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Bed Expansion of a Squared Gas-Solid Promoted Fluidized Bed By Modified Godard - Richardson Equation

By

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Abstract

Gas-solid fluidized bed is characterized by the formation of bubbles and slugs. The expansion beyond the point of incipient fluidization is primarily due to the gas bubbles. Based on Godard and Richardson's [2] correlation for the bed expansion in a bubbling two-inch (5cm) cylindrical bed, the modified correlations for a bubbling 8.3cm squared cross section fluidized bed have been developed for both promoted and un-promoted beds considering the effect of material and the fluid properties, the column geometry and the presence of promoter. The bed expansion ratios calculated with the developed correlations have been compared with the experimental ones and fairly good agreement has been observed. The correlations for the correlation factor 'm' have also been obtained for both the promoted and un-promoted beds to predict the bed expansion ratio.

Key words: *Squared fluidized bed, gas-solid system, bed expansion, disc promoter and the correlation factor 'm'.*

INTRODUCTION:

Knowledge of bed expansion is important in fixing the height of a gas-solid fluidized bed when recommended for process applications. The expansion behaviour has been studied by many authors mostly for cylindrical beds of smaller diameters. Limited information on the bed dynamics is available for promoted cylindrical beds. Leva's [1] correlation for bed expansion in terms of the bed pressure drop and other system variables is given as:

$$\frac{\Delta P}{H_F} = (1-\varepsilon_F)(\rho_P - \rho_F) \times \frac{g}{g_c} \tag{1}$$

Godard and Richardson [2] have developed the following correlation for the expanded bed height as:

$$\frac{H_F - H_O}{H_O} = \frac{U - U_O}{m \times \left(0.35\sqrt{gD_t}\right)} \tag{2}$$

Singh and Singh [3] have modified the above correlation considering the effect of particle size and density as follows:

$$\frac{\mathrm{H_F} - \mathrm{H_O}}{\mathrm{H_O}} = \mathrm{R} - 1 = 21 \times \left[\left(\frac{\mathrm{d_p}}{\mathrm{D_t}}\right)^{-0.82} \times \left(\frac{\rho_\mathrm{p}}{\rho_\mathrm{F}}\right)^{-1} \times \left(\frac{\mathrm{U} - \mathrm{U_O}}{\left(0.35\sqrt{\mathrm{gD_t}}\right)}\right)\right] \tag{3}$$

Where $m = \frac{1}{21} \times \left[\left(\frac{d_p}{D_t}\right)^{0.82} \times \left(\frac{\rho_p}{\rho_F}\right)\right]$

The necessity of correlating 'm' in equation-(2) is obvious for the prediction of expanded bed height. With respect to the bed expansion, the effect of column geometry and promoter has not been dealt extensively. The use of a squared fluidized bed has been advocated for some specific applications in view of its certain advantages [4]. While some information relating to expansion dynamics is available for a conventional gas-solid fluidized bed with promoters [5], no information is available for a promoted squared bed. In this communication it has been attempted to develop correlations for the expanded bed height in case of un-promoted and promoted squared fluidized beds from a dimensional analysis approach. In addition, attempt has also been made to modify the Singh and Singh's [3] correlation with respect to column geometry for the above-cited bed conditions.

EXPERIMENTAL:

The experimental set-up (Fig. 1) consists of a 1.0m long perspex column of squared cross section with inner side measuring 8.3cm. A conical distributor filled with glass beads has been used for the uniform distribution of the fluidizing medium. An 80-mesh screen serves as the grid. Other accessories include rotameter, valves, compressor, manometer, pressure gauge and an accumulator. Pressure drop across the fluidized bed is measured by a manometer with carbon tetrachloride as the manometric liquid. The scope of the experiment includes the four closely sized fractions (of average diameter 1.7, 1.125, 0.725 and 0.55mm), three bed materials (of density 2.86, 2.25 and 1.528 gm/cm^3) and four bed heights (of height 6, 8, 10 and 12cm). Accurately weighed amount of material was fed into the column and adjusted for a specified initial static bed height. Air flow rate through the bed was slowly increased. After the particle movement beyond the minimum fluidization velocity, the expanded bed heights and the corresponding air flow rates were noted. The same procedure was repeated for different materials by varying the particle size and initial static bed heights and with a disc promoter.

RESULTS AND DISCUSSION:

Equivalent Diameter:

Values of equivalent diameters for the un-promoted and promoted bed (D_E and D_E') have been calculated from actual values of flow area and wetted perimeter considering the bed cross-section and the promoter configuration. Thus D_E and D_E' were found out to be 8.3 and 6.25cm respectively.

Factor-'m':

Modifying Singh and Singh's [03] approach for a squared column where the functionality for the bed expansion ratio has been modified for a squared fluidized bed and the final plots of modified expansion ratio against the system parameters are shown in Fig.-2 for the promoted and un-promoted beds. Based on Godard and Richardson [2] the 'm'- factor in the present work for different beds have been developed as follows:

For un-promoted bed:

$$m = \frac{1}{3.112} \times \left\{ \left(\frac{d_p}{D_E} \right)^{0.096} \times \left(\frac{\rho_p}{\rho_F} \right)^{-0.054} \times \left(\frac{U - U_O}{0.35 \times \sqrt{gD_E}} \right)^{0..96} \right\} \qquad (4\text{-A})$$

For disc promoted bed:

$$m = \frac{1}{28.908} \times \left\{ \left(\frac{d_p}{D'_E} \right)^{0.036} \times \left(\frac{\rho_p}{\rho_F} \right)^{0.14} \times \left(\frac{U - U_O}{0.35 \times \sqrt{gD'_E}} \right)^{0.73} \right\} \quad \text{(4-B)}$$

