extent of the fluctuation and its estimation are important for specifying the height of a fluidizer. Hence, consistent efforts have made *to* reduce fluctuation ratio and to correlate it in terms of static and dynamic parameters of the system.

Out of the two methods (namely, the uniformity index method and the fluctuation ratio method), the latter has widely been used to quantify fluidization quality. The use of a suitable promoter and proper gas distributor can improve fluidization quality with better gas-solid contact through minimization of channelling and slugging and limit the size of bubbles and their growth. This results in ultimate reduction of bed fluctuation to a considerable extent and thereby limiting the size of the equipment. A number of investigators have stressed the use of promoters to improve fluidization quality and to increase the range of applicability of gas-solid fluidized beds.

LITERATURE REVIEW

Balakrishanan and Rao[1] studied the effect of horizontal screen disk baffle on fluidized bed pressure drop and minimum fluidizing velocity. Horizontal baffles in reactors were used by Lewis, *et al*[2] and Massimilla and Johnstone[3] for the hydrogenation of ethylene and oxidation of ammonia, respectively. Kai, *et al*[4], carried out investigations with horizontal perforated disk on hydrogen chloride conversion and pressure fluctuation. Yong, *et al*[5], reported the effect of pagoda type vertical internals on improving the performance of gas-fluidized beds. Dutta and Suciu[6] investigated qualitatively the effect of perforated plate, wire mesh, angle iron grid and some other types of baffles in breaking bubbles in fluidized bed. Olowson[7] carried out investigations to study the influence of pressure and fluidization velocity on hydrodynamics of a fluidized bed containing horizontal tubes. Volk, *et al*[8] suggested that vertical tubular surfaces may be inserted in large dia beds in order to prevent the development of very large bubbles. Overcashier, *et al*[9], Glass and Harrison[10] and Rowe and Evertt[11] studied the effect of horizontal baffles on the quality of fluidization. Krishnamurthy, *et al*[12], proposed the following correlation for the prediction of fluctuation ratio for gas-fluidized beds using longitudinal rod type baffles.

$$r = 0.59\left(\frac{G_f}{G_{mf}}\right)^{1.01}\left(\frac{d_p}{D_c}\right)^{-0.12}\left(\frac{D_c}{h_s}\right)^{-0.20}\left(\frac{\rho_s}{\rho_f}\right)^{-0.02} \qquad (1)$$

Agarwal and Roy[13] studied the effect of stirrer type of baffles on fluidization quality and proposed a correlation as

$$r = 2.49\left(\frac{G_f}{G_{mf}}\right)^{1.75}\left(\frac{d_p}{D_c}\right)^{-0.07}\left(\frac{D_c}{h_s}\right)^{-0.29}\left(\frac{\rho_s}{\rho_f}\right)^{-0.25} \qquad (2)$$

Kar and Roy[14] used co-axial rod and co-axial disk type promoters for their studies on fluidization quality and developed the following correlations for bed fluctuation ratio.

$$r = 0.004\left(\frac{h_s}{D_c}\right)^{0.15}\left(\frac{d_p}{D_c}\right)^{-0.29}\left(\frac{\rho_s}{\rho_f}\right)^{0.29}\left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.3} \qquad (3)$$

for bed with co-axial rod type promoter

$$r = 0.87\left(\frac{h_s}{D_c}\right)^{0.04}\left(\frac{d_p}{D_c}\right)^{-0.04}\left(\frac{\rho_s}{\rho_f}\right)^{0.02}\left(\frac{G_f - G_{mf}}{G_{mf}}\right)^{0.04} \qquad (4)$$

for bed with co-axial disk promoter

Other studies relating to bed dynamics in promoted gas-solid fluidized beds include disk promoter by Ravi, *et al*[15], twisted

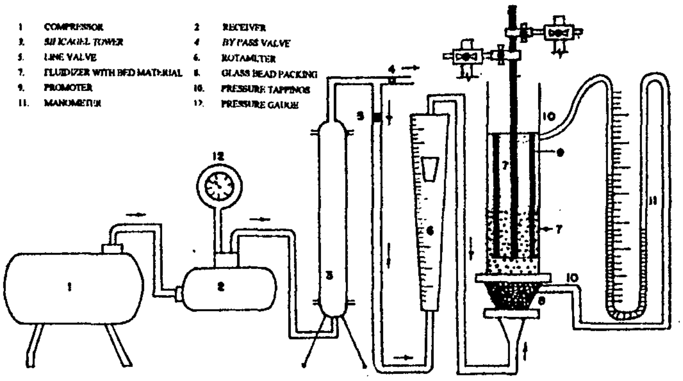

Figure 1 Schematic representation of the experimental set-up with details of the promoters

