Effect of Liquid Viscosity on Pressure Drop in Batch Liquid - solid Fluidized Beds

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The present study deals with the development of correlations in order to predict pressure drop in a batch liquid-solid fluidized bed with liquids of varying viscosity, for unpromoted bed as well as a bed with triangular rod promoter. Experiments have been conducted to obtain pressure drop and bed expansion data with different system variables namely, initial static bed height, particle size and density, mass velocity and viscosity of the fluidizing medium. Expressions relating the pressure drop data, in terms of Euler number, with the system parameters have been obtained in case of beds having with and without promoter. The values of Euler number predicted with the help of correlations developed have been found to agree fairly well with the corresponding experimental ones. A comparison of the pressure drop values has also been made for beds with and without promoter for varying conditions of system parameters.

Keywords : Fluidization; Promoter; Viscosity; Pressure drop

NOTATION

c_1, c_2	: intercepts of regression lines, dimensionless
D_c	: dia of the conduit (fluidizer), m
D_p	: particle dia, m
Eu	: Euler number $\left(\dfrac{\Delta p}{\rho_f V_f^2}\right)$, dimensionless
H_e	: expanded bed height, m
H_s	: static bed height, m
n_1, n_2	: slopes of regression lines, dimensionless
Δp	: pressure drop across the bed, Nm^{-2}
Re	: Reynolds number $\left(\dfrac{V_f D_p}{\nu}\right)$, dimensionless
v_f	: velocity of flow of liquid through fluidizer, ms^{-1}
ρ_f	: density of fluid (liquid), kg m^{-3}
ρ_s	: density of solids, kg m^{-3}
ν	: kinematic viscosity of fluidizing liquid, $m^2 s^{-1}$

INTRODUCTION

In the recent past, various types of turbulence promoters have been used as internals in fluidized beds. The use of such promoters has improved the quality of gas-solid fluidization by breaking the slugs and channels and by hindering the bubble coalescence in the bed. In case of liquid-solid fluidized beds, high heat and mass transfer rates can be achieved at a comparatively low flow rate using turbulence promoters. However, higher transfer rates at low flow rate in a promoted bed are associated with high pressure drop values. Consequently, the pressure drop data are a prerequisite for the development of liquid fluidized bed systems with promoters.

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This paper (modified) was received on July 8, 2002. Written discussion on the paper will be received until November 30, 2002.

Investigations relating to the bed dynamics have been reported in literature, wherein the performances of different types of promoters have been codified in terms of correlations for pressure drop, friction factor and Euler number by relating with various system parameters. These include pressure drop studies by Venkateswarlu and Raju[1] and Ravi, *et at* (using disc promoter), Evan and Churchill[3] (employing strings of discs and stream-lined bodies), Raju, *et al*[4] (in the presence of cone-promoter assembly) and Ramabrahman, *et al*[5] (using a ring promoter assembly). In a recent study Kumar, *et al*[6] have presented the effect of co-axial rod promoter on pressure drop in terms of Euler number as under

$$\mathrm{Eu} = 74\left(\frac{H_s}{D_c}\right)^{1.98}\left(\frac{H_e}{D_c}\right)^{-2.23}\left(\frac{\rho_s}{\rho_f}\right)^{-0.30}\left(\frac{D_p}{D_c}\right)^{-0.80}, \quad (1)$$

for bed without promoter

$$\mathrm{Eu} = 15\left(\frac{H_s}{D_c}\right)^{2.79}\left(\frac{H_e}{D_c}\right)^{-2.20}\left(\frac{\rho_s}{\rho_f}\right)^{-0.66}\left(\frac{D_p}{D_c}\right)^{-1.23}, \quad (2)$$

for bed with promoter

In the present study, an attempt has been made to incorporate the effect of liquid viscosity on the bed pressure drop expressed in terms of Euler number.

EXPERIMENTATION

The experimental set-up with promoter and other details are same as used by Kumar, *et at* for their study. Five liquids (namely, water and four glycerine-water solutions of 4%, 8%, 12% and 16%) have been used as the fluidizing medium. For a particular run, the variation of pressure drop was noted with the gradual increase of liquid flow rate. For fluidized bed condition, bed expansion data were also noted. Experimental runs were repeated by varying the liquid viscosity, initial static bed height, bed material and particle size with and without promoter. The scope of the experiments is given in Table 1.

