Effect of Fluid Viscosity and Promoter Parameter on Pressure Drop in a Batch Liquid-solid Fluidized Bed with Go-axial Disc Promoter

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A correlation has been developed for the prediction of pressure drop in terms of friction factor for a batch liquid-solid fluidized bed with a co-axial disc promoter using fluids of varying viscosity. The experimental data obtained for pressure drop with different fluid mass velocity, initial static bed height and disc spacing of the promoter have been analyzed using dimensional group. In this article, the pressure drop data have been expressed in terms of friction factor to develop the correlation. The predicted values of friction factor using the developed correlation have been compared with the corresponding experimental ones and have been found to agree well.

Keywords : Promoter parameter, Friction factor, Liquid-solid fluidization.

NOTATION

D_A	:	dia of annulus, m
D_C	:	dia of conduit, m
D_k	:	disc dia, m
D_p	:	particle dia, m
D_o	:	$(D_C + D_R)$, m
D_R	:	cross-sectional dia of ring, m
Eu	:	Euler number, $\Delta p/\rho_f V^2$
f	:	friction factor, $\Delta p g_c D_p (1-\varepsilon)/2\rho_f L V^2 \varepsilon^3$
f'	:	modified friction factor, $(\Delta p . g D_p . \varepsilon)/2LV^2 (1-\varepsilon)$
Fr	:	Froude number, $V^2/\varepsilon^2 g D_p$
g	:	acceleration due to gravity, m/s^2
g_c	:	conversion factor, kg - m/s^2 - N
H_e	:	expanded bed height, m
H_s	:	initial static bed height, m
L	:	length between taps, m
S	:	spacing, m
Δp	:	pressure drop, Pa
Re	:	Reynolds number based on annulus dia, $(\rho_f D_A V/\mu)$
Re_p	:	particle Reynolds number, $(\rho_f D_p V/\mu)$
Re'_p	:	modified Reynolds number, $[\rho_f D_p V/\mu(1-\varepsilon)]$
V	:	superficial velocity of liquid, m/s
V_f	:	volume of fluidized bed, m^3
V_p	:	volume of promoter assembly, m^3
V_s	:	volume of solid in the bed, m^3
ε	:	void fraction, $[1 - V_s/(V_f - V_p)]$
θ	:	cone angle, dimensionless
μ	:	viscosity of liquid medium, N – s/m^2
ν	:	kinematic viscosity, m^2/s
ρ_f	:	density of fluid, kg/m^3
ρ_s	:	density of solid, m^2/s

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INTRODUCTION

The use of a suitable promoter improves the quality of fluidization by reducing channelling, bubbling and slugging in gas-solid fluidized beds. In liquid-solid system, the use of promoter imparts particulate behaviour in case where the same is not achieved in a conventional bed. Further, enhanced heat and mass transfer rates are obtained in a promoted bed where turbulent flow condition can be achieved with relatively low fluid mass velocity.[1] Higher rates of heat and mass transfer and improved fluidization quality in a promoted bed are associated with increase of bed pressure drop. So the influence of promoter parameter, viscosity of the fluidizing liquid, and other related system parameters on pressure drop expressed in terms of friction factor is of much interest.

Investigations relating to liquid-solid fluidized beds with different types of promoters are available in literature, where the bed dynamics have been codified in terms of correlations for pressure drop, friction factor and Euler number relating to various system parameters. Ravi, *et al*[2] studied the effect of disc promoter assembly on pressure drop in a liquid-solid fluidized bed and correlated pressure drop in terms of friction factor with varying flow rate, static bed height, particle size, disc dia and spacing between discs as

$$f = 0.83\left(\frac{\mathrm{Re}_p}{1-\varepsilon}\right)^{0.22}\left(\frac{D_p}{D_c}\right)^{0.14}\left(\frac{S}{D_c}\right)^{-0.033}\left(\frac{D_k}{D_c}\right)^{0.51}\left(\frac{V^2}{\varepsilon^2 D_p g}\right)^{-0.68} \quad (1)$$

