SHORT COMMUNICATION

Minimum Fluidization Velocity in Gas-Solid Fluidized Beds with Co-axial Rod and Disk Promoters

A. Kumar
Department of Applied Mechanics and Hydraulics
Regional Engineering College, Rourkela 769 008, Orissa

G.K.Roy*
Principal, Regional Engineering College,
Rourkela 769 008, Orissa

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Experiments have been conducted to study the effect of different types of turbulence promoters on minimum fluidization velocity in a gas-solid fluidized bed. Four number of rod promoters and seven number of disk promoters with different configuration and dimension have been used. Two different correlations relating minimum fluidization velocity with system and promoter parameters have been developed as under:

(i) Bed with rod promoters :

$$G'mf = \left[0.000829 + 0.0001\left(\frac{D_e}{D_c}\right)^{-0.48}\right]\left[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu\right]$$

and

(ii) Bed with disk promoters :

$$G'mf = \left[0.000829 + 3x10^{-5}\left(\frac{t}{D_c}\right)^{-0.88}\left(\frac{D_k}{D_c}\right)^{2.80}\right]\left[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu\right]$$

The predicted values of minimum fluidization mass velocity have been found to be in close agreement with the corresponding experimental ones. The experimental results show that the minimum fluidization mass velocity is influenced by the presence of a promoter, thus giving relatively higher values in a promoted bed as compared to the unpromoted ones for identical operating parameters.

Gas-solid fluidized beds have found extensive industrial applications due to easy handling of materials, rapid heat and mass transfer rate, thereby minimizing overheating in case of sensitive products, amenability to reliable control by automatic or manual methods, and rapid solid mixing leading nearly to isothermal conditions throughout the bed. In spite of the above mentioned advantages of gas-solid fluidized beds, their applications have been constrained due to certain inherent drawbacks, viz. channeling, bubbling and slugging, which not only reduce the transfer rate, thereby affecting the output of the system, but influence the fluidization quality to a considerable extent also. The formation of bubble and their growth causes erratic bed expansion with intense bed fluctuation.

Out of various techniques such as vibration and rotation of bed, use of improved distributor, different types of turbulence promoters, and application of non-cylindrical conduits in place of the columnar one, the use of suitable promoters has been found to be more effective in controlling fluidization quality as compared to other methods. The introduction of a turbulence promoter increases gas-solid contact with enhanced solid mixing, reduces the formation of bubbles and their growth and dampens the bed fluctuation. Kar and Roy [1] observed that for identical system parameters, fluctuation ratio decreases for both rod and disk type promoters when compared with unpromoted bed having lower values for the latter one. All of these improvements in fluidization parametes are related to minimum fluidization mass velocity. Balakrishnan and Rao [2], based on their studies on horizontal screen disk baffled air fluidized beds, have concluded that the use of promoter promotes fluidization quality by increasing minimum fluidizing mass velocity as compared to an unpromoted b d. Although considerable work [2-7] have been reported on the dynamic aspects of horizontal screen-provided beds, such as the improvements obtained in the homogeneity of fluidized bed, bed expansion, bubble phenomena, particle motion and fluid and solids mixing, limited work has been carried out to investigate the effect of promoters directly on minimum fluidizing mass velocity [2].

In the present work an attempt has been made to study the effect of rod and disk promoters directly on minimum fluidization mass velocity - an important parameter of fluidization quality.

Experimental

Fig.l represents the schematic diagram of the experimental setup. Compressed air at about 22°C has been used as the fluidizing medium. A GI plate of 1 mm

* Author to whom correspondence should be addressed

'thickness, having 37 nos. of 2.5 mm diameter holes placed in an equilateral triangular pitch of 7.5 mm, has been ,used as gas distributor. A mild steel wire mesh has been placed over the distributor to prevent entry of materials into the calming section. The detailed positioning and configuration of rod and disk promoters have been presented in Fig. 2 and Fig. 3. For a particular run, the bed pressure drop data with varying flowrate have been noted. The same has been repeated with varying particle size and density for promoted as well as unpromoted beds. The values of minimum fluidization mass velocity for every run have been obtained by using plot of pressure drop across the bed versus mass flow rate from each set of data. The scope of the experiment has been given in Table 1.