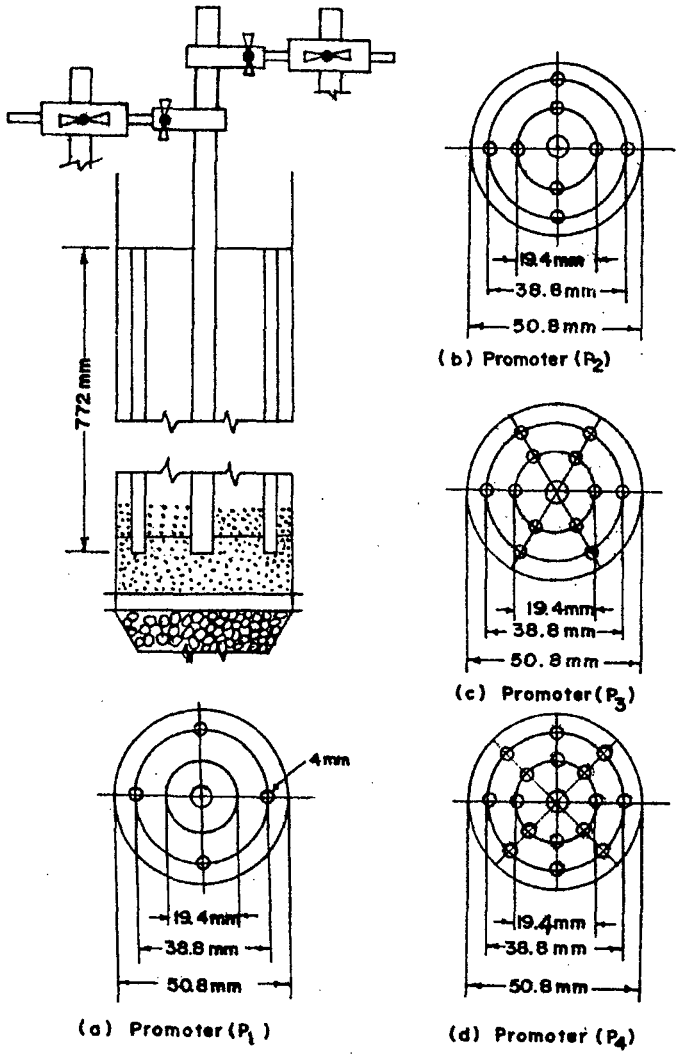

Figure 2 Details of rod promoters

Table 1 Scope of experiment

Properties of Bed Material			
Materials	**$d_p \times 10^3$, m**	**$\rho_s \times 10^{-3}$, kg/m^3**	
Dolomite	1.1250	2.817	
Dolomite	0.7250	2.817	
Dolomite	0.4625	2.817	
Dolomite	0.3900	2.817	
Dolomite	0.3275	2.817	
Alum	0.7250	1.691	
Iron-ore	0.7250	3.895	
Manganese-ore	0.7250	4.880	
Bed Parameter			
Initial static bed height, $h_s \times 10^2$, m	8 12 16 20		
Distributor Parameters			
Distributor	**Number of Orifice**	**Dia of Orifice, (d_o), mm**	
D_1	37	3.00	
D_2	37	2.50	
D_3	37	2.00	
D_4	37	1.50	
D_5	37	1.00	
Promoter Details			
Promoter Specification	**$D_k \times 10^3$, m**	**$t \times 10^3$, m**	**Number of 4-mm dia Longitudinal Rods**
Rod : P_1	—	—	4
P_2	—	—	8
P_3	—	—	12
P_4	—	—	16
Disk : P_5	28.000	3.18	—
P_6	28.000	6.36	—
P_7	28.000	9.54	—
P_8	28.000	12.72	—
P_9	20.260	6.36	—
P_{10}	34.000	6.36	—
P_{11}	39.125	6.36	—
Blade : P_{12}	38.000	6.36	—
Flow Property			
Maximum, kg/(h-m^2)		Minimum, kg/(h-m^2)	
5500		200	

strips and wire coils by Colburn and King[16], co-axially placed cones by Rao, *et al*[17-18], ring promoter assembly by Ramabramhan, *et al*[19,20], string of spheres by Sitaraman[21], mesh and brush inserts by Magerlin, *et al*[22], Sujatha[23], Prasad[24] and Rao, *et al*[25].