DEVELOPMENT OF CORRELATION

The dimensional analysis of various system parameters have been carried out to establish the inter-dependency of variables.

Table 1 Scope of experiments

Bed Material	Particle Size $(D_p) \times 10^3$, m	Particle Density (ρ_s), kg/m^3	Initial Bed Height $(H_s) \times 10^2$, m	Kinematic Viscosity $(v) \times 10^6$, m^2/s
Dolomite	1.350	2720	8.0	0.992
Dolomite	1.350	2720	12.0	0.992
Dolomite	1.350	2720	16.0	0.992
Dolomite	1.350	2720	20.0	0.992
Dolomite	1.350	2720	8.0	0.892
Dolomite	1.350	2720	8.0	1.068
Dolomite	1.350	2720	8.0	1.177
Dolomite	1.350	2720	8.0	1.362
Dolomite	1.850	2720	8.0	0.992
Dolomite	0.800	2720	8.0	0.992
Dolomite	0.550	2720	8.0	0.992
Dolomite plus iron ore	1.350	3370	8.0	0.992
Iron ore	1.350	4254	8.0	0.992
Coal	1.350	1411	8.0	0.992

The pressure drop data (in terms of Euler number), have been correlated with other non-dimensional parameters of the system. Two correlations, one for a normal fludized bed and the other for a bed with a turbulent promoter, have been developed which are appended below

$$\mathrm{Eu} = c_1\left[\left(\frac{H_s}{D_c}\right)^{2.11}\left(\frac{H_e}{D_c}\right)^{-1.29}\left(\frac{\rho_s}{\rho_f}\right)^{-0.46}\left(\frac{D_p}{D_c}\right)^{-1.10}(\mathrm{Re})^{-1.90}\right]^{n_1} \quad (3)$$

for a fluidized bed without promoter

$$\mathrm{Eu} = c_2\left[\left(\frac{H_s}{D_c}\right)^{2.18}\left(\frac{H_e}{D_c}\right)^{-1.11}\left(\frac{\rho_s}{\rho_f}\right)^{-0.51}\left(\frac{D_p}{D_c}\right)^{-1.19}(\mathrm{Re})^{-1.88}\right]^{n_2} \quad (4)$$

for a fluidized bed with promoter

The values of c_1 and n_1 of equation (3) and c_2 and n_2 of equation (4) have been obtained from the regression analysis of the data as shown in Figure 1 and Figure 2, respectively.

The final correlations thus obtained are given below

$$\mathrm{Eu} = 3.37 \times 10^3\left(\frac{H_s}{D_c}\right)^{1.06}\left(\frac{H_e}{D_c}\right)^{-0.65}\left(\frac{\rho_s}{\rho_f}\right)^{-0.23}\left(\frac{D_p}{D_c}\right)^{-0.55}(\mathrm{Re})^{-0.96} \quad (5)$$

for a fluidized bed without promoter

$$\mathrm{Eu} = 3.6 \times 10^3\left(\frac{H_s}{D_c}\right)^{1.23}\left(\frac{H_e}{D_c}\right)^{-0.62}\left(\frac{\rho_s}{\rho_f}\right)^{-0.28}\left(\frac{D_p}{D_c}\right)^{-0.67}(\mathrm{Re})^{-1.06} \quad (6)$$

for a fluidized bed with promoter.

