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FLUIDIZED BED PRESSURE DROP IN PROMOTED GAS-SOLID BEDS WITH COAXIAL ROD, DISK, AND BLADE TYPE PROMOTERS

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Bed pressure drop equations have been formulated for gas-solid fluidized beds with different types of promoters using Ergun's equation (Ergun, 1952) and experimental data. Four rod promoters, seven disk promoters, along with one blade promoter were used in beds supported on five different distributors with open areas of 12.9%, 8.96%, 5.74%, 3.23%, and 1.43% of the column section. The predicted values of bed pressure drop using a modified (i.e., modified numerical constant) Burke-Plummer (Burke and Plummer, 1928) equation were compared with the corresponding experimental as well as the respective values obtained with the help of Kumar et al. (submitted) and traditional gas-solid fluidized bed equations.

Keywords: Fluidized bed; Promoter; Pressure drop

INTRODUCTION

Promoters are effective in improving fluidization quality by minimizing slugging and breaking the bubbles and limiting their size and growth in a gas-solid fluidized bed. This results in reduced bed expansion and fluctuation over conventional unpromoted beds. Kumar et al. (2002, in press)

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and several other investigators (Balakrishnan and Raja Rao, 1975; Yong et al., 1980; Dutta and Suciu, 1992; Olowson, 1994; Volk et al., 1962; Overcashier et al., 1959; Glass and Harrison, 1964; Rowe and Evertt, 1972; Krishnamurthy et al., 1981; Agarwal and Roy, 1987; Kar and Roy, 2000) have carried out studies using different types of promoters on different aspects of fluidized beds. Kumar et al. (submitted) proposed the following correlations for bed pressure drop in the case of a gas-solid fluidized bed promoted with rod, disk, and blade promoters:

Bed with rod promoter:

$$\Delta p_b = (\Delta p_d) \Big/ \left[8.66 \times 10^{-5} G_{mrf}^{1.26} \left(\frac{\rho_s}{\rho_f}\right)^{0.53} \left(\frac{A_{do}}{A_c}\right)^{-2.01} \left(\frac{d_p}{d_o}\right)^{0.94} \left(\frac{h_s}{D_c}\right)^{-1.18} \left(\frac{D_e}{D_c}\right)^{-0.21} \right] \tag{1}$$

Bed with disk promoter:

$$\Delta p_b = (\Delta p_d) \Big/ \left[9.41 \times 10^{-5} G_{mrf}^{1.16} \left(\frac{\rho_s}{\rho_f}\right)^{0.51} \left(\frac{A_{do}}{A_c}\right)^{-1.9} \left(\frac{d_p}{d_o}\right)^{0.93} \left(\frac{h_s}{D_c}\right)^{-1.06} \left(\frac{t}{D_c}\right)^{-0.12} \left(\frac{D_k}{D_c}\right)^{0.22} \right] \tag{2}$$

Bed with blade promoter:

$$\Delta p_b = (\Delta p_d) \Big/ \left[1.31 \times 10^{-4} G_{mrf}^{1.17} \left(\frac{\rho_s}{\rho_f}\right)^{0.48} \left(\frac{A_{do}}{A_c}\right)^{-1.87} \left(\frac{d_p}{d_o}\right)^{0.92} \left(\frac{h_s}{D_c}\right)^{-1.04} \right] \tag{3}$$

In the present work, the bed pressure drop equations for the promoted bed have been formulated in the line of Ergun (1952) and Burke-Plummer (1928) using experimental data, and the predicted values have been compared with the experimental data, and those obtained from Equations (1)-(3). A pressure drop equation for a traditional gas-solid fluidized bed as given below has also been used to check and compare the results predicted.

