Effect of Different Types of Promoters on Bed Expansion in a Gas-Solid Fluidized Bed with Varying Distributor Open Areas

AWADHESH KUMAR[1] AND GOPENDRA K. ROY[2]
[1]*Department of Applied Mechanics and Hydraulics, Regional Engineering College, Rourkela-769 008, India*
[2]*Principal, Regional Engineering College, Rourkela-769 008, India*

Keywords**:** Gas-Solid, Fluidization, Promoter, Distributor, Expansion Ratio

Experiments were carried out extensively to study the effectiveness of promoters in reducing bed expansion in gas-solid fluidized beds with distributors of varying open areas. Four types of rod promoters, seven types of disk promoters along with one blade promoter were used in beds supported respectively on five distributors with open areas of 12.9, 8.96, 5.74, 3.23 and 1.43% of the column section. Four correlations for bed expansion ratio were developed respectively for the unpromoted and the promoted beds with rod, disk and blade type promoters.

The values of bed expansion ratio obtained from the developed correlations agreed fairly well with the experimental values.

Introduction

The use of a suitable promoter and proper gas distributor can improve fluidization quality by minimizing slugging and reducing the size of bubbles and their growth. This results in ultimate reduction of the height of the expanded bed to a considerable extent, thereby limiting the size of the equipment. Balakrishanan and Rao (1975) studied the effect of horizontal screen disk baffled fluidized beds on pressure drop and minimum fluidizing velocity. Krishnamurthy *et al.* (1981) studied the effect of horizontal baffles on the quality of fluidization. Stirrer type baffles were used by Agarwal and Roy (1987), co-axial rod and co-axial disk type promoters by Kar and Roy (2000) for their studies on fluidization quality.

Ghosh and Saha (1987) showed that the quality of bubble formation is strongly influenced by the type of the gas distributor used. Swain *et al.*(1996) used distributors having 3 mm diameter orifices distributed in two zones, viz. the annular and the central with equal open area which varied from 2.28 to 6.36% of the column sectional area.

In the present study the combined effect of the promoter and the distributor on bed expansion was investigated.

Received on November 19, 2001. Correspondence concerning this article should be addressed to G. K. Roy (E-mail address: gkroy@rec.ren.nic.in).

1. Experimental

A schematic diagram of the set up with details is presented in **Fig. 1**. Compressed air was used as the fluidizing medium. Four rod type promoters, seven disk type promoters and one blade type promoter with five different distributors of varying open areas were used in the experiment. The promoters were placed centrally at 1.0 cm above the distributor level to facilitate the functioning of all the orifices. To minimize the accumulation of bed material over the disks, these have been fixed at an inclination of 10° with the horizontal alternatively in the opposite direction. The details of rod, disk and blade type promoters are shown in **Figs. 2**(**A**)–(**C**). The scope of the experiment is given in **Table 1**.

For a particular run, data for bed pressure drop and expansion with varying flow rate was noted. Two scales attached on the opposite sides of the fluidizer were used to measure the bed height (average value). The procedure was repeated for all the system variables (Table 1). The values of minimum fluidization and terminal velocities used in the analysis were obtained from the correlation developed by Kumar *et al.* (2000) and the empirical equation given by Chattopadhyay (1993) respectively.

2. Development of Correlations

Bed expansion ratio is a function of static and dynamic properties of the fluidized bed. The relation can be expressed as functions of dimensionless groups

