Effect of Co-Axial Rod Promoters on the Dynamics of a Batch Gas-Solid Fluidized Bed

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Gas-solid fluidization often suffers from inherent drawbacks like channeling, bubbling, and slugging which affect the quality of fluidization. Efforts have been made in this paper to improve the quality of fluidization in gas-solid fluidized beds by using two different types of co-axial rod promoters. The effects of fluid and solid properties, bed characteristics, and the promoters on fluidization quality (in terms of fluctuation ratio) and bed pressure drop (in terms of Euler Number) have been presented in the form of correlations. The predicted and experimental values of fluctuation ratio and Euler number have been found to agree fairly well.

Gas-solid fluidized beds suffer from certain inherent drawbacks like channeling, bubbling, and slugging which result in poor homogeneity of the bed, thereby affecting the quality of fluidization. Investigations have been made to study the effect of turbulence promoters of different shapes, size and configuration on the quality of fluidization and bed pressure drop. Different types of bed internals such as diplegs, nozzles, immersed objects, slotted baffles, tubes, horizontal and vertical baffles are used for improving the quality of fluidization.

Overcashier et al., Glass and Harrison, and Rowe & Everett studied the effect of horizontal baffles on the quality of fluidization. Volk et al. suggested that vertical tubular surfaces should be inserted in large diameter beds in order to prevent the development of very large bubbles. Krishnamurthy et al. proposed the following correlation for the prediction of fluctuation ratio for gas-fluidized beds using horizontal baffles.

\[
    r = 0.59(Gf / Gmf)^{1.01} (D_p / D_v)^{-0.12} (Dc / Hs)^{-0.20} (\rho_s / \rho_f)^{-0.02}
\]

(1)

Agarwal et al. studied the effect of stirrer type baffles on fluidization quality and proposed a correlation for the prediction of fluctuation ratio:

\[
    r = 2.49(Gf / Gmf)^{1.75} (D_p / Dc)^{-0.07} (Dc / Hs)^{-0.29} (\rho_s / \rho_f)^{-0.25}
\]

(2)

Singh studied the effect of various system parameters on fluctuation ratio in case of unpromoted non-cylindrical beds, viz, square, hexagonal and semicylindrical ones and proposed the following correlations.

For semicylindrical bed:

\[
    r = 2.3 (D_p / Dc)^{0.08} [(Dc / Hs) \times (\rho_f / \rho_s)]^{0.04}
\]

\[
    [(Gf - Gmf) / Gmf]^{0.07}
\]

(3)

For hexagonal bed:

\[
    r = 2.3 (D_p / Dc)^{0.06} [(Dc / Hs) \times (\rho_f / \rho_s)]^{0.05}
\]

\[
    [(Gf - Gmf) / Gmf]^{0.06}
\]

(4)

For square bed:

\[
    r = 2.55 (D_p / Dc)^{0.09} [(Dc / Hs) \times (\rho_f / \rho_s)]^{0.04}
\]

\[
    [(Gf - Gmf) / Gmf]^{0.08}
\]

(5)

Other studies relating to bed dynamics in promoted gas-solid fluidized beds include disc promoter by Ravi et al., twisted strips and wire coils by Colburn and King, co-axially placed cones by Sarveswara Rao et al., ring promoter assembly by Ramabramham et al., string of spheres by Sitaraman, mesh and brush insert by Magerlin et al., Sujatha, Prasad and Koteswara Rao et al. In the present communication, an attempt has been made to report the bed dynamics of gas-solid fluidized beds using two different types of rod promoters in terms of correlations developed for fluctuation ratio (for fluidization quality) and Euler number (for bed pressure drop).

Experimental
The experimental setup used has been detailed elsewhere. For a particular run, bed pressure drop (for fixed and fluidized bed conditions) and bed expansion
and fluctuation (for fluidized condition) have been noted with varying fluid flow rate. The procedure has been repeated for different bed material of varying particle size and static bed height and also for two types of promoters, viz. the rod type and the disc type. The scope of the experiment is given in table-1.