$$\frac{\Delta p_b}{L} = \rho_s(1 - \varepsilon)g \tag{4}$$

THEORETICAL ANALYSIS

Ergun's (Ergun, 1952) equation can in general be written as

$$\frac{\Delta p_b}{L} = K_1 \frac{(1-\varepsilon)^2 \mu u}{\varepsilon^3 \phi^2 d_p^2} + K_2 \frac{(1-\varepsilon)}{\varepsilon^3} \frac{\rho_f u^2}{\phi d_p} \text{ or,} \tag{5}$$

$$\frac{\Delta p_b}{L} \frac{\varepsilon^3 \phi^2 d_p^2}{(1-\varepsilon)^2 \mu u} = K_1 + K_2 \frac{1-\varepsilon}{\varepsilon^3} \frac{\rho_f u^2}{\phi d_p} \frac{\varepsilon^3 \phi^2 d_p^2}{(1-\varepsilon)^2 \mu u}$$

At higher Reynolds number, constant K_1 is neglected (Burke-Plummer equation), i.e.,

$$\frac{\Delta p_b}{L} \frac{\varepsilon^3 \phi^2 d_p^2}{(1-\varepsilon)^2 \mu u} = K_2 \frac{1-\varepsilon}{\varepsilon^3} \frac{\rho_f u^2}{\phi d_p} \frac{\varepsilon^3 \phi^2 d_p^2}{(1-\varepsilon)^2 \mu u} = K_2 \frac{\rho_f u \phi d_p}{(1-\varepsilon)\mu} = K_2 N'_{Re} = f_v \tag{6}$$

i.e., $f_v = K_2 N'_{Re}$

$$\text{where } \varepsilon = \frac{V_e - V_s - V_p}{V_e}, \quad \text{and} \quad L = Rh_s \tag{7}$$

For unpromoted beds, Singh (1997) reported the value of K_2 to be independent of particle size and density and the initial static bed height. However, for the promoted beds the constant K_2 will depend on the type of promoters used in the beds and can be obtained as the slopes of the respective plots between f_v versus modified Reynolds number on Cartesian coordinates for beds with rod, disk, and blade promoters. Thus, the pressure drop for fluidized beds can be obtained from Equation (6) as

$$\Delta p_b = K_2 L N'_{Re} \frac{(1-\varepsilon)^2 \mu u}{\varepsilon^3 \phi^2 d_p^2} \tag{8}$$

EXPERIMENTAL

The experimental setup consists of an air compressor, rotameter, silica gel column, 50.8 mm i.d. Perspex column (fluidizer) with two pressure tappings, and a differential U-tube manometer containing carbon

Table I Scope of the Experiment

A. Properties of bed material

Materials	$d_p \times 10^3$, m	$\rho_s \times 10^{-3}$, kg/m^3
Dolomite	1.125	2.817
Dolomite	0.725	2.817
Dolomite	0.463	2.817
Dolomite	0.390	2.817
Dolomite	0.328	2.817
Alum	0.725	1.691
Iron-ore	0.725	3.895
Manganese-ore	0.725	4.880

B. Initial static bed height, $h_s \times 10^2$, m

8	12	16	20

C. Distributor parameters

Distributor	Number of orifice	Diameter of orifice, $d_o \times 10^3$, m
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

D. Promoter details

Promoter specification	$D_k \times 10^3$, m	$t \times 10^3$, m	No. of 4×10^{-3} m dia. longitudinal
Rod: P_1	—	—	4
P_2	—	—	8
P_3	—	—	12
P_4	—	—	16
Disk: P_5	28.00	3.18	—
P_6	28.00	6.36	—
P_7	28.00	9.54	—
P_8	28.00	12.72	—
P_9	20.26	6.36	—
P_{10}	34.00	6.36	—
P_{11}	39.13	6.36	—
Blade: P_{12}	38.00	6.36	—

(continued)

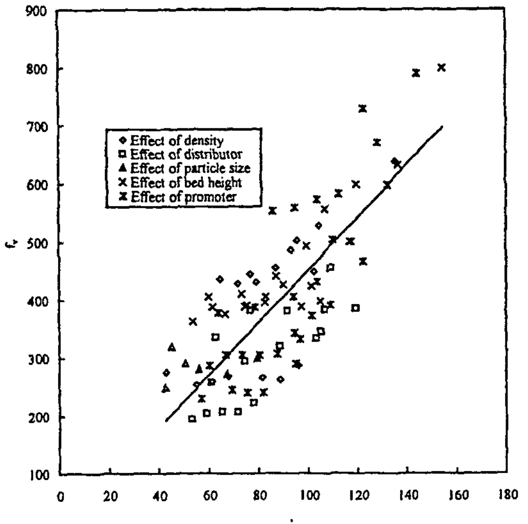
Table I (continued)