They observed that the disc spacings of the promoter have insignificant effect on friction factor. Venkateswarlu, *et al*[3], conducted tests in homogeneous liquid fluidization with turbulence promoter assembly consisting of a central rod mounted with a string of cones equally spaced longitudinally in a conical bed. They developed the following correlations for friction factor in terms of particle size, spacing of cones, cone dia, cone angle and voidage

$$2f' = 10.8\left(\mathrm{Re}'_p\right)^{-0.23}\left(\frac{D_p}{D_c-D_k}\right)^{0.29}\left(\frac{S}{D_c-D_k}\right)^{-0.1} \times \left(\frac{D_k}{D_c-D_k}\right)^{0.4}(\theta)^{0.1} \quad (2)$$

and

$$f = 0.644\left(\mathrm{Re}_p\right)^{-0.08}\left(\frac{S}{D_c-D_k}\right)^{-1.14}\left(\frac{D_k}{D_c-D_k}\right)^{2.69}(\theta)^{0.75} \quad (3)$$

The effect of ring promoter assembly on friction factor has been established by Ramabrahmam, *et al*[1] considering system variables as flow rate, cross-sectional dia of the ring and spacing between rings as

$$f = 6.18(\mathrm{Re})^{-0.265}\left(\frac{D_R}{D-D_0}\right)^{1.22}\left(\frac{S}{D-D_0}\right)^{-0.285} \quad (4)$$

Venkateswarlu and Raju[4] have related the effect of promoter assembly and other system variables, namely, the flow rate, dia of the disc and inter disc spacing of the promoter assembly on friction factor as

$$f = 0.116\left(\frac{S}{D_c-D_k}\right)^{-0.31}\left(\frac{D_c}{D_c-D_k}\right)^{1.608} \quad \text{for } e/S \geq 0.26 \quad (5)$$

$$f = 0.165\left(\frac{S}{D_c-D_k}\right)^{-0.455}\left(\frac{D_k}{D_c-D_k}\right)^{2.97} \quad \text{for } e/S < 0.26 \quad (6)$$

Kumar, *et al*[5] have conducted experiments to study the effect of co-axial rod promoter on the pressure drop under varying conditions of flow rate, bed height, particle size and density. A promoter consisting of three rods placed at the three vertices of an equilateral triangle and one rod in the centre of the triangle to produce circumferential as well as central influence has been used. They have developed the following correlations.

For a Batch Liquid Fluidized Bed without Promoter

$$\mathrm{Eu} = 74\left(\frac{Hs}{D_c}\right)^{1.98}\left(\frac{He}{D_c}\right)^{-2.23}\left(\frac{\rho_s}{\rho_f}\right)^{-0.3}\left(\frac{D_p}{D_c}\right)^{-0.8} \quad (7)$$

For a Batch Liquid Fluidized Bed with Promoter

$$\mathrm{Eu} = 15\left(\frac{Hs}{D_c}\right)^{2.79}\left(\frac{He}{D_c}\right)^{-2.2}\left(\frac{\rho_s}{\rho_f}\right)^{-0.66}\left(\frac{D_p}{D_c}\right)^{-1.23} \quad (8)$$

Further studies by the authors of this article include the effect of varying viscosity of the fluidizing medium. Thus developed correlations are

For Bed without Promoter

$$\mathrm{Eu} = 3.37\times 10^3\left(\frac{Hs}{D_c}\right)^{1.06}\left(\frac{He}{D_c}\right)^{-0.65}\left(\frac{\rho_s}{\rho_f}\right)^{-0.23} \times \left(\frac{D_p}{D_c}\right)^{-0.55}(\mathrm{Re})^{-0.96} \quad (9)$$