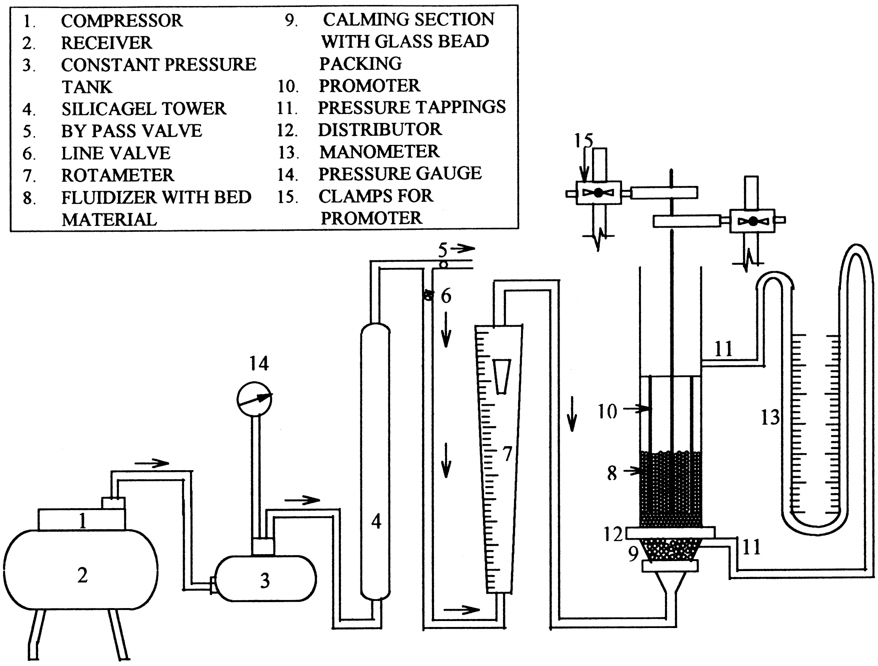

Fig. 1 Experimental setup

containing bed, distributor and promoter parameters and the properties of the fluidized particles and the medium as:

$$(R-1)=\phi\left(G_{\mathrm{R}},\frac{\rho_{\mathrm{s}}}{\rho_{\mathrm{f}}},\frac{A_{\mathrm{do}}}{A_{\mathrm{c}}},\frac{d_{\mathrm{p}}}{d_{\mathrm{o}}},\frac{h_{\mathrm{s}}}{D_{\mathrm{c}}},\frac{D_{\mathrm{e}}}{D_{\mathrm{c}}},\frac{t}{D_{\mathrm{c}}},\frac{D_{\mathrm{k}}}{D_{\mathrm{c}}}\right) \quad (1)$$

or,

$$(R-1) = KG_{\mathrm{R}}{}^{\mathrm{a}}\left(\frac{\rho_{\mathrm{s}}}{\rho_{\mathrm{f}}}\right)^{\mathrm{b}}\left(\frac{A_{\mathrm{do}}}{A_{\mathrm{c}}}\right)^{\mathrm{c}}\left(\frac{d_{\mathrm{p}}}{d_{\mathrm{o}}}\right)^{\mathrm{d}}\left(\frac{h_{\mathrm{s}}}{D_{\mathrm{c}}}\right)^{\mathrm{e}}\left(\frac{D_{\mathrm{e}}}{D_{\mathrm{c}}}\right)^{\mathrm{f}}\left(\frac{t}{D_{\mathrm{c}}}\right)^{\mathrm{g}}\left(\frac{D_{\mathrm{k}}}{D_{\mathrm{c}}}\right)^{\mathrm{h}} \quad (2)$$

Analyzing the experimental data for the effect of the individual dimensionless group, the values of constants and the exponents obtained by the regression analysis of the data for the respective beds are presented in **Table 2**. One typical correlation plot for the bed with a rod promoter is shown in **Fig. 3**.