Modified Bed Expansion Ratio, R':

Based on the work of Godard and Richardson [2] and using factor-'m' from above correlations (Eqns. 4-A and 4-B), the final correlations for the bed expansion ratio have been obtained through Fig. 2 – (A) & (B) as under:

For un-promoted bed:

$$R = 1 + 3.112 \times \left\{ \left(\frac{d_p}{D_E} \right)^{-0.096} \times \left(\frac{\rho_p}{\rho_F} \right)^{0.054} \times \left(\frac{U - U_O}{0.35 \times \sqrt{gD_E}} \right)^{0.04} \right\} \quad \text{(5-A)}$$

For disc promoted bed:

$$R = 1 + 28.908 \times \left\{ \left(\frac{d_p}{D'_E} \right)^{-0.036} \times \left(\frac{\rho_p}{\rho_F} \right)^{-0.14} \times \left(\frac{U - U_O}{0.35 \times \sqrt{gD'_E}} \right)^{0.27} \right\} \quad \text{(5-B)}$$

Bed Expansion Ratio, R:

The plots for bed expansion ratio against the system parameters on the basis of dimensional analysis (the traditional method) have been shown in Fig-3. The final correlations for bed expansion ratio on the basis of dimensional analysis obtained through Fig. 3 – (A) & (B) are as under:

For un-promoted bed:

$$R = 1.6535 \times \left\{ \left(\frac{d_p}{D_E} \right)^{-0.449} \times \left(\frac{H_S}{D_E} \right)^{-0.675} \times \left(\frac{\rho_p}{\rho_F} \right)^{-0.867} \times \left(N_{\mathrm{Re}} \right)^{1.067} \right\} \quad \text{(6-A)}$$

For disc promoted bed:

$$R = 0.6606 \times \left\{ \left(\frac{d_p}{D'_E} \right)^{-0.298} \times \left(\frac{H_S}{D'_E} \right)^{-0..218} \times \left(\frac{\rho_p}{\rho_F} \right)^{-0.466} \times \left(N_{\mathrm{Re}} \right)^{0.8} \right\} \qquad \text{(6-B)}$$

The expansion is reduced in case of a promoted bed. The promoter (insert) breaks the bubbles (in the earlier stage of expansion i.e. a bubbling bed) and slugs (in the later stage of expansion i.e. a slugging bed) thereby reducing the height of the expanded bed as compared to an un-promoted one under identical flow conditions.

The bed expansion ratios calculated by both the methods viz. by dimensional analysis and the modified Singh and Singh's [3] correlation have been compared against the experimental values in Fig. 4 - (A) & (B) for both un-promoted and disc-promoted beds. It is observed that calculated bed expansion ratio by modified Singh and Singh's [3] correlation have relatively less deviation against the experimental values in comparison with those calculated by the dimensional analysis method. The values of bed expansion ratio for the promoted bed have been compared with those for the un-promoted ones in Fig.-5 (A and B). The calculated values of bed expansion ratio for promoted bed have been observed less than those for the un-promoted bed. This implies that the disc promoter limits the height of the expanded bed. Mean and standard deviation for the calculated values by the Dimensional Analysis approach are found out to be 11.99, 7.88 for un-promoted bed and 11.78, 7.08 for disc promoted bed (as per equations no. 6-A & 6-B)respectively. The same things by the Modified Singh and Singh's approach were found to be 4.04, 3.09 for un-promoted bed and 7.25, 6.93 for disc promoted bed (as per equations no. 5-A & 5-B) respectively. The coefficient of determination obtained from the statistical analysis (for equations no. 6-A & 6-B) for the un-promoted and promoted beds by the Dimensional- Analysis approach were found to be 0.7329 and 0.6697 respectively. The same things by the Modified Singh and Singh's approach were found to be 0.6222 (for equation no. 5-A) for un-promoted bed and 0.829 (for equation no. 5-B) for disc promoted bed. Table-1 shows a comparison of correlation factor-m calculated by equations- 4-A and 4-B for both the un-promoted and promoted beds. The values of 'm' indicate that bubble velocity increases with increase of particle size and density. Also it is observed that the correlation factor – m increases with the increase of velocity above the fluidization velocity. It is also observed that the factor 'm' is less for un-promoted bed in comparison with the disc-promoted bed thereby implying less expansion for the bed with the disc promoter. The maximum value of 'm' in the cases of un-promoted and disc-promoted bed in the present work is less than 0.025 and 0.026 respectively. However, for large sized, heavier particles the value of 'm' may be more than these values. Thus, it can be concluded that most of the points can be correlated for $m<0.025$. This value represents in the squared bed of small sized particles. Also by allowing the particles to fluidize at higher velocities the value of factor-m might be increased.

CONCLUSION:

Comparison of bed expansion ratios for promoted bed with those of the un-promoted ones reveals that the bed expansion ratios are less in magnitude when calculated by both the methods viz. the modified Singh and Singh's [3] correlation and the Dimensional analysis approach. The same thing is again proved by the correlation factor 'm' which is more for the disc promoted bed than the un-promoted bed. Thus it is concluded that the use of disc promoter in a squared gas-solid fluidized bed affects the bed expansion ratio thereby limiting the height of the expanded bed for process applications. However out of the two methods developed; the modified Singh and Singh's [3] correlation can be used for the calculation of the expanded bed height in case of the disc promoted bed with reasonable accuracy. The suggested correlations for the factor 'm' might be used to predict the bed expansion of squared bed over a wide range of parameters with and without the use of promoters.