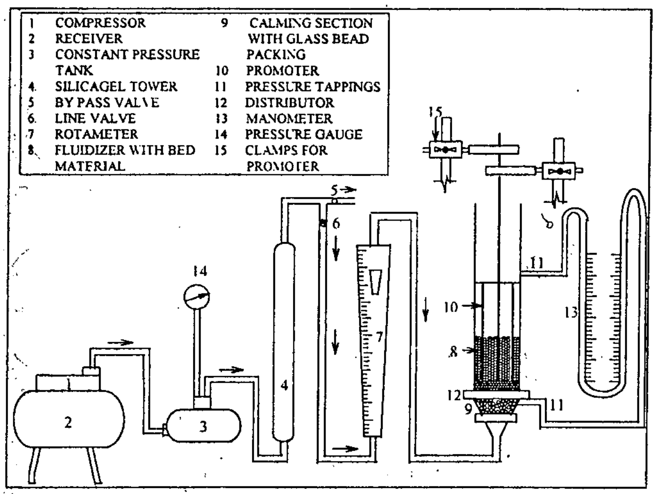

Fig. 1 : Experimental Setup

Development of Correlations

Based on drag force consideration, Davies and Richardson [8] and Pillar and Rao [9] developed the following expression for minimum fluidization mass velocity:

$$G_{mf} = Cd_p^2 \rho_f (\rho_s - \rho_f) g / \mu \qquad (1)$$

where the constant C depends on particle size, shape, orientation and density of the particle in the bed. Later equation (1) was modified by Balakrishnan and Rao [2] for a promoted bed. In a solid-fluid system, the increase in minimum fluidization mass velocity observed in a promoted bed can be attributed to the presence of promoters, and equation (1) can be modified (considering also sphericity factor) as :

$$G'_{mf} = C' \phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu \qquad (2)$$

The value of constant C depends on the promoter parameters in addition to particle and bed properties. From equation (1) and equation (2), minimum fluidization mass velocity in promoted beds over unpromoted ones can be expressed as :

Table 1: Scope of the Experiments

A Bed properties			
Materials	d_px10^3, m	ρ_s x10^{-3}, kg/m^3	ϕ_s
Dolomite	1.125	2.817	0.7679
Dolomite	0.725	2.817	0.6319
Dolomite	0.4625	2.817	0.8715
Dolomite	0.39	2.817	0.9108
Dolomite	0.3275	2.817	0.9452
Alum	0.725	1.691	0.7050
Iron-Ore	0.725	3.895	0.6929
Manganese-Ore	0.725	4.880	0.7261
B Rod promoter details			
Promoter	Specifications		
P_1	1 no. of ϕ 6.1 mm central rod and 4 nos. of ϕ 4 mm rods		
P_2	1 no. of ϕ 6.1 mm central rod and 8 nos. of ϕ 4 mm rods		
P_3	1 no, of ϕ 6.1 mm central rod and 12 nos, of ϕ 4 mm rods		
P_4	1 no. of ϕ 6.1 mm central rod and 16 nos. of ϕ 4 mm rods		
C Disk promoter details			
Promoter specification	D_kx10^3, m	tx10^3, m	Rod promoters of same blockage
P_5	28.000	3.18	P_1(4)*
P_6	28.000	6.36	P_2(8)*
P_7	28.000	9.54	P_3(12)*
P_8	28.000	12.72	P_4(16)*
P_9	20.260	6.36	P_1
P_{10}	34.000	6.36	P_3
P_{11}	39.125	6.36	P_4
D Properties of fluidizing medium		ρ_f kg/m^3	μ x10^7, Ns/m^2
Air at 22°C		1.2	181.9
E Flow properties			
Maximum, kg/hr-m^2		minimum, kg/hr-m^2	
5500		200	