Ghose and Saha[26] and Saxena, *et al*[27] showed that the quality of bubble formation is strongly influenced by the type of gas

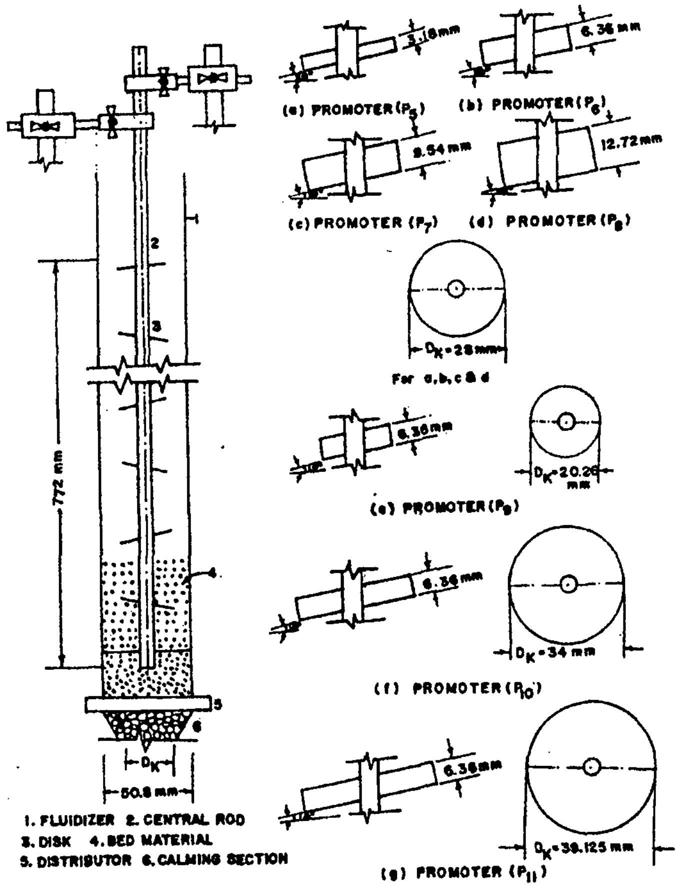

Figure 3 Details of disk promoters

distributor used. Swain, *et al*[28] used distributors having three mm dia orifices distributed in two zones, namely, the annular and the central with equal open area which varied from 2.28 per cent to 6.36 per cent of the column section and proposed the following correlation for bed fluctuation ratio

$$r = 3.136\left(\frac{G_f}{G_{mf}}\right)^{0.60}\left(\frac{h_s}{D_c}\right)^{-0.35}\left(\frac{d_p}{D_c}\right)^{-0.43}\left(\frac{A_{do}}{A_c}\right)^{0.24} \times \left(\frac{A_A}{A_c}\right)^{-0.11}\left(\frac{\rho_s}{\rho_f}\right)^{-0.23} \quad (5)$$

Although considerable studies have been reported on bed dynamics (namely, improvement obtained in the homogeneity of the fluidized bed, bubble phenomena, particle motion, fluid-solid mixing, pressure drop, minimum fluidization velocity of promoted bed supported by different types of distributors), limited information is available on the improvement of fluidization quality in terms of fluctuation ratio for such beds. Further, practically no study (except one by the present authors) has been reported on the combined effect of promoter and distributor in gas-solid fluidized beds.

In the present study, the combined effect of promoter and distributor on bed fluctuation has been investigated.