3. Results and Discussion

The values of the bed expansion ratio calculated with the help of the developed correlation of Eq. (2) and Table 2 for unpromoted and promoted beds were compared with the corresponding experimental ones and found to be in good agreement. The mean and standard deviation of the experimental values from the calculated ones for the bed expansion ratio in the case

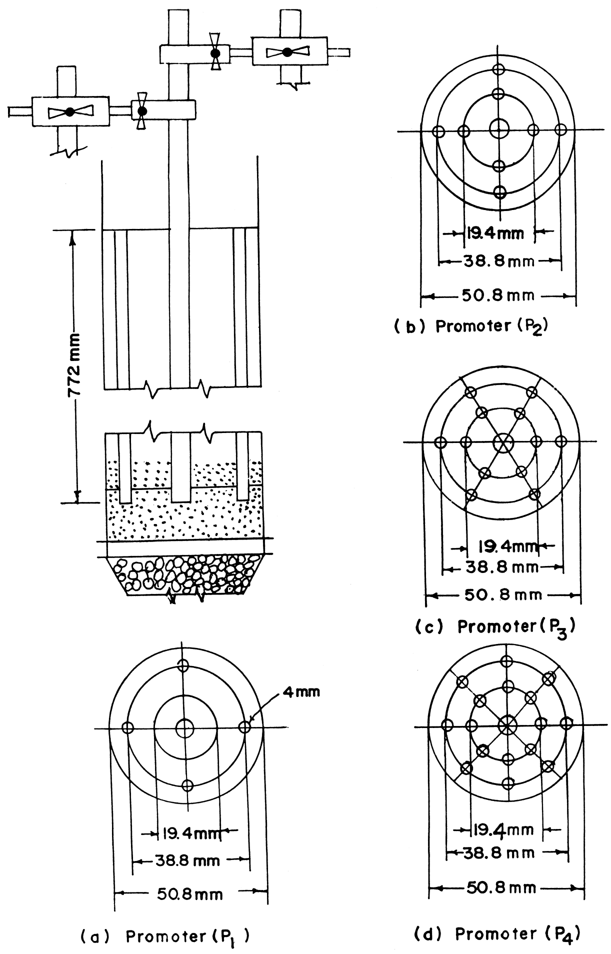

Fig. 2(A) Details of rod promoters

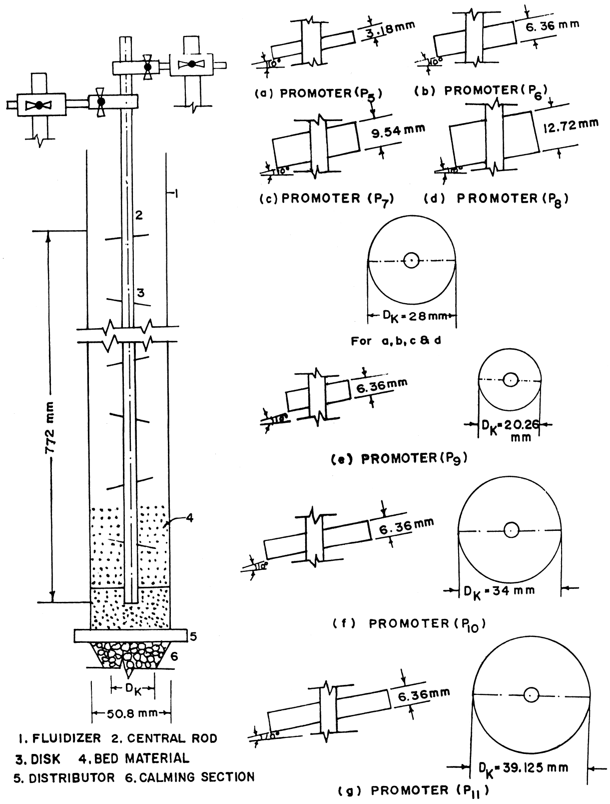

Fig. 2(B) Details of disk promoters

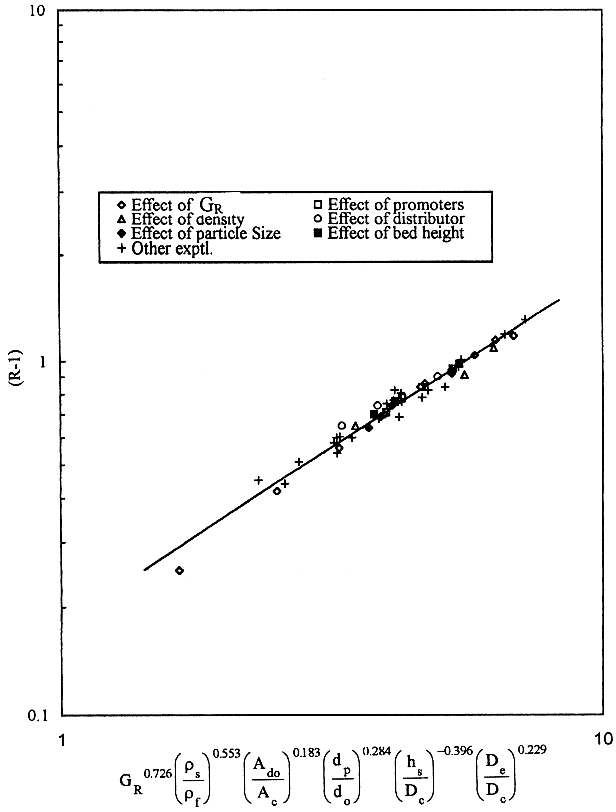

Fig. 3 Variation of $(R - 1)$ with system parameters for the bed with a rod promoter

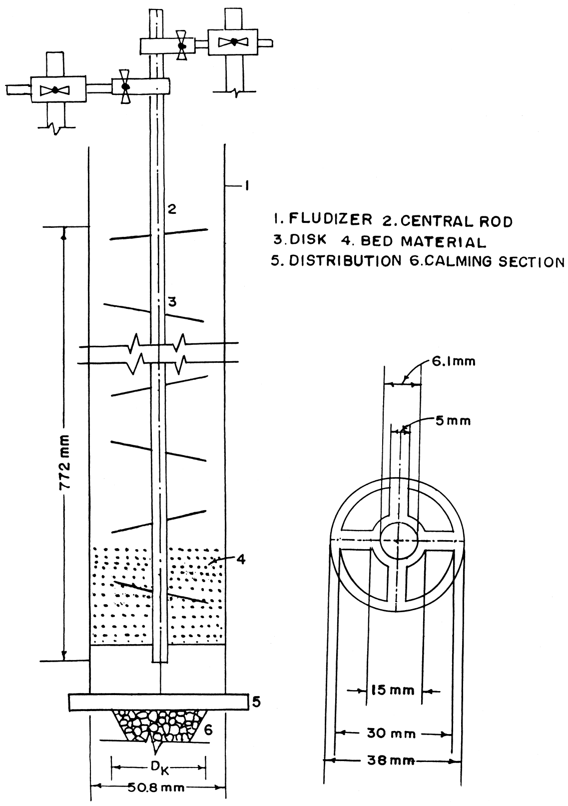

Fig. 2(C) Details of blade type promoters

of unpromoted and promoted beds with a rod, disk and blade promoters were found respectively as (3.61, 4.53), (3.00, 3.85), (1.89, 2.48) and (3.63, 4.48). As observed the reduction in bed expansion in the case of the promoted beds over the unpromoted beds can be attributed to the breaking up of bubbles and controlling their size and growth. The radial promoter elements facilitate smooth fluidization with negligible channelling and slugging compared to the unpromoted beds and the beds with rod type promoters. The reduction of bed expansion with the increase in blockage volume by the promoters in terms of larger number of rods for the case of the rod promoter and the increase in disk diameter/thickness for the disk promoter is due to the increase in the effectiveness of the promoter elements in breaking bubbles and minimizing slugging (**Table 3**, Sl. nos. 15–17, column nos. 5 and 8 for the rod promoter and Sl. nos. 15–20, column nos. 6 and 9 for the disk promoter).

Further, the reduction of bed expansion with the decrease of the distributor open area may be due to the formation of bubbles of smaller sizes generated from orifices of smaller diameter (no. of orifices are the same for all the distriburors) and better distriburion of the fluidizing medium.