* nos. of radial rods

$$G'_{mf} - G_{mf} = (C' - C)[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu] \qquad (3)$$

$$\text{Or, } C' - C = \frac{(G'_{mf} - G_{mf})}{[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu]} = \text{f(promoter parameters)} \qquad (4)$$

Equations (4) has been expressed in terms of present promoter parameter as under :

For beds with rod promoter :

$$C'-C = \frac{(G'_{mf} - G_{mf})}{[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu]} = f_1\left(\frac{D_e}{D_c}\right) = C_1\left(\frac{D_e}{D_c}\right)^{n_1} \quad (5)$$

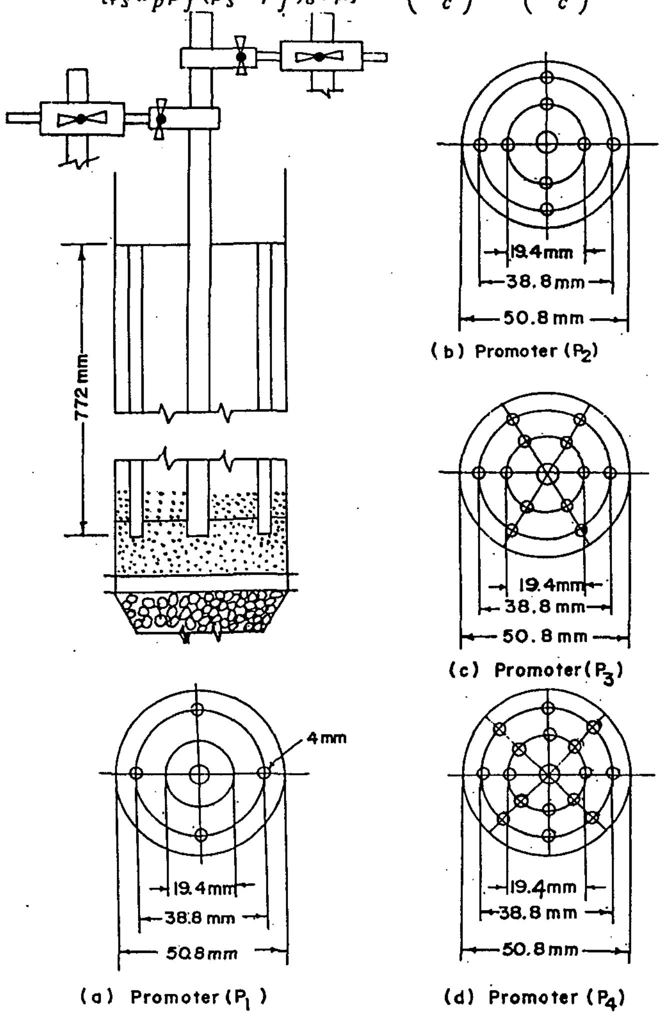

Fig. 2 : Details of Rod Promoters

And, for beds with disk promoters :

$$C'-C = \frac{(G'_{mf} - G_{mf})}{[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu]} = f_2\left(\frac{t}{D_c}, \frac{D_k}{D_c}\right)$$

$$= C_2\left[\left(\frac{t}{D_c}\right)^{n}\left(\frac{D_k}{D_c}\right)^{n_3}\right]^{n_4} \quad (6)$$

The exponents n_1, n_2, n_3, n_4 and constants C_1 and C_2 have been obtained from the $\frac{(G'_{mf} - G_{mf})}{[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu]}$ versus respective promoter parameters plots. Thus, the final correlations obtained as follows :