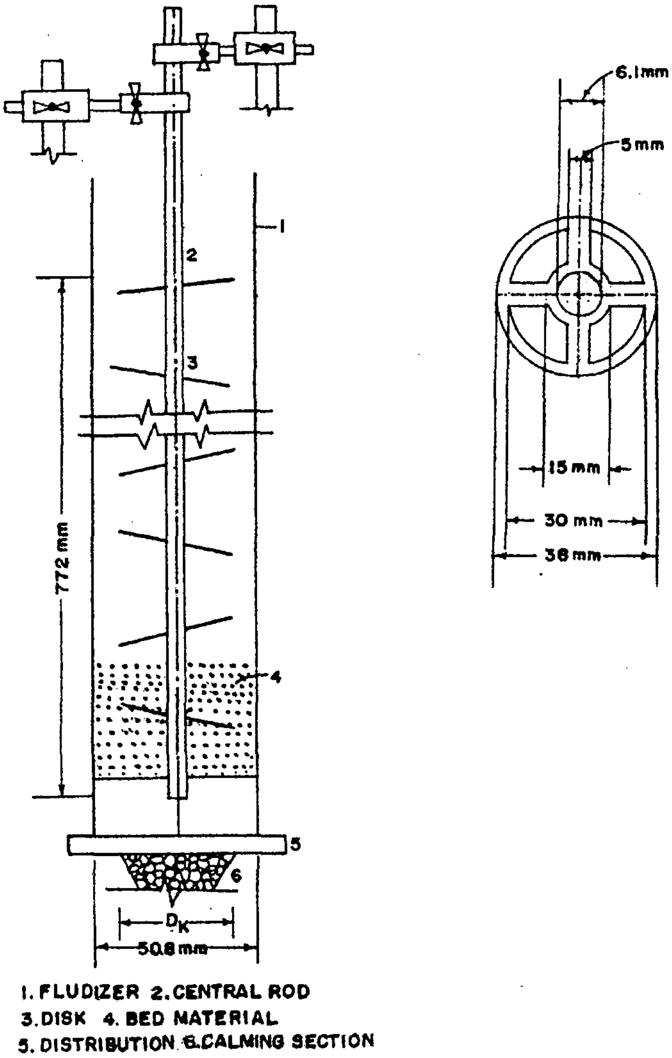

Figure 4 Details of blade promoters

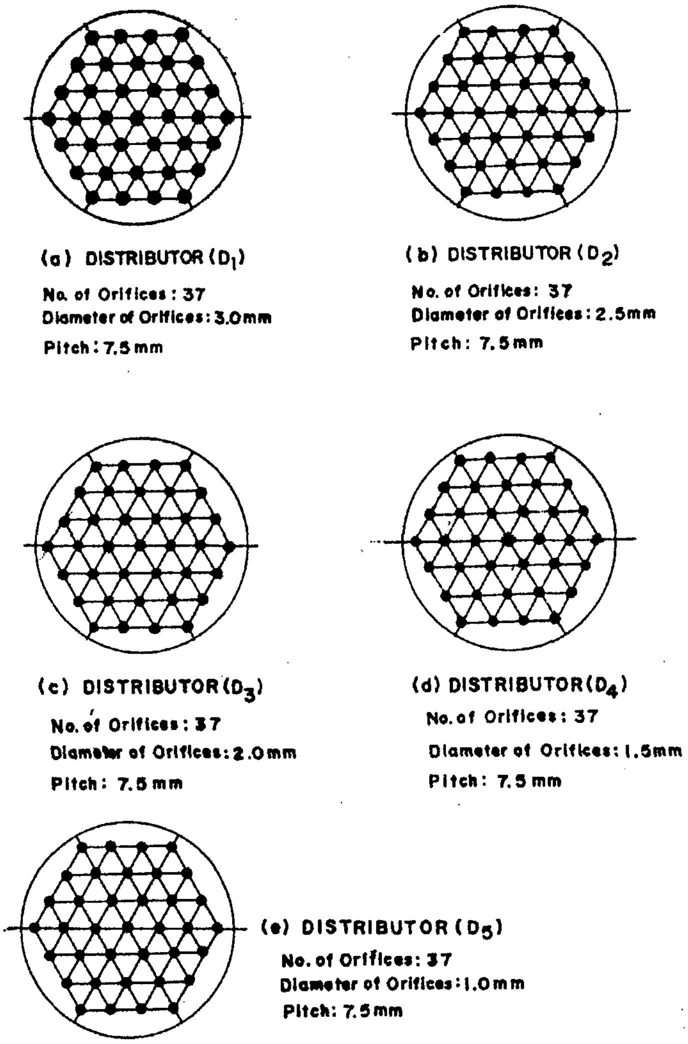

Figure 5 Details of distributors

EXPERIMENTATION

A schematic representation of the experimental set-up with details of the promoters is shown in Figure 1. Compressed air at 22°C has been used as the fluidizing medium. Four rod type promoters, seven disk type promoters and a blade type promoter have been used with five different distributors of varying open area. The disks of disk promoters have been fixed at an inclination of 10° with the horizontal alternatively in opposite directions to minimize the accumulation of bed material over the disks. The scope of the experiment is given in Table 1.

For a particular run, data for bed pressure drop and expansion with varying flowrate have been noted and the same have been repeated for different bed materials of varying particle size, initial bed height, promoters and distributors. The values of minimum fluidization velocity and terminal velocity used in the analysis have been obtained by using correlation developed by Kumar, *et al*[29], and Chattopadhyay[30], respectively.

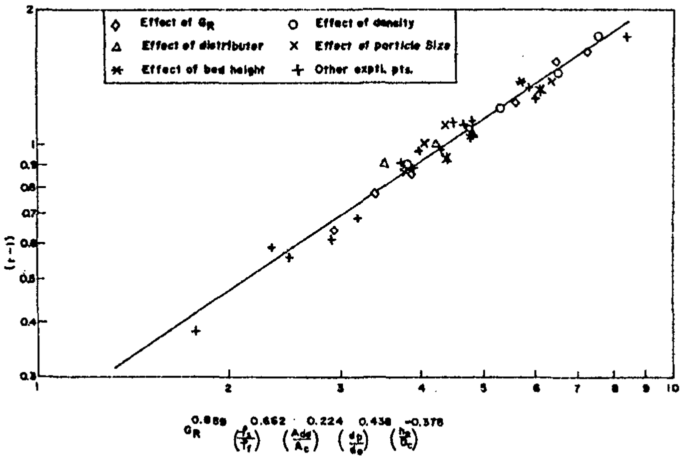

Figure 6 Variation of $(r - 1)$ with system parameters for unpromoted bed

DEVELOPMENT OF CORRELATION

The system variables like bed height, column dia, particle size and density, mass velocity of the fluidizing medium,