Table 1 Scope of the experiment

(a) Properties of bed material

Materials	$d_p \times 10^3$ [m]	$\rho_s \times 10^3$ [kg·m^{-3}]	G_{mf} [kg·m^{-2}·h^{-1}]	G_t [kg·m^2·h^{-1}]
Dolomite	1.125	2.82	2748	26914
Dolomite	0.725	2.82	1686	23002
Dolomite	0.463	2.82	884	18243
Dolomite	0.390	2.82	686	16489
Dolomite	0.328	2.82	521	14645
Alum	0.725	1.69	853	16195
Iron-Ore	0.725	3.90	1898	25717
Mangnese-Ore	0.725	4.88	2611	30028

(b) Bed parameter

Initial static bed height, $h_s \times 10^2$ [m]	8, 12, 16, 20

(c) Distributor parameters

Distributor	Number of orifice	Diameter of orifice, d_o [mm]	Pitch of orifices [mm]
D_1	37	3.00	7.5
D_2	37	2.50	7.5
D_3	37	2.00	7.5
D_4	37	1.50	7.5
D_5	37	1.00	7.5

(d) Promoter details

Promoter specification		$D_k \times 10^3$ [m]	$t \times 10^3$ [m]	No. of 4-mm-dia. longitudinal rods
Rod	P1	—	—	4
	P2	—	—	8
	P3	—	—	12
	P4	—	—	16
Disk	P5	28.00	3.18	—
	P6	28.00	6.36	—
	P7	28.00	9.54	—
	P8	28.00	12.72	—
	P9	20.26	6.36	—
	P10	34.00	6.36	—
	P11	39.13	6.36	—
Blade	P12	38.00	6.36	—

(e) Flow properties

Maximum [kg·hr^{-1}·m^{-2}]	Minimum [kg·hr^{-1}·m^{-2}]
5500	200

Table 2 Values of constants and exponents for different beds

Bed Particulars	Constant K	Exponents a	b	c	d	e	f	g	h
UP	0.37	0.85	0.59	0.20	0.41	−0.32	—	—	—
RP	0.18	0.74	0.56	0.19	0.29	−0.40	0.23	—	—
DP	0.08	0.75	0.56	0.19	0.26	−0.47	—	−0.24	−0.48
BP	0.24	0.73	0.51	0.17	0.22	—	—	—	—

UP = unpromoted bed; RP = bed with a rod promoter; DP = bed with a disk promoter; BP = bed with a blade type promoter