For bed with rod promoter

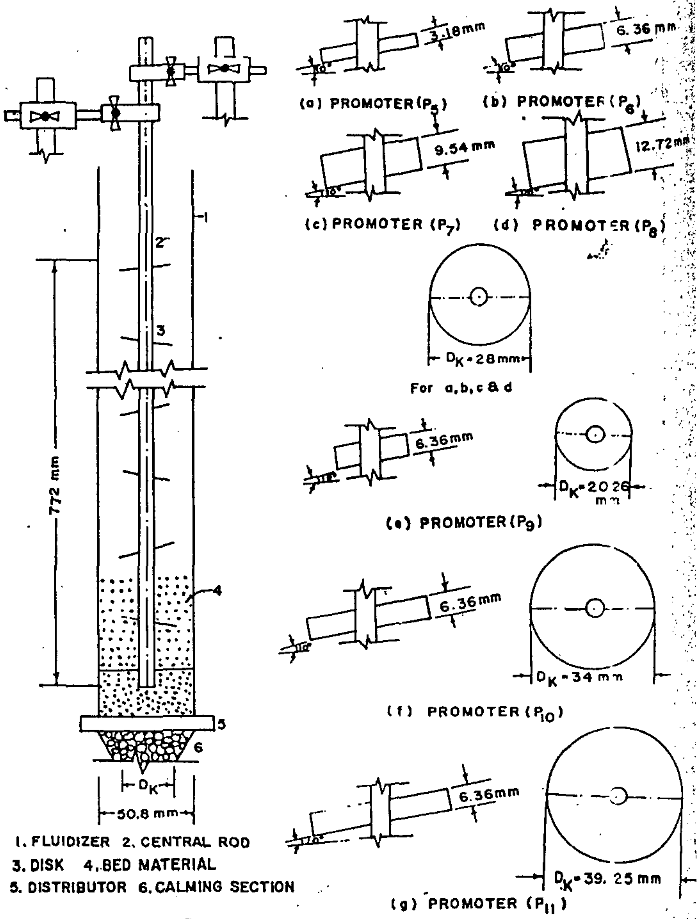

Fig. 3 : Details of Disk Promoters

$$\frac{\left(G'_{mf} - G_{mf}\right)}{\left[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu\right]} = (C' - C) = 0.0001\left(\frac{D_e}{D_c}\right)^{-0.48} \quad (7)$$

which on rearrangement gave

$$G'_{mf} = \left[C + 0.0001\left(\frac{D_e}{D_c}\right)^{-0.48}\right] x \left[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu\right] \quad (8)$$

For beds with disk promoter :

$$\frac{\left(G'_{mf} - G_{mf}\right)}{\left[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu\right]} = (C' - C)$$

$$= 3x10^{-5}\left(\frac{t}{D_c}\right)^{-0.88}\left(\frac{D_k}{D_c}\right)^{2.80} \quad (9)$$

and on rearrangement

$$G'_{mf} = \left[C + 3x10^{-5}\left(\frac{t}{D_c}\right)^{-0.88}\left(\frac{D_k}{D_c}\right)^{2.80}\right] x$$

$$\left[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu\right] \quad (10)$$

From the fluidization of unpromoted beds with varying particle size and density, the value of C has been found to vary from 0.000698 to 0.000983. An average value of C=0.000829 has been taken in the present work. Substituting for C in equation (8) and equation (10), the proposed final correlations for predicting minimum fluidization mass velocity become :

For beds with rod promoters:

$$G'_{mf} = \left[0.000829 + 0.0001\left(\frac{D_e}{D_c}\right)^{-0.48}\right]\left[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu\right] \quad (11)$$

and for beds with disk promoters :

$$G'_{mf} = \left[0.000829 + 3x10^{-5}\left(\frac{t}{D_c}\right)^{-0.88}\left(\frac{D_k}{D_c}\right)^{2.80}\right]$$

$$\left[\phi_s^2 d_p^2 \rho_f (\rho_s - \rho_f) g / \mu\right] \quad (12)$$

Results and Discussion

An average value of the constant, C=0.000829 obtained experimentally in unpromoted fluidized beds with different materials of varied sizes, has been comparable with the value 0.00078, 0.000701, and 0.000691 reported by Davies and Richardson [8], Pillai and Rao [9], and Balakrishnan and Rao [2] respectively. The reason for little higher value of C than those reported might be because of multiorifice distributor used in the study as against wire mesh distributor used by the earlier investigators. The variation of Δ p versus G_f plots (Figs. 4, 5 and 6) for different beds show the relative increase in G'mf over Gmf in unpromoted bed. The predicted values of G'mf in promoted bed with rod and disk promoters using the developed correlations have been found to agree fairly well with the respective experimental values.