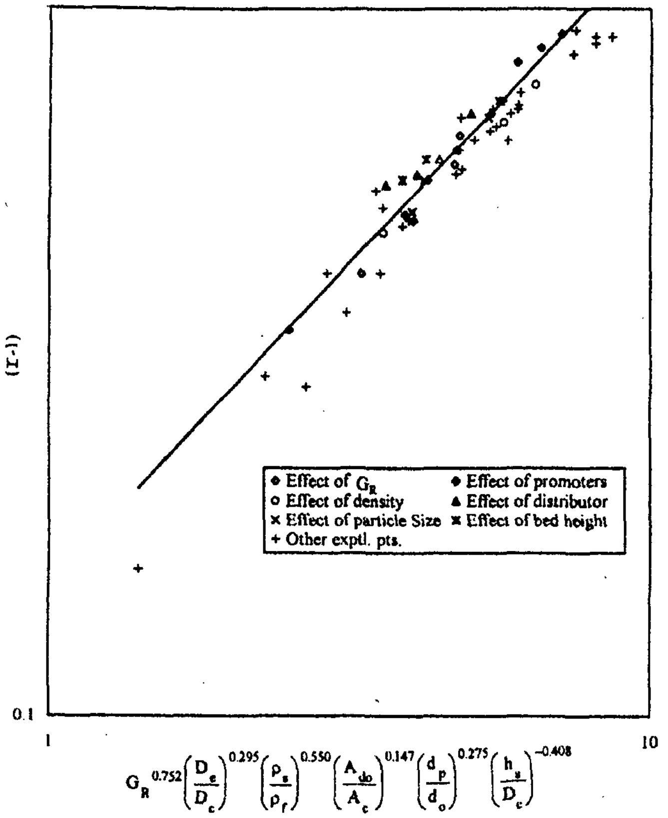

Figure 7 Variation of $(r-1)$ with system parameters for bed with rod promoters

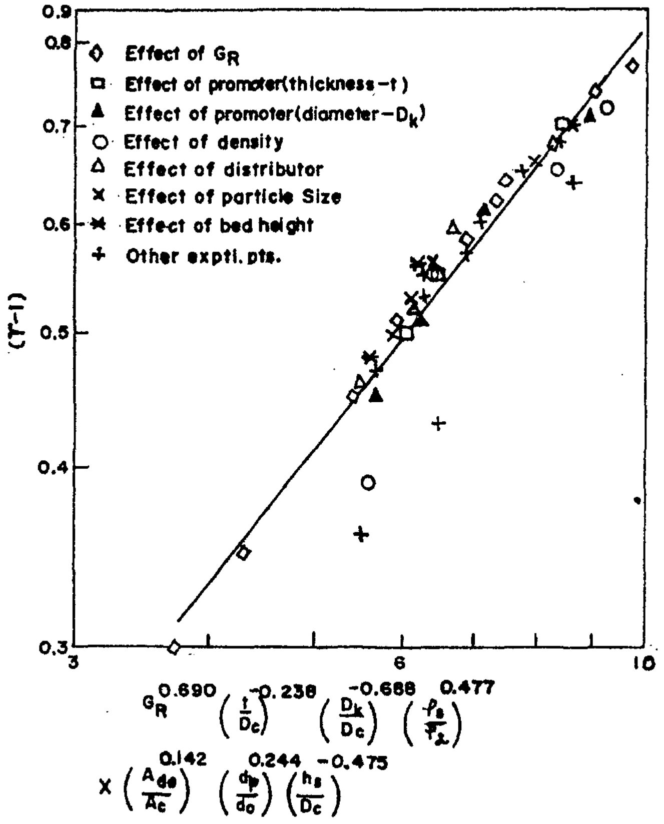

Figure 8 Variation of $(r-1)$ with system parameters for bed with disk promoter

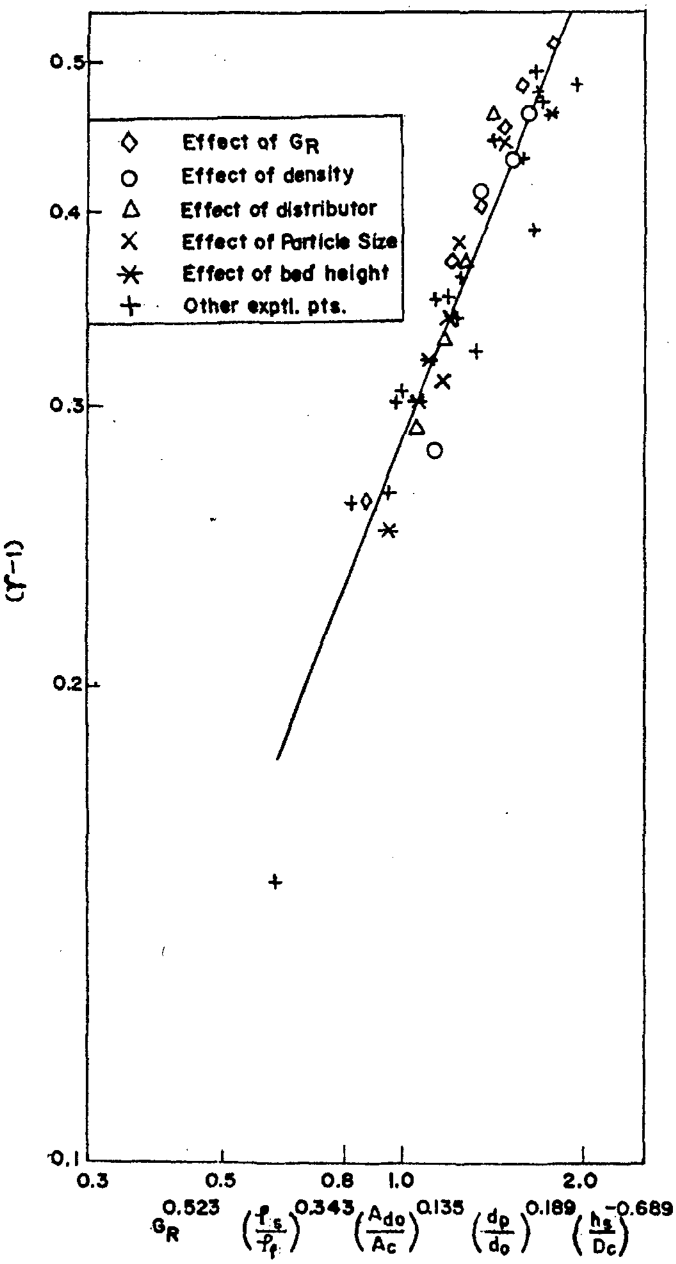

Figure 9 Variation of $(r-1)$ with system parameters for bed with blade type of promoter

distributor open area, disk thickness and dia of disk promoter and equivalent dia for rod promoter influencing the bed fluctuation have been grouped into following non-dimensional parameters.