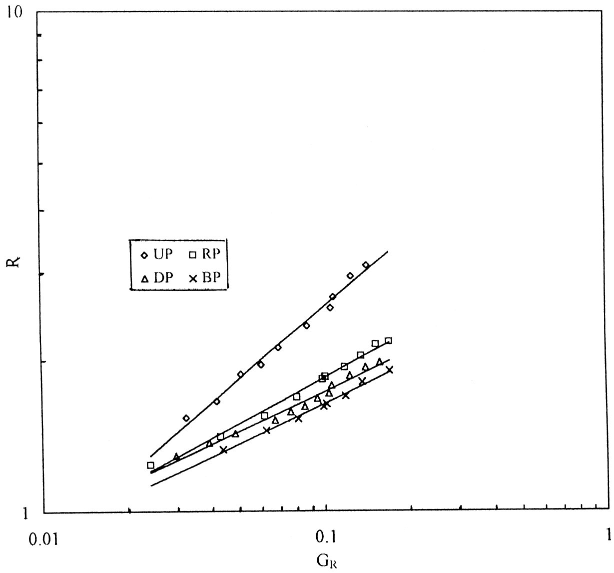

Fig. 4 Variation of R with G_R for different beds

Conclusions

For identical operating parameters, the bed expansion increases with an increase in gas velocity (**Fig. 4**). In addition, the bed expansion is significantly influenced by the distributor and promoter parameters and other system variables (Table 3). The comparison of the calculated results (Table 3) for the bed expansion ratio for the unpromoted beds and beds with rod, disk and blade promoters shows that all types of promoters used in the investigation are quite effective in reducing the bed expansion over the unpromoted ones. Further, it was observed that the disk and blade type promoters are more effective (with blade type being better in performance) in reducing bed expansion when compared with beds having rod type promoters and the unpromoted ones. Also, the decrease of the distributor open area results in the reduction of bed expansion. The reduction in bed expansion for both the above parameters, viz. the promoters and the distributors are evident for almost the complete regime of fluidization except in the neighbourhood of the minimum fluidization condition (i.e. $G_R \leq 0.015$) where the bed dynamics was not fully stabilized.

Thus, the combined effect of an appropriate promoter and a distributor with a decreased open area will result in better quality gas-solid fluidization with reduced bubble formation and slugging, and thereby limiting the size of the bed with appreciable reduction of total dis-engaging height (TDH).

Nomenclature

a, b, c, d, e, f, g, h	=	exponents	[—]
A_c	=	area of the column	[m^2]
A_{do}	=	open area of the distributor	[m^2]
A_o	=	open area in the promoted bed with rod promoters	[m^2]
D_c	=	column diameter	[m]
D_e	=	$4A_o/P$, equivalent diameter of the promoter	[m]
D_k	=	disk diameter	[m]
d_o	=	orifice diameter	[m]
d_p	=	particle size	[m]
G_f	=	fluidization mass velocity	[kg·m^{-2}·h^{-1}]
G_{mf}	=	minimum fluidization mass velocity in promoted beds	[kg·m^{-2}·h^{-1}]
G_R	=	$(G_f - G_{mf})/(G_t - G_{mf})$, mass velocity ratio	[—]
G_t	=	terminal mass velocity	[kg·m^{-2}·h^{-1}]
h_{av}	=	average bed height	[m]
h_{max}	=	maximum height of the fluidized bed	[m]
h_{min}	=	minimum height of the fluidized bed	[m]
h_s	=	initial static bed height	[m]
K	=	constant	[—]
P	=	total rod perimeter	[m]
R	=	h_{av}/h_s, bed expansion ratio	[—]
t	=	disk thickness	[m]
ϕ	=	function	[—]
ρ_f	=	density of fluid	[kg·m^{-3}]
ρ_s	=	density of solid	[kg·m^{-3}]

Literature Cited

Agarwal, S. K. and G. K. Roy; "A Qualitative Study of Fluidization Quality in Baffled and Conical Gas-Solid Fluidized Bed," *J. Instn. Engrs. India*, **68**, 35–38 (1987)

Balakrishnan, D. and M. Raja Rao; "Pressure Drop and Minimum Fluidizing Velocity in Baffled Fluidized Beds," *Indian Journal of Technology*, **13**, 199–204 (1975)

Chattopadhyay, P.; Unit Operations of Chemical Engineering, I, p. 469, Khanna Publisher, Delhi, India (1993)

Ghosh, A. and R. K., Saha; " Multiorifice Distributor Plates in a Gas-Solid Fluidized Bed," *Indian Chem. Engr.*, **29**, 50–53 (1987)

Kar, S. and G. K., Roy; "Effect of Co-Axial Rod Promoters on the

Table 3 Comparison between calculated values of the bed expansion ratio for the unpromoted bed and beds with rod, disk and blade type promoters