NOMENCLATURE:

a, b	Exponent for the dimensionless groups
d_p	Particle diameter, m
Dt	Diameter of column, m
D_E	Equivalent diameter of column, m
D'_E	Equivalent diameter of column with disc promoter, m
g	Gravitational acceleration, 9.81m/sec^2
g_c	Gravitational constant
H_F	Height of expanded bed, m
H_O, Hs	Height of initial static bed, m
K	Constant
m	Correlation factor, dimensionless
n	Exponent for the correlation
N_{Re}	Reynolds number, dimensionless
P	Pressure across the bed, kpa
R	Bed expansion ratio, dimensionless
R'	Modified bed expansion ratio, R-1
U	Fluidizing velocity, m/sec
U_O	Incipient fluidizing velocity, m/sec
ΔU	Velocity factor, (U-Uo) / (0.35*((g*D_E) ^0.5)), dimensionless

Greek Symbols:

ρ_p	Density of particle ,kg/m^3
ρ_F	Density of air, kg / m^3
Δ	Change in magnitude, delta
ε	Porosity of the fluidizing bed

Abbreviations:

Up-bed Un-promoted bed

Dp-bed Disc promoted bed

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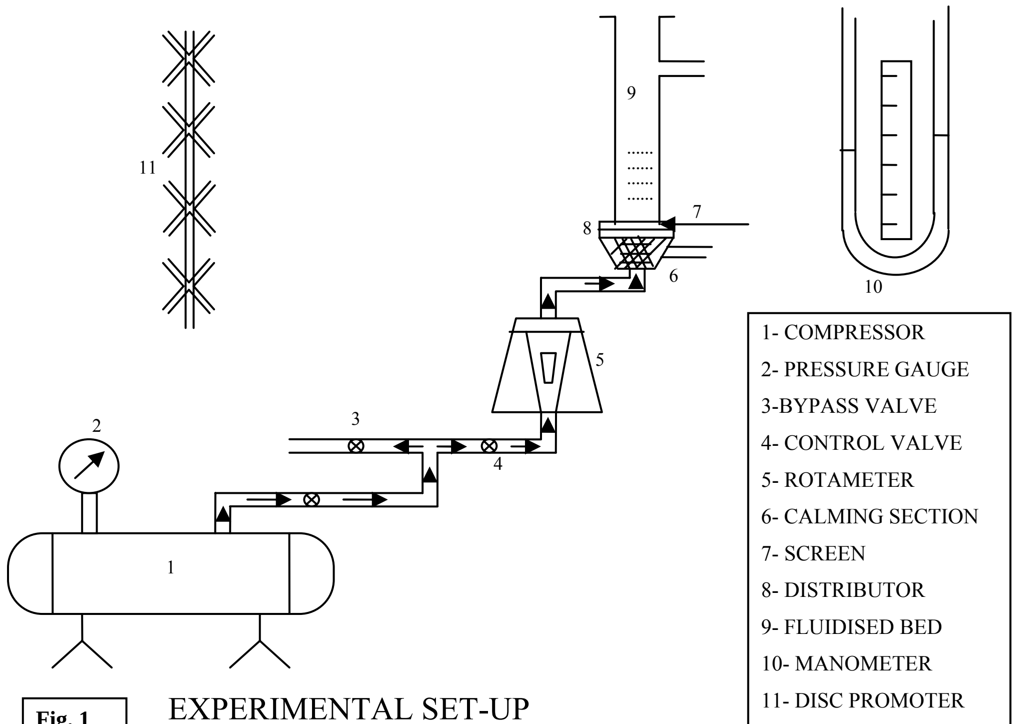