Flow parameter (G_R)	:	$(G_f - G_{mf})/(G_t - G_{mf})$
Bed parameters	:	h_s/D_c, d_p/d_o, ρ_s/ρ_f
Distributor parameter	:	A_{do}/A_c
Rod promoter parameter	:	D_e/D_c
Disk promoter parameter	:	t/D_c, D_k/D_c
Blade promoter	:	t/D_c, D_k/D_c

Analyzing the experimental data for the effect of individual dimensionless group, the final correlation (Figures 2-5) have

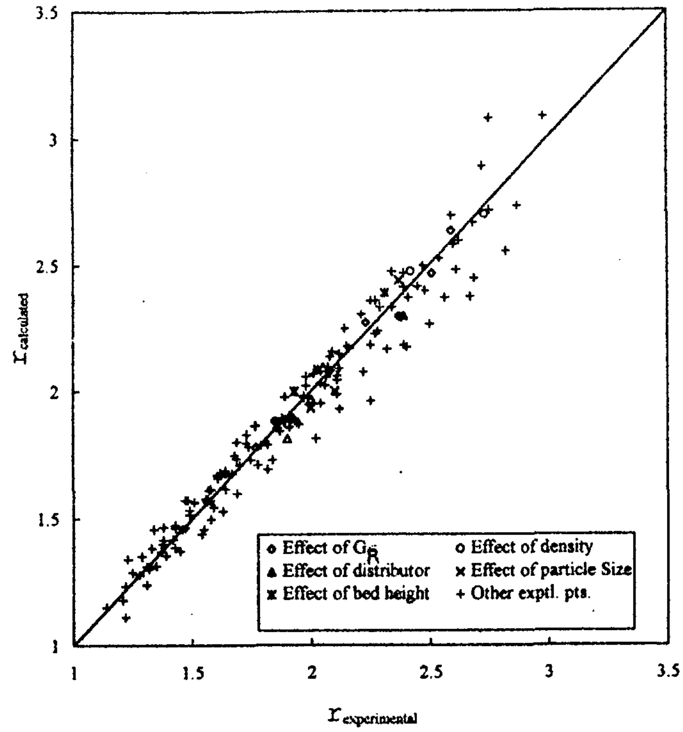

Figure 10 Comparison between experimental and calculated values of bed fluctuation ratio for unpromoted bed