E. Flow properties (air at 20°C, atmospheric pressure = 101 ± 2, KPa)	
Maximum, kg/hr-m^2	Minimum, kg/hr-m^2
5500	200

tetrachloride as the manometric liquid. Compressed air was used as the fluidizing medium. Four rod promoters, seven disk promoters, and one blade promoter with five different distributors of varying open area were used in the experiment. The disks for the disk promoters were fixed at an inclination of 10° with the horizontal alternatively in opposite directions to minimize the accumulation of bed material over the disks. The details of experimental setup, rod, disk, and blade promoters, and distributors have been given elsewhere (Kumar and Roy, 2002; Balakrishnan and Raja Rao, 1975). The scope of the experiment is given in Table I. The correlations developed by Kumar and Roy (in press) were used for the values of expanded bed height in Equation (7).

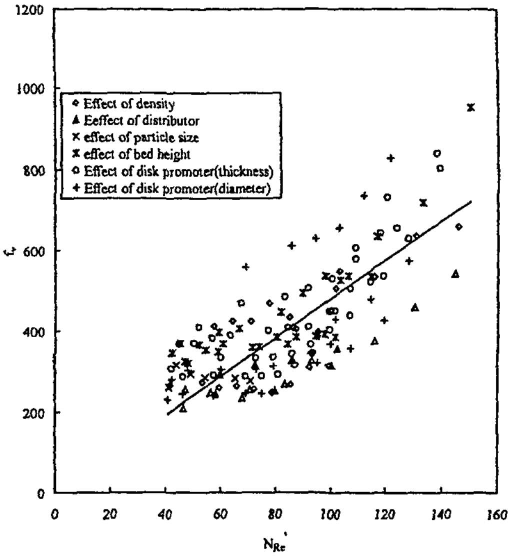
RESULTS AND DISCUSSION

The values of K_2 obtained from the experimental plots of f_v versus modified Reynolds number for the beds with rod, disk, and blade of



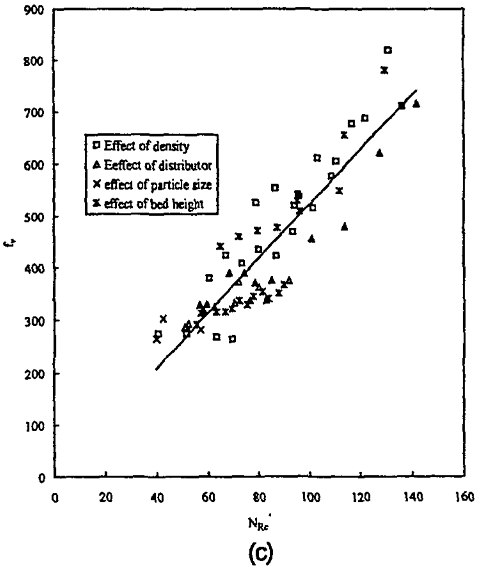
(a)

Figure 1. (a) Variation of f_v versus N'_{Re} for bed with rod promoter.



(b)

Figure 1. (b) Variation of f_v versus N'_{Re} for bed with disk promoter.



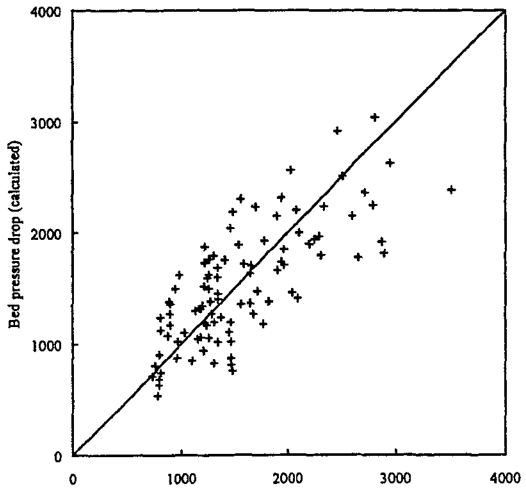
(c)

Figure 1. (c) Variation of f_v versus N'_{Re} for bed with blade type promoter.