The mean and the standard deviations in case of the promoted beds with rod and disk promoters have been obtained as 7.13 and 8.50 and 9.02 and 8.73 respectively.

Conclusion

The comparison of the experimental and predicted values of minimum fluidization mass velocities for promoted as well as unpromoted beds show that the minimum fluidization mass velocity is higher in promoted beds compared to conventional unpromoted ones. Also, it can be concluded that the minimum fluidization mass velocity in a promoted fluidized beds with rod type of promoters is higher than those in promoted fluidized beds with disk promoters for the same blockage area. A rod promoter can increase the minimum fluidization mass velocity upto a maximum of about 15% whereas disk promoters can enhance upto a maximum of about 11% depending upon their configuration and other specifications. Further, it can be observed that in case of beds with rod promoter, the minimum fluidization mass velocity increases with increase in number of rods. For the case of beds with disk promoter, the minimum fluidization mass velocity have been found to increase with decrease in disk thickness and increase in disk diameter. The combined effect of disk thickness and disk diameter is to increase the minimum fluidization mass velocity over conventional unprompted bed. Thus, the developed correlations can be used safely to predict the minimum fluidization mass velocity for promoted gas-solid fluidized beds with rod and disk type of promoters in the range of present experimental limits.

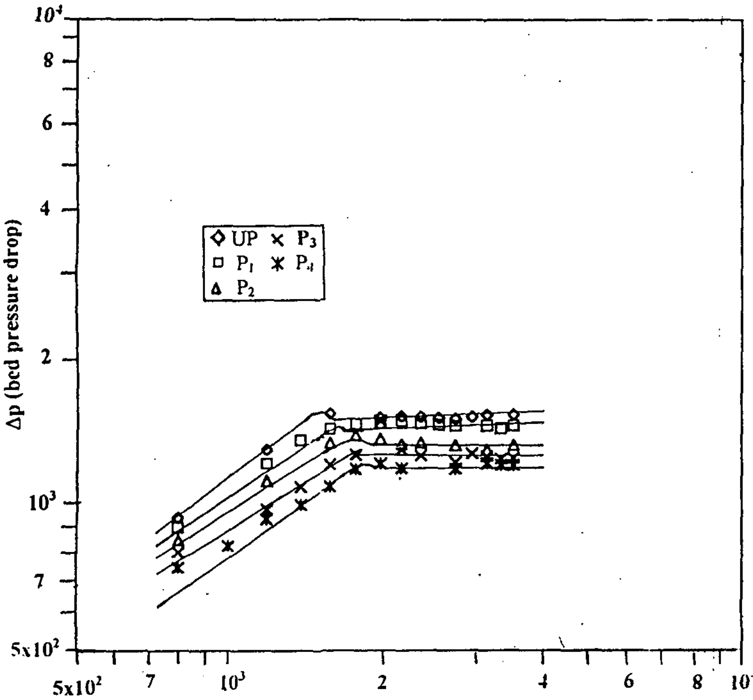

Fig. 4 : Variation of Δ p with G_f for Unpromoted Bed and Bed with Rod Promoter

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Nomenclature

A_o Open area in promoted bed with rod promoters, m^2
C Constant in equation (1)
C' Constant in equation (2)
C_1 Constant in equation (5)
C_2 Constant in equation (6)
D_c Column diameter, m
D_e Equivalent diameter of the promoted bed ($4A_o/P$), m
D_k Disk diameter, m
d_p Particle size, m
f, f_1, f_2 Functions
G_f Mass velocity of fluid, kg/hr.m^2