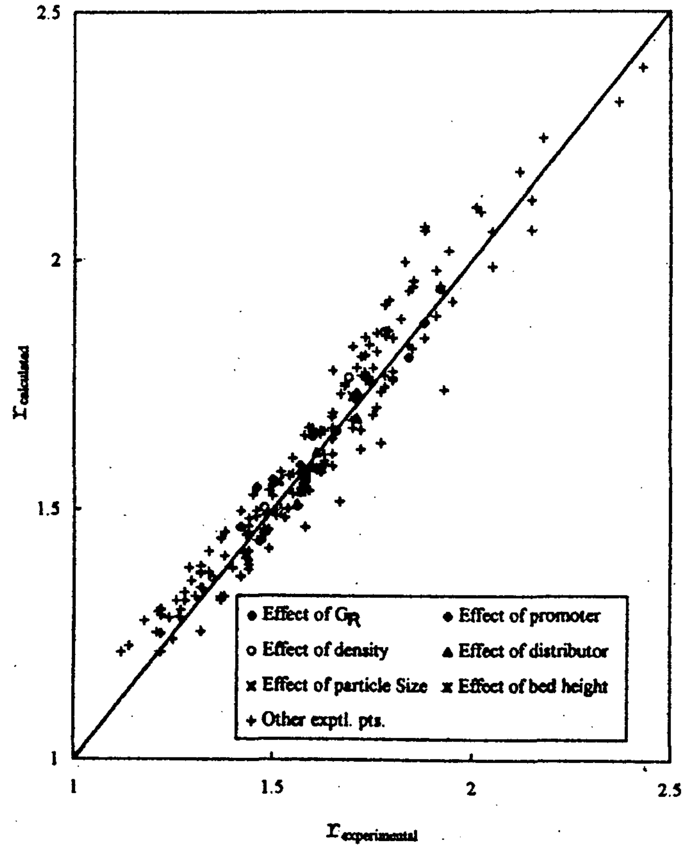

Figure 11 Comparison between experimental and calculated values of bed fluctuation ratio for bed with rod promoter

been obtained as under

$$(r-1) = 0.24 G_R^{0.85} \left(\frac{\rho_s}{\rho_f}\right)^{0.63} \left(\frac{A_{do}}{A_c}\right)^{0.21} \left(\frac{d_p}{d_o}\right)^{0.41} \left(\frac{h_s}{D_c}\right)^{-0.36} \quad (6)$$

for unpromoted bed

$$(r-1) = 0.16 G_R^{0.69} \left(\frac{\rho_s}{\rho_f}\right)^{0.50} \left(\frac{A_{do}}{A_c}\right)^{0.13} \left(\frac{d_p}{d_o}\right)^{0.25} \left(\frac{h_s}{D_c}\right)^{-0.38} \left(\frac{D_e}{D_c}\right)^{0.27} \quad (7)$$

for bed with rod promoter

$$(r-1) = 0.09 G_R^{0.67} \left(\frac{\rho_s}{\rho_f}\right)^{0.46} \left(\frac{A_{do}}{A_c}\right)^{0.14} \left(\frac{d_p}{d_o}\right)^{0.24} \left(\frac{h_s}{D_c}\right)^{-0.46} \left(\frac{t}{D_c}\right)^{-0.23} \left(\frac{D_k}{D_c}\right)^{-0.67} \quad (8)$$