Fig. 1 EXPERIMENTAL SET-UP

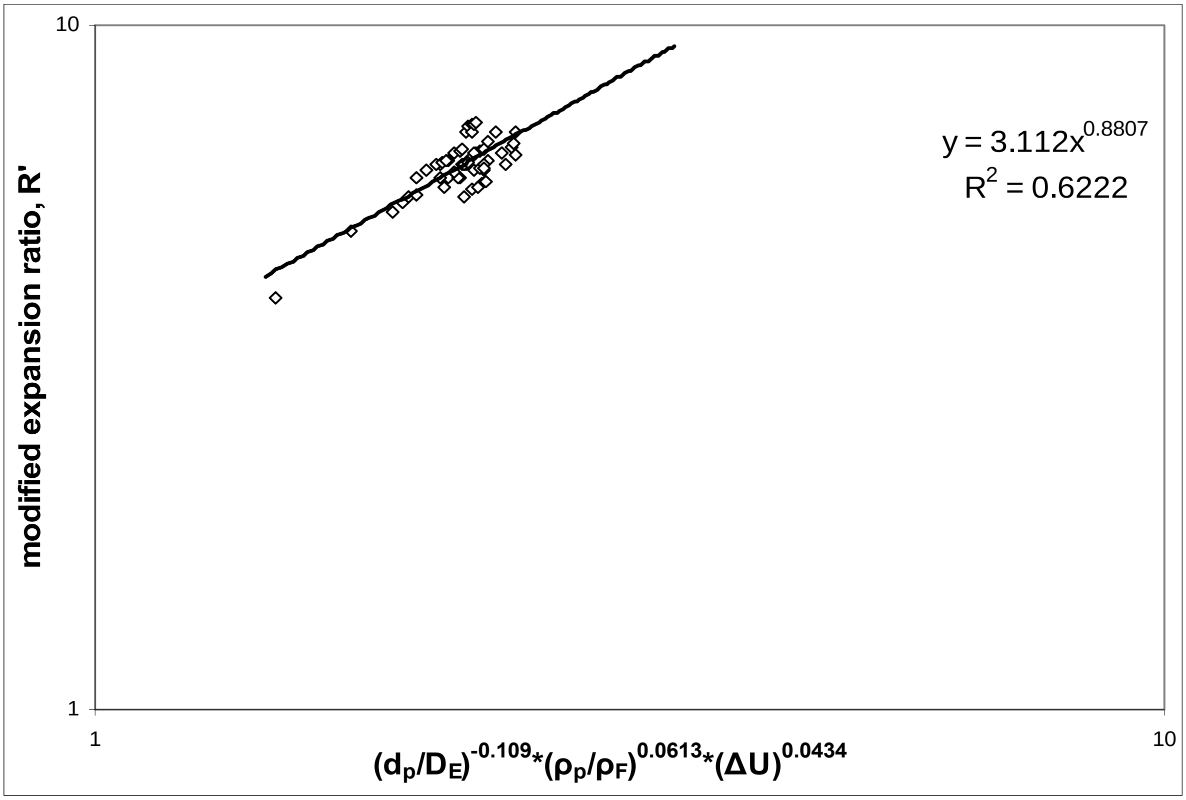

Fig.2-(A): Variation of modified bed expansion ratio with system parameters (the correlation plot by the Modified Singh and Singh's method) for un-promoted bed.

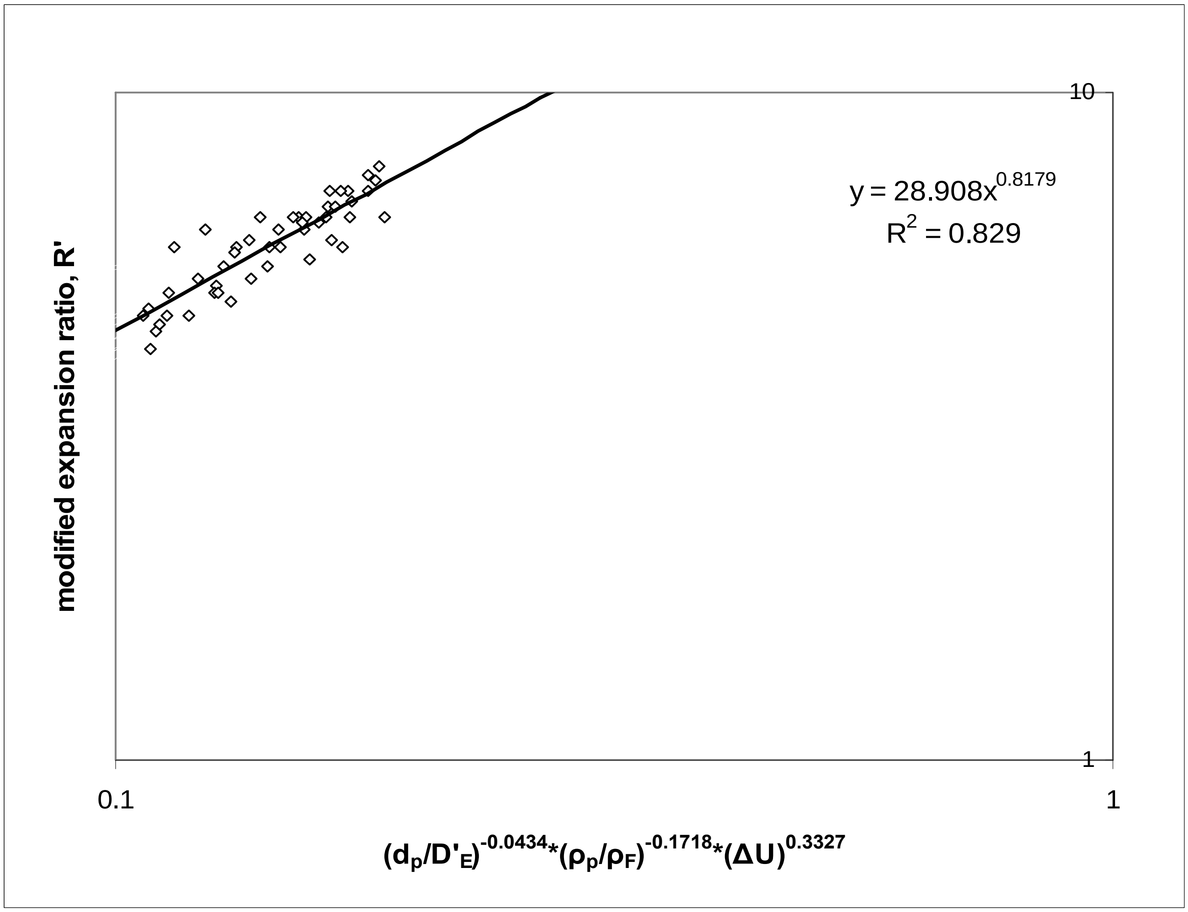

Fig. 2 (B): Variation of modified bed expansion ratio with system parameters (the correlation plot by the Modified Singh and Singh's method) for disc promoted bed