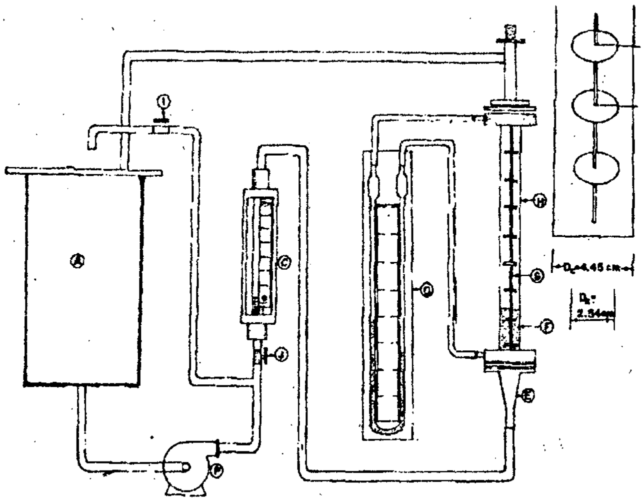
For Bed with Promoter

$$\mathrm{Eu} = 3.6\times 10^3\left(\frac{Hs}{D_c}\right)^{1.23}\left(\frac{He}{D_c}\right)^{-0.62}\left(\frac{\rho_s}{\rho_f}\right)^{-0.28} \times \left(\frac{D_p}{D_c}\right)^{-0.67}(\mathrm{Re})^{-1.06} \quad (10)$$

The present study is aimed at developing correlation for friction factor using a disc promoter with different disc spacing and fluidizing liquids of varying viscosity.

EXPERIMENTATION

The experimental set-up consists of a 4.45 cm internal dia with 90 cm long perspex column as fluidizer, a storage lank of 401 capacity, a 0.5 hp centrifugal pump to recirculate the fluidizing liquid through the fluidizer, a rotameter calibrated in USGPM (range 0-2 USGPM) to measure flow rate, and a differential



A : Storage tank, C : Rotameter, D : Manometer, E : Calming section, F : Bed particles, G : Disc promoter assembly, H : Fluidizer, I : Bypass valve, J : Control valve, P : Centrifugal pump,

Fig 1 Experimental set-up

manometer with carbon tetra-chloride as manometric liquid connected between two pressure tappings to measure bed pressure drop (Fig 1). Glycerin-water solutions with8%, 10%, 12% and 16% glycerin content have been used as fluidizing liquid. Four different promoters each consisting of 2.54 cm dia discs mounted on a central rod of 8 mm dia and spaced at equal interval of 4 cm, 6 cm, 8 cm and 10 cm, respectively have been used. Glass beads of 1 mm dia and density 2.6 g/cm^3 have been used as bed material. For a particular run, variation of bed pressure drop has, been noted with gradual increase of liquid flow rate. For fluidized bed condition, bed expansions with flow rate have also been noted. Experiments have been repeated with varying initial static bed heights, disc spacing of the promoter and viscosity of the fluidizing medium. The scope of the experiments is given in Table **1.**

DEVELOPMENT OF CORRELATION

Expressing bed pressure drop in terms of friction factor and using dimensional analysis approach, the various system variables which are likely to influence it, are grouped into three dimensionless parameters, namely, Reynolds number, Froude number and Promoter parameter. The variation of friction factor with Reynolds number, Froude number and promoter parameter is shown in Fig 2, Fig 3 and Fig 4, respectively and the values of the exponents are obtained as under

$$f = C\left[\left(\frac{\mathrm{Re}_p}{1-\varepsilon}\right)^{-1.78} (\mathrm{Fr})^{-0.42} \left(\frac{S}{D_c - D_k}\right)^{-0.25}\right]^n \tag{11}$$

The constant C and the exponent n of equation (11) have been obtained from the regression analysis of the data shown in Fig 5.

Table 1 Scope of experiment

Variables	Minimum	Maximum
Flow rate, $(Q \times 10^6)$, m^3/s	10.000	100.000
Initial bed height, (Hs $\times 10^2$), m	6.000	12.000
Kinematic viscosity, ($\nu \times 10^6$), m^2/s	1.122	1.365
Promoter disc spacings, (S $\times 10^2$), m	4.000	10.000