for bed with disk promoter

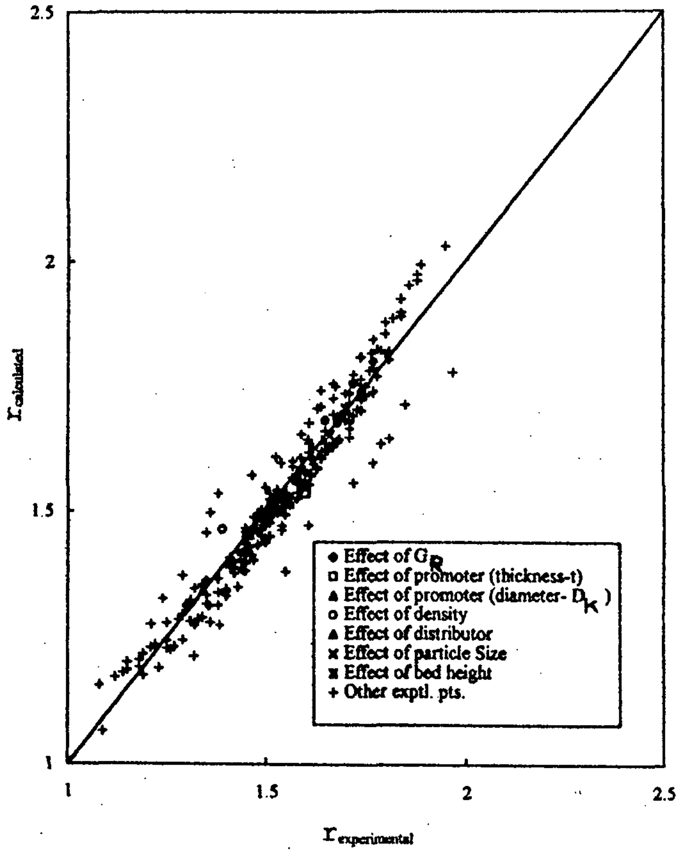

Figure 12 Comparison between experimental and calculated values of bed fluctuation ratio for bed with disk promoter

$$(r-1)=0.29G_R^{0.51}\left(\frac{\rho_s}{\rho_f}\right)^{0.33}\left(\frac{A_{do}}{A_c}\right)^{0.13}\left(\frac{d_p}{d_o}\right)^{0.18}\left(\frac{h_s}{D_c}\right)^{-0.67} \quad (9)$$

for bed with blade promoter

DISCUSSION

It is evident from the developed correlations that the bed fluctuation is significantly influenced by the distributor and promoter parameters in addition to other system parameters, It has also been observed that bed fluctuation decreases significantly with the increase of the blockage area of rod or disk promoters. The comparison of the bed fluctuation ratio for unpromoted beds and beds with rod, disk and blade type promoters shows that all the types of promoters used in the investigation are quite effective in reducing the bed fluctuation over the unpromoted ones for almost the complete regime of fluidization except near the neighbourhood of minimum fluidization condition (that is, $G_R \leqslant 0.015$) where the bed dynamics appears to be not fully stabilized. The reduction in bed fluctuation can be attributed to the breaking up of bubbles and controlling their size and growth. Further, it has been observed that the disk and blade type of promoters are more effective (with blade type being better in performance) in reducing bed fluctuation over the unpromoted and the promoted one with rod type of promoter (Figure 6). This may be attributed to the transverse elements which facilitate smooth fluidization with negligible channelling and slugging as compared to unpromoted bed and bed with rod type promoters.

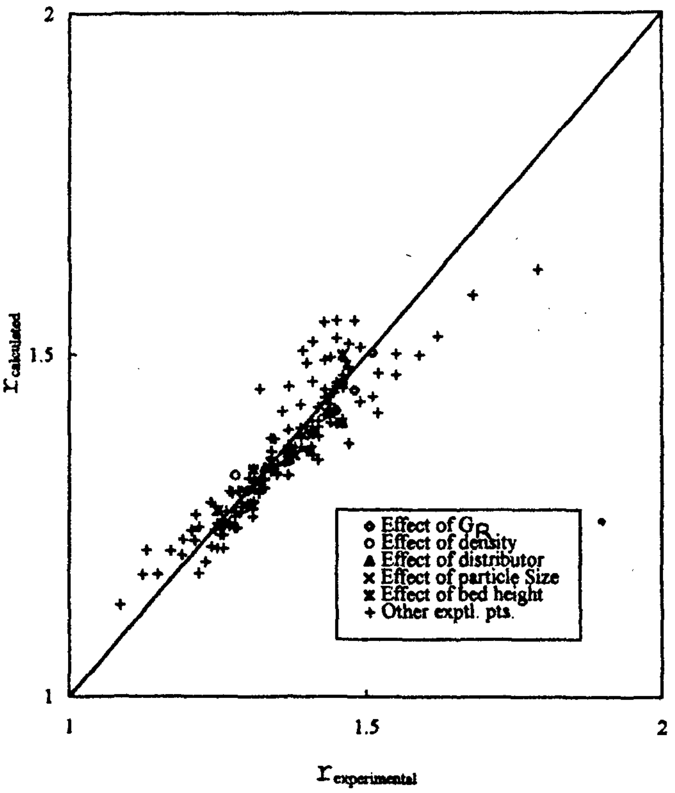

Figure 13 Comparison between experimental and calculated values of bed fluctuation ratio for bed with blade type of promoter

On the other hand, decrease in distributor open area results in the reduction of bed fluctuation. This may be attributed to the formation of small length spouts (at the origin) in case of smaller dia orifices rather than long channels in the bed with distributors of larger diameter orifices.

CONCLUSION

The values of bed fluctuation ratio calculated with the help of developed correlations [equations (6)-(9)] for unpromoted bed and beds with rod, disk and blade type of promoters have been compared with the corresponding experimental ones in Figures 7-10 and found to be in good agreement. The mean and standard deviation of the experimental values from the calculated ones for bed fluctuation ratio in case of unpromoted and promoted beds with rod, disk and blade promoters have been given in the respective Figures 7-10.

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