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Identify the Impact of Flow Pattern on Solid Mixing in Bubbling Fluidization

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Abstract: In this study, we attempted to predict solid and bubble flow patterns in a bubbling fluidized bed based on operational conditions, the air distributor and particle velocity, and investigated the impact of flow pattern on solid mixing behaviour. The solid mixing behaviour was estimated based on the dispersion coefficient of particles, the active index (AI), and the distribution of particle residence time within the entire bed. It was found that the flow patterns are a result of a combination of operational conditions, properties of bed materials, and bed designs. A 'Flow Pattern Parameter (FPP)' was proposed to identify the solid flow pattern in a bubbling fluidized bed. Different flow pattern corresponds to a certain range of the Flow Pattern Parameter. The particle dispersion coefficient, AI, and the distribution of particle residence time clearly agree with solid flow patterns and bubbling behavior within the beds.

1 Introduction

Bubbling fluidization has been employed to many industrial processes, such as granulation, coating and drying, mixing, coal combustion and gasification, renewable energy production, chemical, petrochemical and metallurgical processes. Intensive research has been conducted to investigate the fluidization behavior experimentally and numerically, and many models have been developed for optimizing reactor design and bed scale up, and the effect of operational conditions, particle properties and bed design on fluidization behavior and mixing. However many factors can affect solid/gas flow pattern and solid mixing in a fluidized bed and make fundamental analysis, modelling and prediction of fluidization behaviour difficult and in some cases impossible. In this study, we use PEPT to directly measure the impact of the operation parameters and air distributor on solid and gas behaviour in a bubbling fluidized bed, and then provide a form of equation to identify the flow structure in bubbling fluidization regime based on bed design and operational conditions. The dispersion coefficients, the distribution of average residence time of the particle at different regions of the bed of particles were calculated based on particle trajectories. An active index (AI) has been developed to evaluate the solid mixing by understanding the frequency and opportunity of particles travelling to different regions within the fluidized beds.

2 Experimental set-up

The fluidization experiments were performed in a Plexiglas cylindrical bed with an inner diameter of 152 mm and a height of 1 m. Experiments were designed to investigate the effect of the aspect ratio (H/D), superficial gas velocity, and air distributor on solid/gas flow structure. The air distributors were sintered metal sheets with pore diameters varying from 1 µm to 0.23 mm. The bed materials were glass beads with the average diameter of 352 microns, and a size range from 300-400 µm. The density of glass beads was 2700 (kg/m3). Tts minimum fluidization velocity was 0.15 m/s. The applied superficial gas velocity varied from 0.306 m/s to 0.642 m/s. The experiments were performed within the bubbling fluidization regime that was characterized by visual observation and the measured bed pressure drop.

3 Results and Discussion

In order to identify certain flow patterns for Geldart B particle beds, a 'Flow Pattern Parameter (FPP)' has been proposed based on the PEPT measurement as shown in *Eq 1*. The FPP takes account of particle kinetic energy, minimum fluidization velocity, superficial gas velocity, the pore size of the air distributor, bed diameter to the bed height ratio. Fig. 1 indicates that the solid flow patterns can be clearly separated via FPP, and each flow patterns fall into a specific FPP range.

$$FPP = \frac{H_B}{D_B} \cdot \sqrt{\frac{V^2}{d_D{}^4 \times \left(u - u_{mf}\right)^2}} = \frac{H_B}{D_B} \cdot \frac{\left|V\right|}{d_D{}^2 \times \left(u - u_{mf}\right)} \qquad Eq\ (1).$$

Where H_B is the packed bed height (mm), D_B is the bed diameter (mm), v is the particle speed (mm/s), d_D is the pore diameter of the air distributor (mm), u is the superficial gas velocity (mm/s), u_{mf} is the minimum fluidization velocity (mm/s).

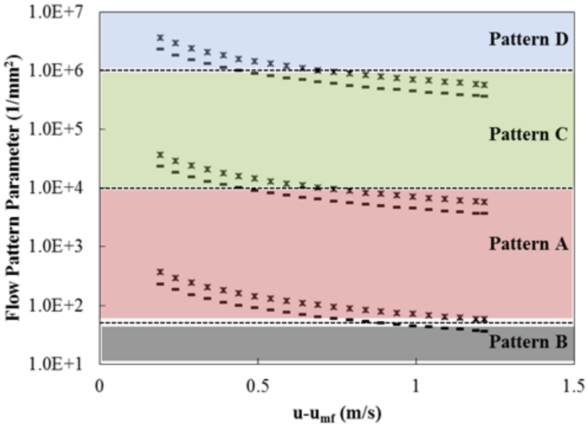

Fig. 1 Prediction of flow patterns using FPP

To calculate the dispersion coefficient, the bed was divided into many small compartments and the dispersion of particles was analysed from different positions. The dispersion coefficient is obtained from the mean squared displacement of the dispersing particles using the Einstein relation (*Eq. 2*) for the vertical direction (1-D) or *Eq 3* for the horizontal direction (2-D) [1, 2], where $S^2(dt)$ is the mean squared displacement at time interval dt, and D is the solid dispersion coefficient. At time t = t_1, the mean position of released particles can be calculated from *Eq 4*, and the dispersion coefficient of particles in the vertical direction (D_v) and horizontal direction (D_h) can then be determined by *Eq 8* from the linear, increasing portion.