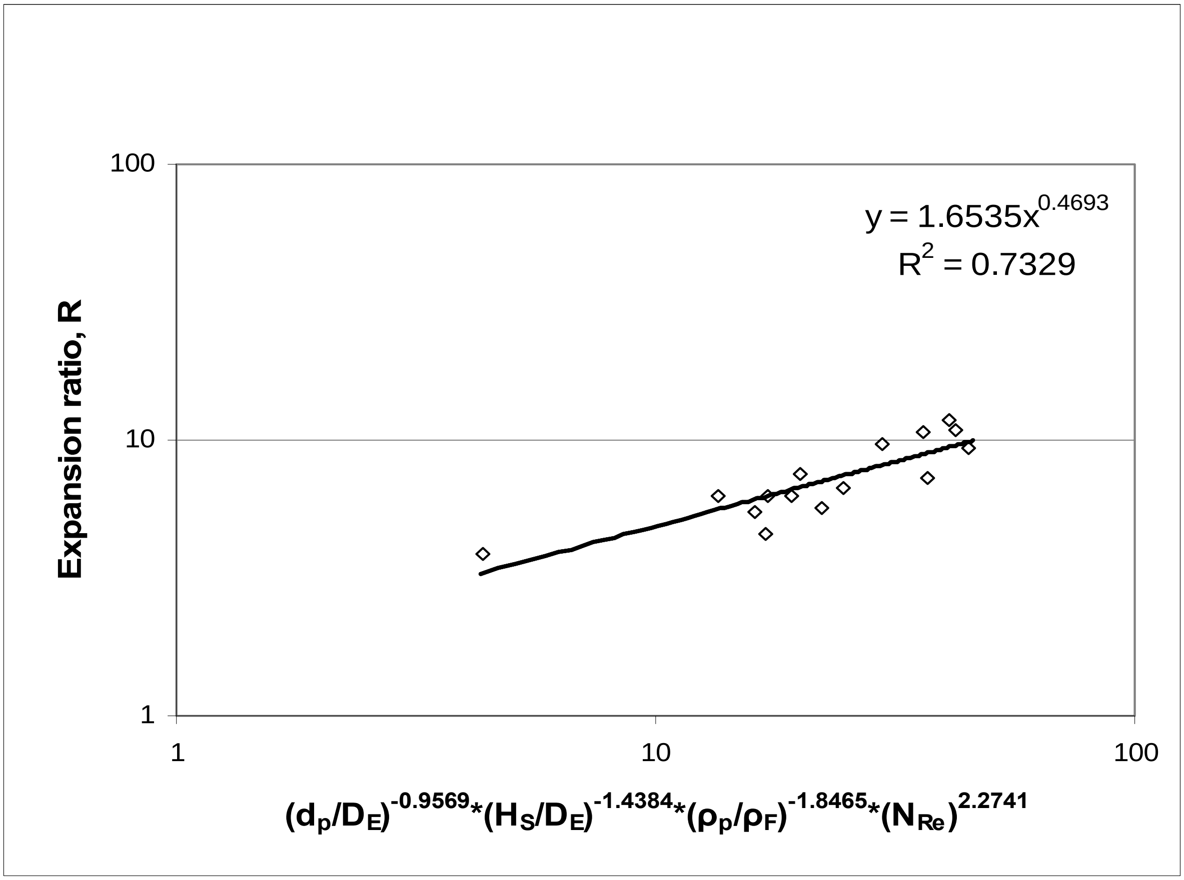

Fig. 3-(A): Variation of bed expansion ratio with system parameters (the correlation plot by the Dimensional analysis approach) for un-promoted bed