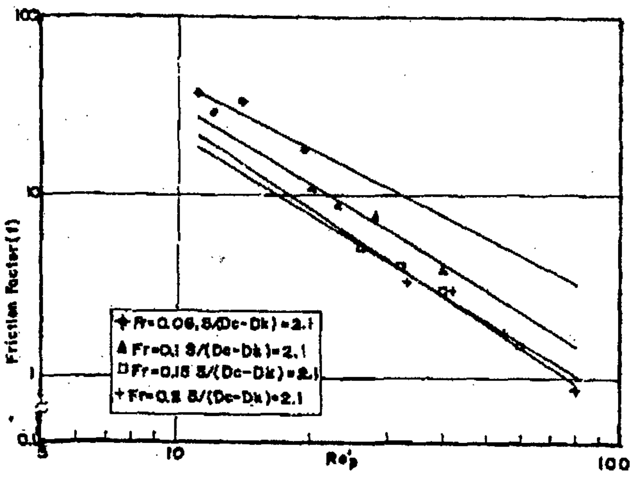


Fig 2 Variation of friction factor with Reynolds number

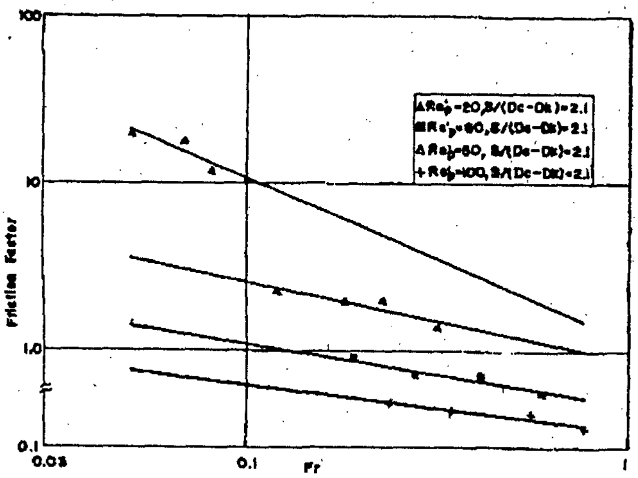


Fig 3 Variation of friction factor with Froude number

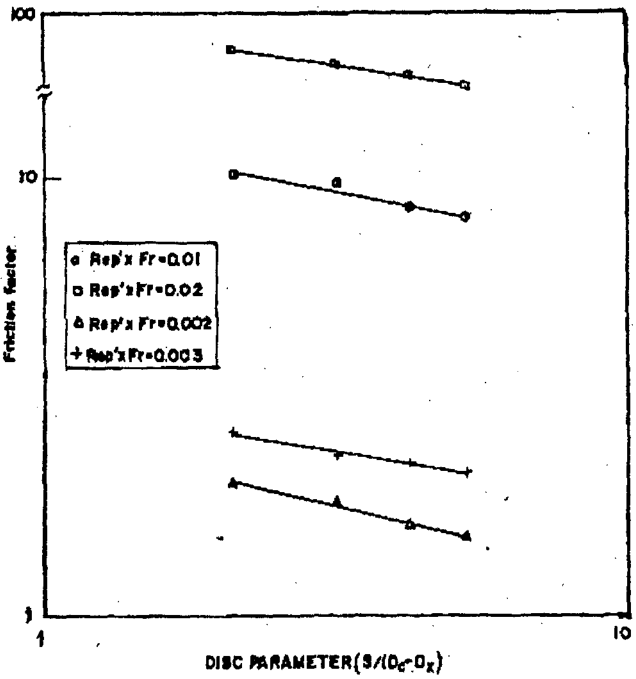


Fig 4 Variation of friction factor with disc parameters

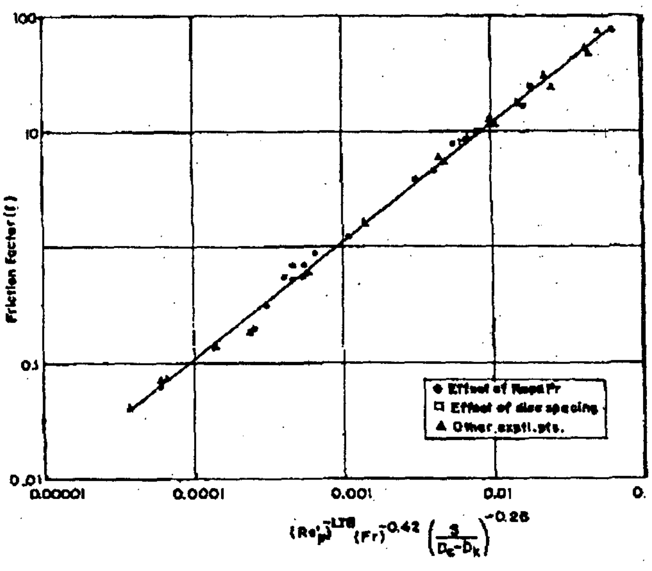


Fig 5 Variation of friction factor with system parameters

Table 2 Comparison of friction factor

$S/(D_c - D_k)$	$Rep/(1-\varepsilon)$	Fr	Friction Factor (f) Experi-mental	Calcu-lated	Deviation, %
2.10	31.560	0.100	4.930	5.360	–8.67
2.10	81.070	0.279	0.569	0.620	–8.64
2.10	117.770	0.373	0.249	0.276	–10.99
2.10	169.430	0.464	0.117	0.130	–10.92
2.10	231.160	0.571	0.064	0.067	–5.36
2.10	8.420	0.026	120.030	106.430	11.33
2.10	10.311	0.034	74.740	64.980	13.05
2.10	11.556	0.041	58.360	48.950	16.12
2.10	19.144	0.072	16.310	15.290	6.24
2.10	100.145	0.394	0.320	0.360	–13.32
2.10	181.718	0.615	0.093	0.101	–8.83
2.10	248.930	0.697	0.047	0.054	–15.15
2.10	22.040	0.098	9.220	10.350	–12.28
3.15	309.340	0.962	0.028	0.032	–13.29
3.15	11.116	0.028	49.810	55.810	–12.48
3.15	74.180	0.278	0.618	0.660	–6.76
3.15	206.780	0.564	0.073	0.075	–2.78
4.20	280.520	0.670	0.042	0.040	4.75
4.20	10.864	0.030	54.190	52.720	2.71
4.20	202.456	0.572	0.076	0.072	5.06
5.25	274.940	0.677	0.042	0.038	8.45
5.25	12.301	0.034	41.820	39.540	5.45
5.25	28.124	0.105	6.180	5.430	12.06
5.25	74.565	0.271	0.630	0.610	2.81
5.25	206.780	0.567	0.140	0.136	2.71

The final correlation thus obtained is

$$f = 1.28 \times 10^3 \left(Re'_p\right)^{-1.82} (Fr)^{-0.43} \left(\frac{S}{D_c - D_k}\right)^{-0.25} \quad (12)$$