### Table 1: Scope of Experiments

<table>
<thead>
<tr>
<th>Bed Materials</th>
<th>Particle density $\rho_s$, Kg/m$^3$</th>
<th>Initial bed height $H_b$,m $\times 10^2$</th>
<th>Particle size $D_p$,m $\times 10^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal (M1)</td>
<td>1430</td>
<td>6.0</td>
<td>0.0925</td>
</tr>
<tr>
<td>Coal+Dolomite (M2)</td>
<td>1950</td>
<td>9.0</td>
<td>0.0780</td>
</tr>
<tr>
<td>Sand (M3)</td>
<td>2810</td>
<td>12.0</td>
<td>0.0605</td>
</tr>
<tr>
<td>Dolomite (M4)</td>
<td>2760</td>
<td>15.0</td>
<td>0.0426</td>
</tr>
<tr>
<td>Manganese (M5)</td>
<td>4836</td>
<td>15.0</td>
<td>0.0102</td>
</tr>
</tbody>
</table>

### B. Promoters used

1. Rod type promoter (P1): Diameter of the rods = 0.6
2. Blade type promoter (P2):
   - No. of blades/disc = 4
   - Disc spacing = 5 cm
   - Disc diameter = 4.4 cm

### Development of Correlations for Bed-dynamics

#### (i) Correlation for pressure drop:

Using dimensional analysis approach pressure drop for batch gas-fluidized beds with and without turbulence, promoters has been correlated in the form of Euler number with various non-dimensional system parameters representing bed and material properties. These parameters are expressed with the Euler number (EU) as:

$$EU = f(\frac{H_s}{D_c}, \frac{H_e}{D_c}, \frac{D_p}{D_c}, \frac{\rho_s}{\rho_f})$$

or,

$$EU = \zeta(\frac{H_s}{D_c})^a \left(\frac{H_e}{D_c}\right)^b (\frac{D_p}{D_c})^c \left(\frac{\rho_s}{\rho_f}\right)^d$$

Analysing the experimental data for the effect of individual parameter, following correlations have been obtained with the help of least square fit:

For unpromoted bed:

$$\frac{\Delta P}{\rho_f U^2} = 0.0124(\frac{H_s}{D_c})^{2.8}\left(\frac{H_e}{D_c}\right)^{-1.51}$$

$$(\frac{D_p}{D_c})^{-1.45} \left(\frac{\rho_s}{\rho_f}\right)^{0.66}$$

For bed with co-axial rod type promoter:

$$\frac{\Delta P}{\rho_f U^2} = 0.003(\frac{H_s}{D_c})^{2.19}\left(\frac{H_e}{D_c}\right)^{-2.15}$$

$$(\frac{D_p}{D_c})^{-1.3} \left(\frac{\rho_s}{\rho_f}\right)^{1.02}$$

For bed with co-axial disc type promoter:

$$\frac{\Delta P}{\rho_f U^2} = 1.842(\frac{H_s}{D_c})^{1.86}\left(\frac{H_e}{D_c}\right)^{-0.93}$$

$$(\frac{D_p}{D_c})^{0.57} \left(\frac{\rho_s}{\rho_f}\right)^{0.34}$$

#### (ii) Correlation for fluctuation ratio:

Fluctuation ratio used as a criterion for the measurement of fluidization quality has been related to different static and dynamic parameters of the system, viz. aspect ratio excess velocity ratio, wall effect and density ratio. Following the aforesaid method, the correlations obtained are as follows:

For unpromoted bed:

$$r = 0.003(\frac{H_s}{D_c})^{0.11}(\frac{D_p}{D_c})^{-0.05}$$

$$(\frac{\rho_s}{\rho_f})^{1.08} \left(\frac{G_f - Gmf}{Gmf}\right)^{0.35}$$

For bed with co-axial rod type promoter:

$$r = 0.004(\frac{H_s}{D_c})^{0.15}(\frac{D_p}{D_c})^{-0.29}$$

$$(\frac{\rho_s}{\rho_f})^{0.29} \left(\frac{G_f - Gmf}{Gmf}\right)^{0.30}$$

For bed with co-axial disc type promoter:

$$r = 0.87(\frac{H_s}{D_c})^{0.04}(\frac{D_p}{D_c})^{-0.04}$$

$$(\frac{\rho_s}{\rho_f})^{0.02} \left(\frac{G_f - Gmf}{Gmf}\right)^{0.04}$$

### Results and Discussion

The effects of fluid and solid properties, bed characteristics (i.e. wall effect, bed expansion and aspect ratio) and two different types of promoters on bed pressure drop (equations 8 to 10) and bed fluctuation (equations 11 to 13) have been obtained.