Serial No.	Variables		Predicted values of bed Expansion ratio, R				% reduction in R over corresponding unpromoted bed		
			UP	RP	DP	BP	RP	DP	BP
			Constants: $G_R = 0.1$, $A_{do}/A_c = 0.09$, $d_p/d_o = 0.29$, $h_s/D_c = 2.36$, $D_e/D_c = 1.248$, $t/D_c = 0.125$, $D_k/D_c = 0.551$						
	ρ_s/ρ_f								
1	1409.17		2.07	1.63	1.55	1.50	21.21	24.73	27.55
2	3245.83		2.74	2.00	1.88	1.76	27.06	31.29	35.85
3	4066.67		2.99	2.14	2.00	1.85	28.60	33.00	38.07
			Constants: $G_R = 0.1$, $\rho_s/\rho_f = 2347.5$, $d_p/d_o = 0.29$, $h_s/D_c = 2.36$ $D_e/D_c = 1.248$, $t/D_c = 0.125$, $D_k/D_c = 0.551$						
	A_{do}/A_c								
4	0.13		2.55	1.89	1.79	1.68	25.65	29.72	33.86
5	0.06		2.31	1.77	1.68	1.60	23.71	27.54	31.03
6	0.03		2.17	1.69	1.61	1.54	22.33	26.00	29.05
7	0.01		1.99	1.59	1.52	1.47	20.38	23.79	26.25
			Constants: $G_R = 0.1$, $\rho_s/\rho_f = 2347.5$, $A_{do}/A_c = 0.09$, $h_s/D_c = 2.36$, $D_e/D_c = 1.248$, $t/D_c = 0.125$, $D_k/D_c = 0.551$						
	d_p/d_o								
8	0.450		2.72	1.95	1.83	1.71	28.48	32.91	37.25
9	0.185		2.20	1.73	1.66	1.58	21.14	24.61	27.94
10	0.156		2.12	1.70	1.63	1.56	19.80	23.08	26.21
11	0.131		2.04	1.66	1.56	1.54	18.46	21.53	24.45
			Constants: $G_R = 0.1$, $\rho_s/\rho_f = 2347.5$, $A_{do}/A_c = 0.09$, $d_p/d_o = 0.29$, $D_e/D_c = 1.248$, $t/D_c = 0.125$, $D_k/D_c = 0.551$						
	h_s/D_c								
12	1.58		2.64	1.98	1.89	1.86	24.91	28.28	29.61
13	3.15		2.31	1.74	1.64	1.52	24.60	28.90	34.07
14	3.94		2.22	1.68	1.58	1.45	24.39	28.89	34.85
			Constants: $G_R = 0.1$, $\rho_s/\rho_f = 2347.5$, $A_{do}/A_c = 0.09$, $d_p/d_o = 0.29$, $h_s/D_c = 2.36$, $D_k/D_c = 0.551$						
	D_e/D_c	t/D_c							
15	2.209	0.063	2.44	1.95	1.87	—	19.99	23.29	—
16	0.856	0.188	2.44	1.77	1.67	—	27.64	31.56	—
17	0.642	0.250	2.44	1.72	1.62	—	29.64	33.39	—
			Constants: $G_R = 0.1$, $\rho_s/\rho_f = 2347.5$, $A_{do}/A_c = 0.09$, $d_p/d_o = 0.29$, $h_s/D_c = 2.36$, $t/D_c = 0.125$						
	D_e/D_c	D_k/D_c							
18	2.209	0.398	2.44	1.95	1.86	—	19.99	23.63	—
19	0.856	0.669	2.44	1.77	1.67	—	27.64	31.45	—
20	0.642	0.770	2.44	1.71	1.63	—	29.64	33.25	—

Dynamics of a Batch Gas-Solid Fluidized Bed," *Indian Chem. Engr. section A*, **42**, 170–174 (2000)

Krishnamurthy, S., J. S. N. Murthy, G. K. Roy and V. S. Pakala; "Gas-Solid Fluidization in Baffled Beds," *J. Instn. Engrs. India*, **61**, 38–43 (1981)

Kumar, A., P. C. Patnaik and G. K. Roy; "Prediction of Minimum Fluidization Velocity in a Promoted Gas-Solid Fluidized Bed," Proc. of the Indian Chemical Engg. Congress, Vol. 1, TP51–TP54 (2000)

Swain, P., P. K. Nayak and G. K. Roy; "Effect of Distributor Parameters on the Quality of Fluidization," *Indian Chem. Engr.*, **38**, 39–42 (1996)