Table II Experimental Values of Constant (K_2)

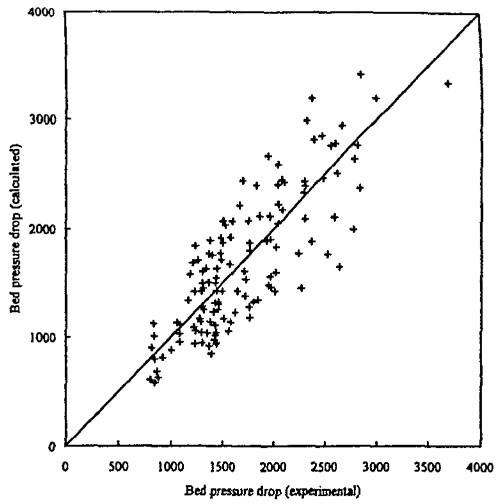
Bed particulars	Constant (K_2)
Bed with rod promoter	4.51
Bed with disk promoter	4.81
Bed with blade promoter	5.23

promoters (Figures 1(a)—(c)) are given in Table II. It can be observed that the constant K_2 is mainly dependent on the type of promoters used in the beds and mostly independent of the bed and distributor characteristics. The results predicted with the help of modified Burke-Plummer equations have been compared with the corresponding experimental ones in Figures 2(a)-(c) for respective beds. The predicted values of bed pressure drop using Equation (8) have also been compared with those obtained from Equation (4). The mean of the absolute values of percentage deviation of the predicted values of bed pressure drop from the respective experimental ones and the corresponding standard deviation are presented in Table III. Although the mean and standard deviations of the predicted bed pressure drop using the traditional equation for most of the promoted beds was found to be close to those obtained by the



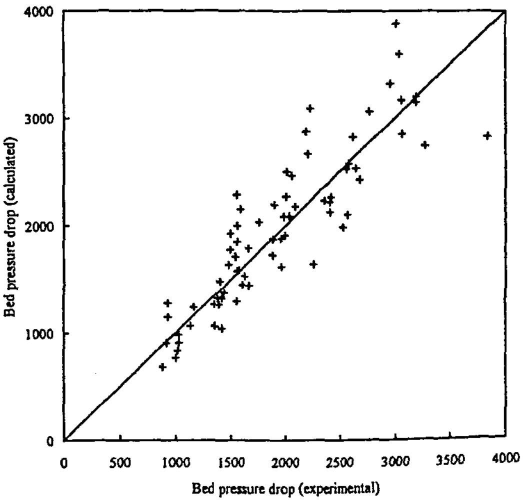
(a)

Figure 2. (a) Comparison between experimental and calculated values of bed pressure drop for bed with rod promoter.



(b)

Figure 2. (b) Comparison between experimental and calculated values of bed pressure drop for bed with disk promoter.



(c)

Figure 2. (c) Comparison between experimental and calculated values of bed pressure drop for bed with blade type promoter.

G_{mf}	minimum fluidization mass velocity in promoted beds, kg m^{-2} h^{-1}
G_{mrf}	G_f/G_{mf}, reduced fluidization mass velocity
h_s	initial static bed height, m
L	R.h_s, expanded bed height, m
N'_{Re}	$\rho_f u \phi d_p/(1-\varepsilon)\mu$, modified Reynolds number
P	total rod perimeter, m
R	L/ h_s, bed expansion ratio
t	disk thickness, m
u	superficial fluid velocity, ms^{-1}
V_e	volume of the expanded bed, m^3
V_p	volume of solid, m^3
V_s	volume of promoter, m^3

Greek letters

ρ_f	density of fluid, kg m^{-3}
ρ_s	density of solid, kg m^{-3}
ε	porosity
ϕ	sphericity
Δp_b	bed pressure drop, Pa
Δp_d	distributor pressure drop, Pa
μ	viscosity, Pa.s

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