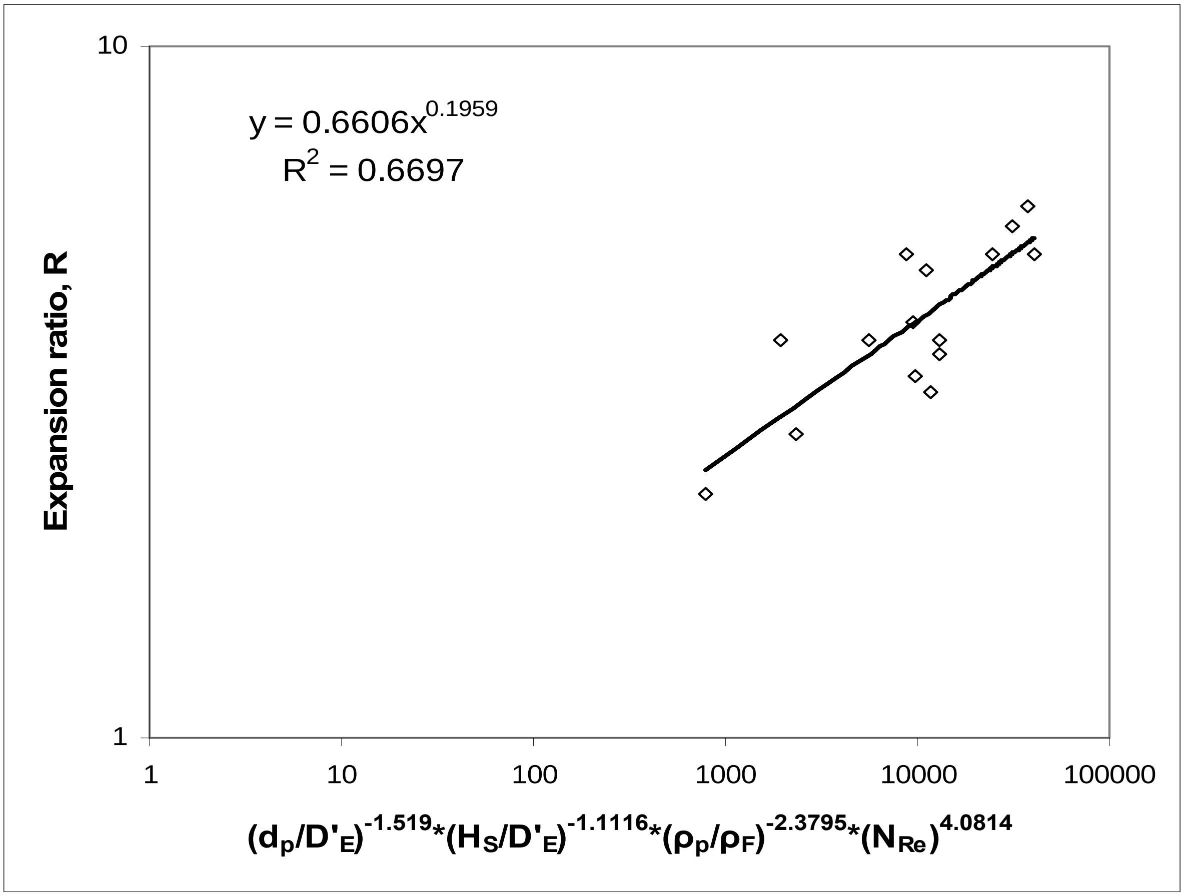

Fig.3-(B): Variation of bed expansion ratio with system parameters (the correlation plot by the Dimensional analysis approach) for disc promoter bed

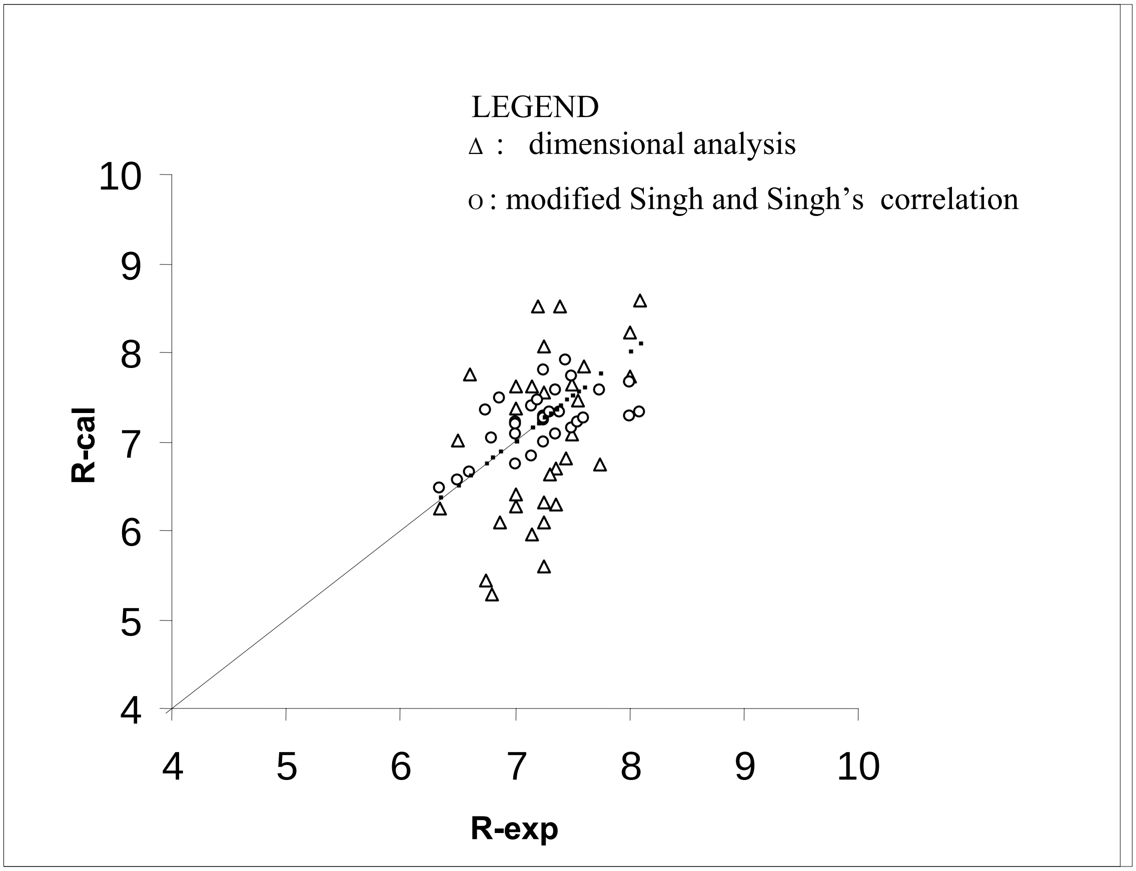

Fig.4-(A): Comparison of calculated values of bed expansion ratio (By modified Singh and Singh's method and dimensional analysis) with the experimental values for un-promoted bed.