#### Bed pressure drop:

The bed pressure drop has been found to increase with the increase in initial static bed height, particle size and density. The values of Euler number calculated from the proposed correlations (equations 8 to 10) agree fairly well with those obtained from experiments as is evident from figure 1 (a, b and c). The mean and standard deviations calculated for unpromoted bed and bed with co-axial rod and disc promoters have been 4.54 and 8.07, 6.89 and 7.82 and 6.44 and 7.29 respectively. Further it is observed that in case of co-axial rod type promoter, there is an increasing trend in pressure drop when compared to an unpromoted bed. The increase in pressure drop indicates that some channels of the fluidized bed
have been broken since the three rods of the rod type promoter are at three different positions of the bed. However, in case of co-axial disc type promoter, a decrease in pressure drop has been observed. In this case the effect of the promoter is restricted to the central region only. Hence channeling has been partly reduced in the centre but increased simultaneously in the annular region (w.r.t. the promoter) thus resulting in a decrease in pressure drop when compared to an unpromoted bed.

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Bed fluctuation and fluidization quality:
It is observed that fluctuation ratio increases with initial static bed height and decreases with increase in particle size and density. The values of fluctuation ratio calculated from the developed correlations (equations 11 to 13) agree fairly well with those obtained from experiments (figures 2.a, b and c). The mean and standard deviations calculated for the unpromoted bed and bed with co-axial rod and disc promoters have been 3.00 and 3.48, 6.00 and 5.34 and 2.54 and 3.01 respectively.
hindrance to the coalescence of bubbles in the central region of the bed where the discs of the promoters are present.

Table 2: Comparison of Fluctuation Ratio
(Fluid mass velocity = 508 kg/hr. m²)

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Material</th>
<th>Hs Cm.</th>
<th>Dp x 10³ m</th>
<th>ρs kg/m³</th>
<th>Fluctuation ratio, r</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP</td>
<td>Bed with</td>
<td>Bed with</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>P2</td>
<td>P1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>M4</td>
<td>6.0</td>
<td>0.0780</td>
<td>2760</td>
<td>1.48</td>
</tr>
<tr>
<td>2</td>
<td>M4</td>
<td>9.0</td>
<td>0.0780</td>
<td>2760</td>
<td>1.68</td>
</tr>
<tr>
<td>3</td>
<td>M4</td>
<td>12.0</td>
<td>0.0780</td>
<td>2760</td>
<td>1.87</td>
</tr>
<tr>
<td>4</td>
<td>M4</td>
<td>15.0</td>
<td>0.0780</td>
<td>2760</td>
<td>1.95</td>
</tr>
<tr>
<td>5</td>
<td>M4</td>
<td>9.0</td>
<td>0.0925</td>
<td>2760</td>
<td>1.35</td>
</tr>
<tr>
<td>6</td>
<td>M4</td>
<td>9.0</td>
<td>0.0605</td>
<td>2760</td>
<td>1.78</td>
</tr>
<tr>
<td>7</td>
<td>M4</td>
<td>9.0</td>
<td>0.0428</td>
<td>2760</td>
<td>1.94</td>
</tr>
<tr>
<td>8</td>
<td>M1</td>
<td>9.0</td>
<td>0.0605</td>
<td>1420</td>
<td>2.00</td>
</tr>
<tr>
<td>9</td>
<td>M2</td>
<td>9.0</td>
<td>0.0605</td>
<td>1950</td>
<td>1.88</td>
</tr>
<tr>
<td>10</td>
<td>M3</td>
<td>9.0</td>
<td>0.0605</td>
<td>2610</td>
<td>1.81</td>
</tr>
<tr>
<td>11</td>
<td>M3</td>
<td>9.0</td>
<td>0.0605</td>
<td>4835</td>
<td>1.52</td>
</tr>
</tbody>
</table>

The developed correlations can be used effectively to predict the bed dynamics and fluidization quality for gas-solid systems in the ranges of variables investigated. In view of comparatively low bed pressure drop and fluctuation ratio for the disc type promoter, further work in this direction may be useful for a better understanding of the promoted gas-solid fluidized bed.

Numerical values for the latter one. This may be due to combined effects of the breaking up of channels and

References