Thus, the expression for pressure drop becomes

$$\Delta_p = 2.56 \times 10^3 \left(Re'_p\right)^{-1.82} (Fr)^{-0.43} \left(\frac{S}{D_c - D_k}\right)^{-0.25} \times \frac{\rho L V^2 \varepsilon^3}{g_c D_p (1-\varepsilon)} \quad (13)$$

RESULTS AND DISCUSSION

The predicted values of friction factor using the developed correlation [equation (12)] for beds with different system variables have been compared with the respective values of friction factor calculated with the help of experimental data (Table 2). Fairly good agreement has been found between the experimental and the predicted values of friction factor. The mean and standard deviation obtained are 8.81% and 9.60%, respectively.

CONCLUSION

From the experimental and the predicted values of friction factor, it is apparent that friction factor increases with increase in static bed height and with an decrease in Reynolds number (that is, increase in fluid viscosity marked by increase in glycerin content) as is evident from Fig 2. The effects of Froude number (which presents the influence of the velocity of the fluidizing medium for a particular particle size), (Fig 3) and that of the promoter disc spacing (Fig 4) on friction factor are negative. Thus, the developed correlation can be used satisfactorily for the prediction of friction factor and then the bed pressure drop for the liquid-solid fluidized beds with co-axial disc promoter in the kinematic viscosity range of the fluidizing medium between 1.122×10^{-6} m^2/s and 1.365×10^{-6} m^2/s.

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