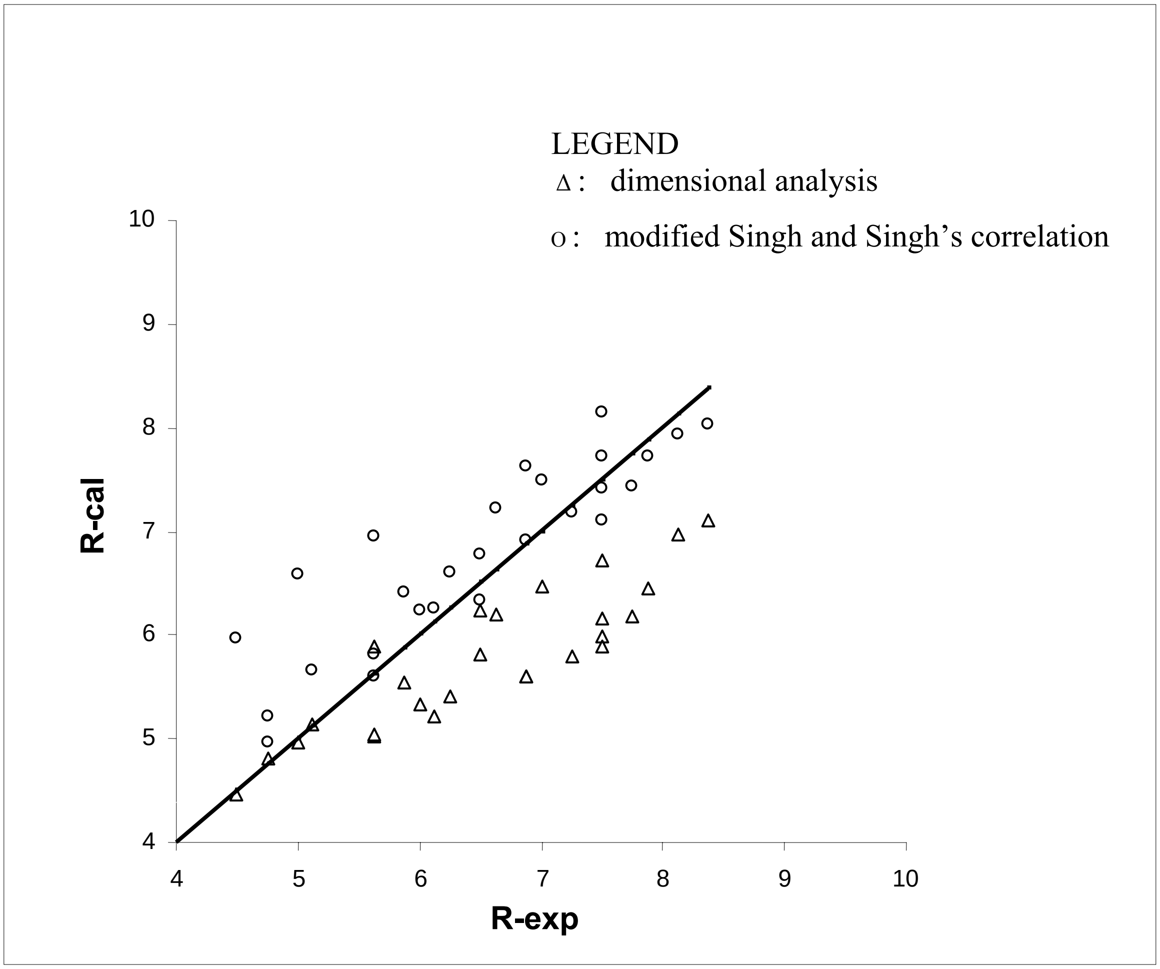

Fig. 4-(B): Comparison of calculated values of bed expansion ratio (By modified Singh and Singh's method and dimensional analysis) with the experimental values for bed with disc promoter.