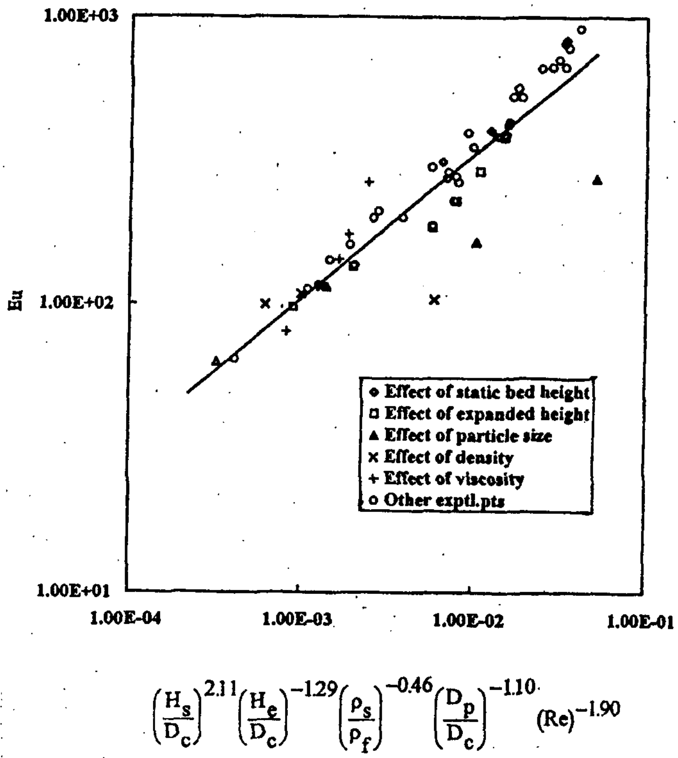

Figure 1 Variation of Euler number with system parameters (without promoter)

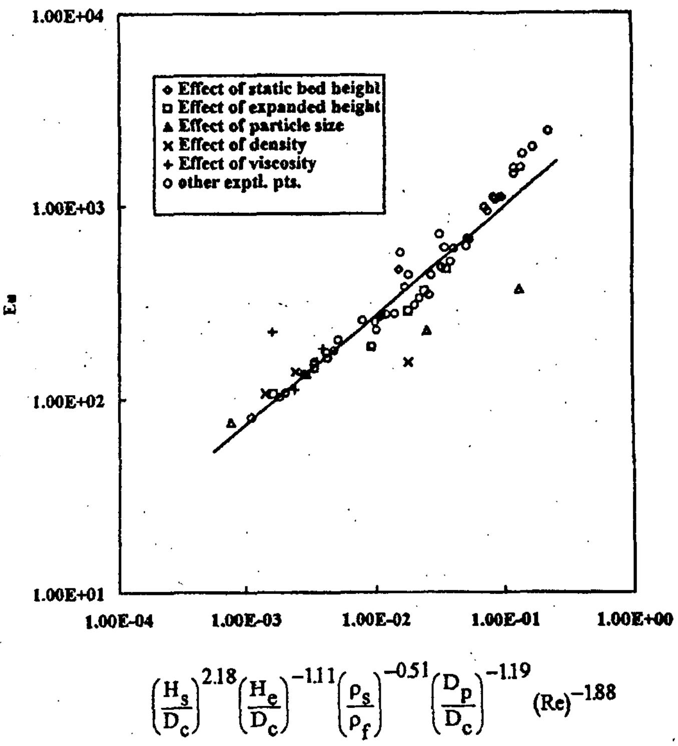

Figure 2 Variation of Euler number with system parameters (with promoter)

RESULTS AND DISCUSSION

The predicted values of Euler number using developed correlations (5) and (6) for beds without and with promoter have been compared with the respective experimental values in Figure 3