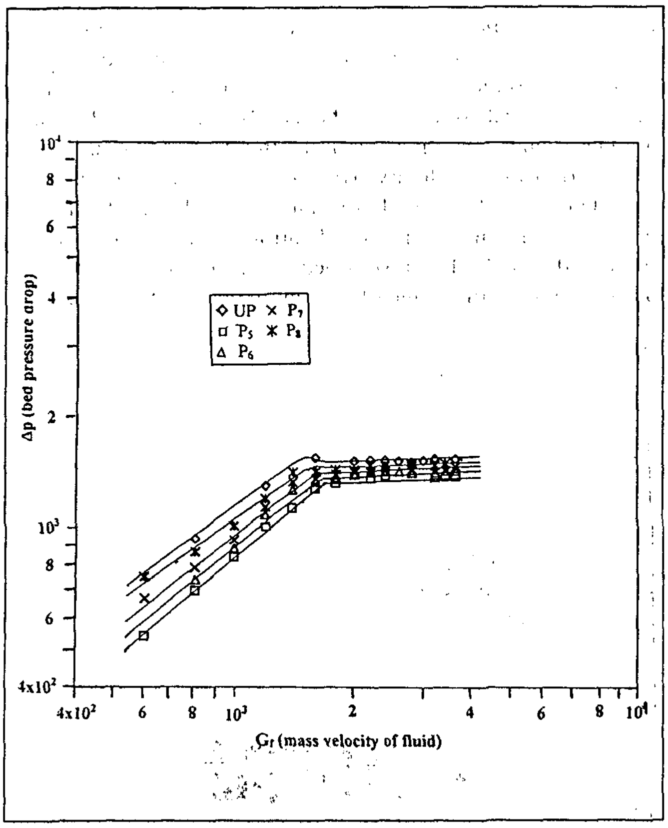

Fig. 5 : Variation of Δ p with G_f for Unpromoted Bed and Bed with Disk Promoter (disk thickness)

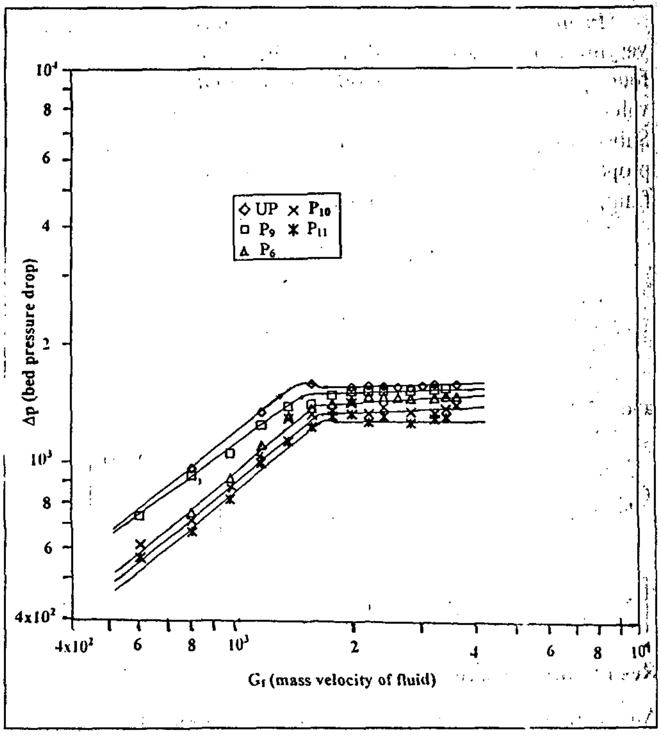

Fig. 6 : Variation of Δ p with G_f for Unpromoted Bed and Bed with Disk Promoter (disk diameter)

G_{mf}	Minimum fluidization mass velocity in unpromoted beds, kg/hr.m^2
g	Acceleration due to gravity, m/hr^2
$n_1 n_2 n_3 n_4$	Exponents
P	Total rod perimeter, m
p_1, p_2, p_3, p_4	rod promoters
$P_5, P_6, P_7, P_8, P_9, P_{10}$ & P_{11}	Disk promoters
t	disk thickness, m

Greek Letters

ρ_f	density of fluid, kg/m^3
ρ_s	density of solid, kg/m^3
ϕ_s	sphericity, dimensionless
μ	viscosity, kg/hr.m
Δ_p	bed pressure drop, N/m^2