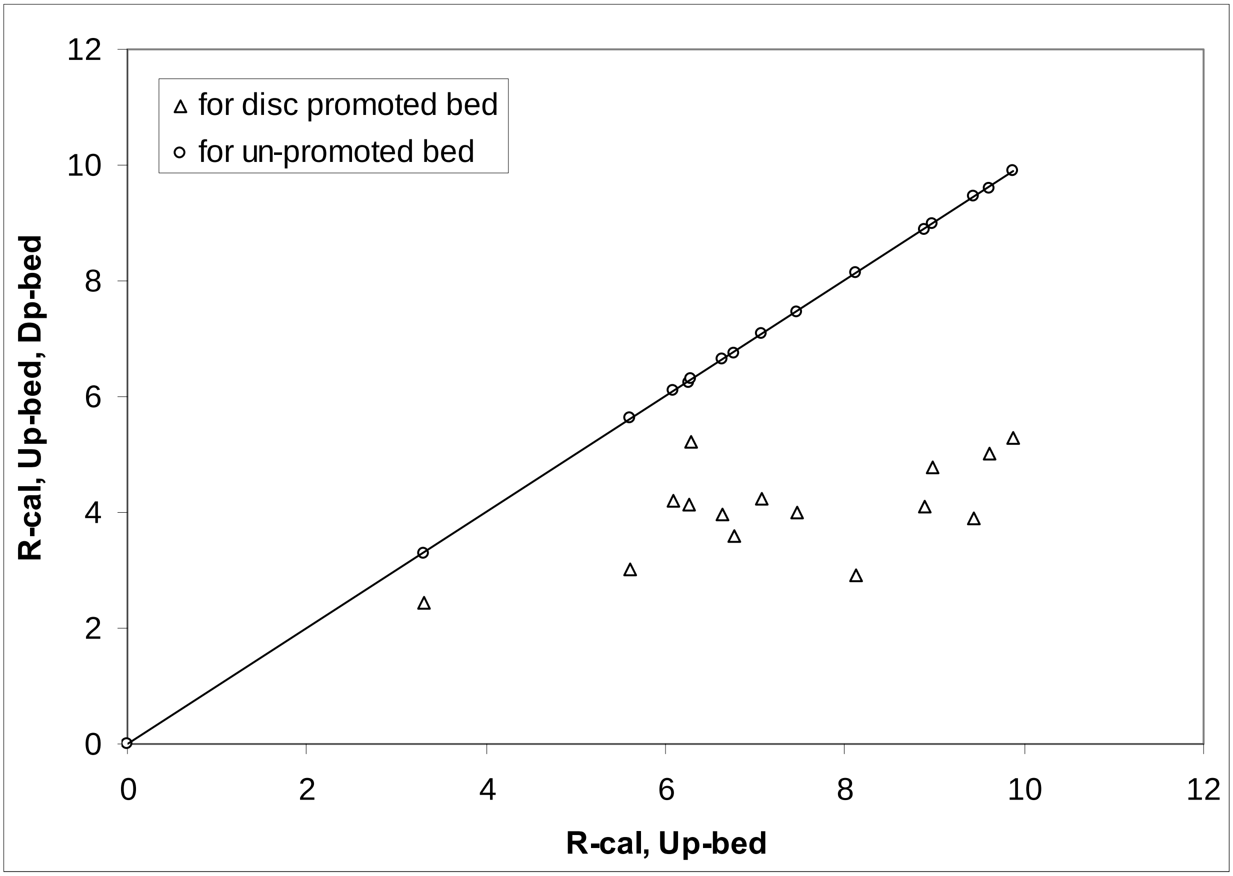

Fig.-5(A): Comparison of calculated values of bed expansion ratio (By Dimensional Analysis approach) for both the un-promoted and disc promoted bed.

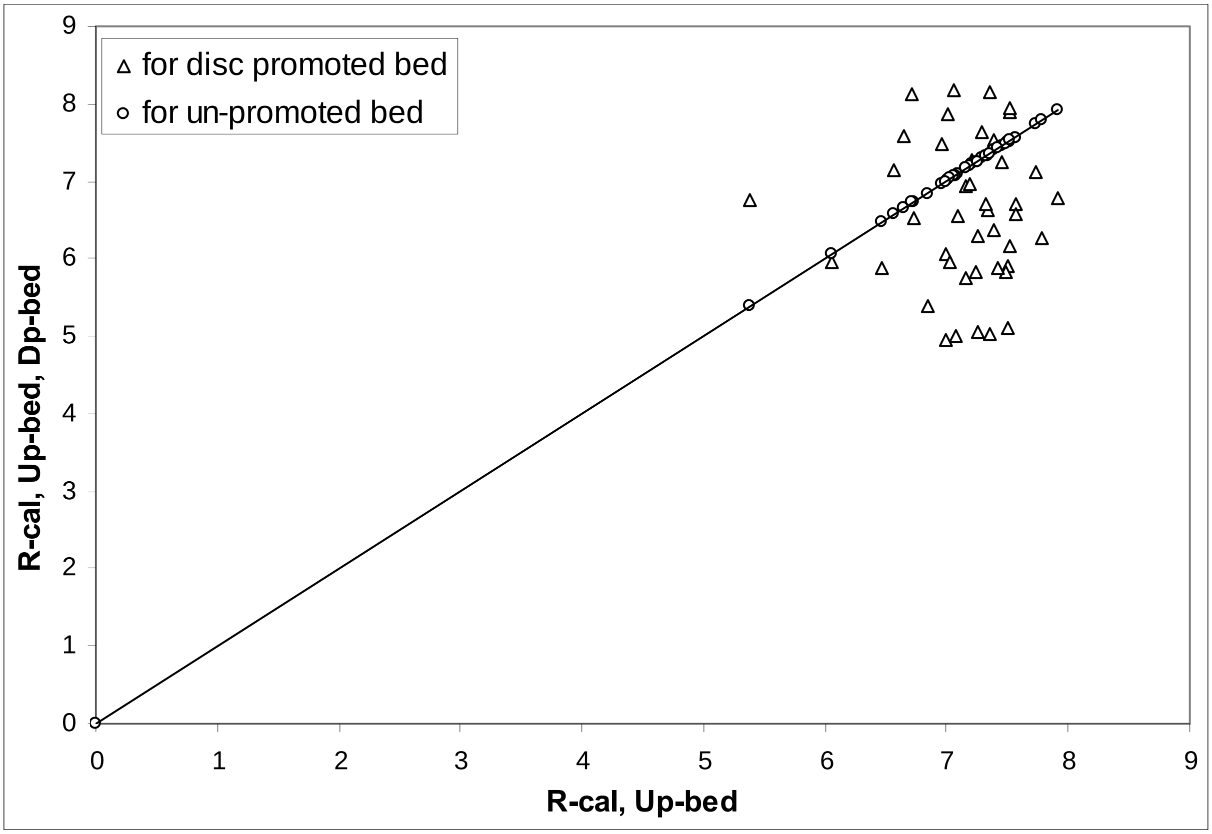

Fig.-5(B): Comparison of calculated values of bed expansion ratio (By Modified Singh and Singh's approach) for both the un-promoted and disc promoted bed.

Table-1: Comparison of correlation factor-m for both the Un-promoted and Disc promoted bed.

Sl.no.	$dp \times 10^3$,m	$\rho_p \times 10^{-3}$,kg/m^3	(U-Uo), m/s	Factor - m	
				Dp-Bed	Up-Bed
1	1.700	2.860	0.0020	0.0025	0.0011
2	1.700	2.860	0.0040	0.0041	0.0022
3	1.700	2.860	0.0060	0.0055	0.0033
4	1.700	2.860	0.0080	0.0067	0.0043
5	1.700	2.860	0.0100	0.0080	0.0053
6	1.700	2.860	0.0200	0.0132	0.0103
7	1.700	2.860	0.0250	0.0156	0.0128
8	1.700	2.860	0.0400	0.0219	0.0201
9	1.700	2.860	0.0500	0.0258	0.0249
10	1.125	2.860	0.0386	0.0039	0.0021
11	0.725	2.860	0.0386	0.0039	0.0020
12	0.550	2.860	0.0385	0.0038	0.0019
13	1.700	2.860	0.0386	0.0040	0.0021
14	1.700	2.250	0.0386	0.0038	0.0022
15	1.700	1.528	0.0385	0.0036	0.0022