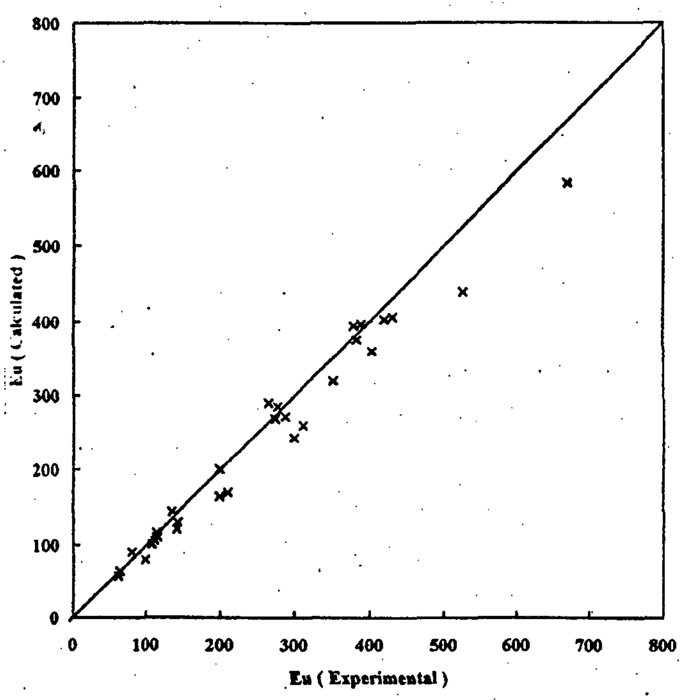

Figure 3 Comparison of Euler number (without promoter)

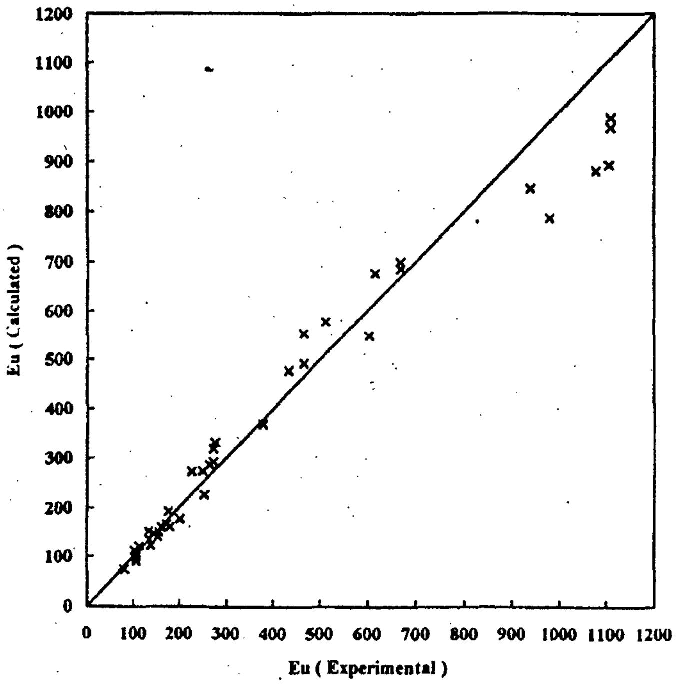

Figure 4 Comparison of Euler number (with promoter)

and Figure 4, respectively. A fairly good agreement has been found between the experimental and the predicted values of Euler number.

The mean and standard deviations in case of a bed without promoter has been obtained as 8.88 and 9.22, respectively and chat for a bed. with turbulence promoter as 9.42 and 10.91, respectively.

The bed pressure drop values for bed with and without promoter have been compared which indicates a marginal increase for beds with promoter. Thus, the use of such a promoter is beneficial with respect to additional pressure drop when compared to disc promoter assembly used by earlier 'investigators where the pressure drop values for bed with promoter were approximately 3-6 times higher than those without promoter". This drastic drop in bed pressure in case of a rod promoter as compared to a disc promoter may be due to reduced resistance to flow offered by rod promoter.

CONCLUSION

The correlations developed can be used for the prediction of Euler number and hence the pressure drop for unpromoted bed (equation 5) and for beds with co-axial vertical rod promoter (equation 6), using fluidizing medium of varying viscosity (the range being 0.892×10^{-6} m^2/s - 1.362×10^{-6} m^2/s). From the above two correlations, it is apparent that the pressure drop is influenced by the initial static bed height, bed expansion, particle size and density as well as viscosity of the fluidizing medium. The pressure drop increase for a bed with co-axial rod has been very marginal when compared with an unpromoted bed, indicating thereby the acceptability of such a promoter for higher transfer rate, with low liquid flow as compared to other types of promoters wherein a relatively high pressure drop was encountered.

ACKNOWLEDGMENT

The authors acknowledge the support received from the Head, Department of Applied Mechanics and Hydraulics of R E College, Rourkela, without which this study would not have been possible. Further, the authors extend their thanks to the Chemical Engineering Department, R E College, Rourkela for providing necessary facilities and guidance in developing the experimental set-up.

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