$$S^2(dt) = 2Ddt \text{ (1-D)} \qquad \textit{Eq (2)}$$

$$S^2(dt) = 4Ddt \text{ (2-D)} \qquad \textit{Eq (3)}$$

$$\begin{cases} \overline{x_1} = \frac{1}{N}\sum_{i=1}^{N} x_{i1} \\ \overline{y_1} = \frac{1}{N}\sum_{i=1}^{N} y_{i1} \\ \overline{z_1} = \frac{1}{N}\sum_{i=1}^{N} z_{i1} \end{cases} \qquad \textit{Eq (4)}$$

$$\begin{cases} S_{vi}(t_1) = |y_{i1} - \overline{y_1}| \\ S_{hi}(t_1) = \sqrt{(x_{i1} - \overline{x_1})^2 + (z_{i1} - \overline{z_1})^2} \end{cases} \qquad \textit{Eq (5)}$$

$$\begin{cases} \overline{S_v(t_1)^2} = \frac{1}{N}\sum_{i=1}^{N} S_{vi}(t_1)^2 \\ \overline{S_h(t_1)^2} = \frac{1}{N}\sum_{i=1}^{N} S_{hi}(t_1)^2 \end{cases} \qquad \textit{Eq (6)}$$

$$\begin{cases} t_2 = \frac{1}{N}\sum_{i=1}^{N} \Delta t_{i2} + t_1 \\ \overline{S_v(t_2)^2} = \frac{1}{N}\sum_{i=1}^{N} S_{vi}(t_2)^2 \\ \overline{S_h(t_2)^2} = \frac{1}{N}\sum_{i=1}^{N} S_{hi}(t_2)^2 \end{cases} \qquad \textit{Eq (7)}$$

$$\begin{cases} D_v = \frac{1}{2} \cdot \frac{d\overline{S_v{}^2}}{dt} \\ D_h = \frac{1}{4} \cdot \frac{d\overline{S_h{}^2}}{dt} \end{cases} \qquad \textit{Eq (8)}$$

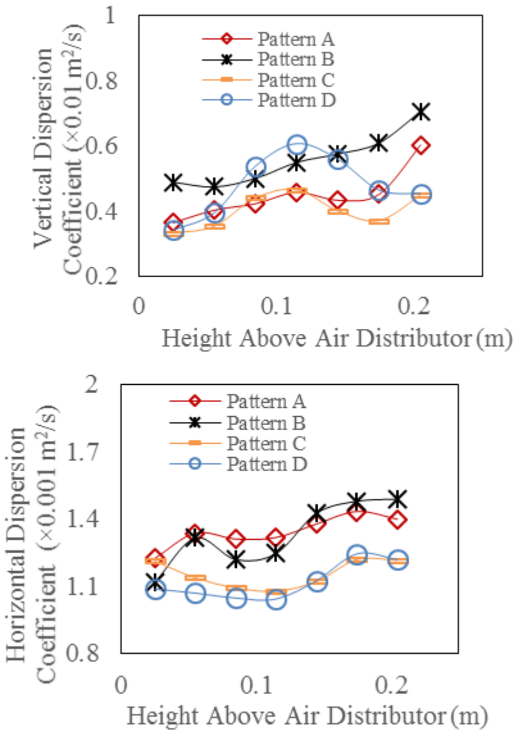

Fig 2. Dispersion coefficients of solids against bed heights

Activity index (AI) is proposed in this study to further evaluate the solid mixing behaviour within fluidized beds. It is defined based on the number of times of particles pass through a unit of volume within a unit of time, as shown in Eq 9. The AI represents the activity of particles in different areas and describes the frequency and probability of particles moving to different locations. For uniform solid mixing, the AI obtained in a different region throughout the entire fluidized bed should have a uniform profile.

$$Activ\ Index = \frac{The\ number\ of\ passes}{Measured\ Volume \times Total\ tracking\ time} \ (/cm^3 \cdot s)$$

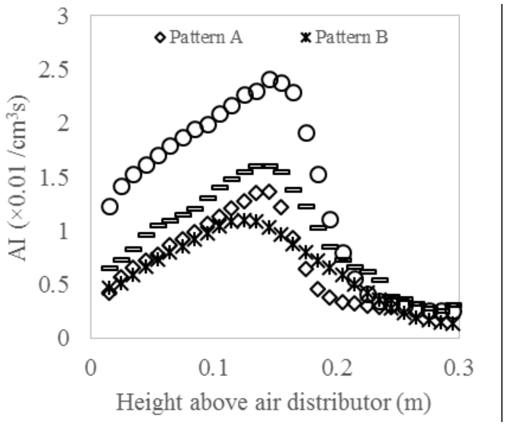

Fig 3. Averaged AI against bed heights.

In addition to the AI, the residence time of solids in a particular area is an important factor in fluidized beds. To determine the distribution of the particle residence time throughout the entire bed, the bed is partitioned into many compartments using the same manner for determining the AI. For each compartment, once a pair of entrance has been detected, the time interval between the inflow and outflow is calculated and recorded. After all pairs of passes have been determined for a compartment, the average residence time for every entrance of the tracer particle in this compartment is calculated. The obtained average residence time of tracer particle is then divided by the compartment volume to calculate the average residence time per unit volume (s/m^3) of the tracer particle at this position. Fig 4 indicate that particles in patterns C and D are much more active than those in patterns A and B.

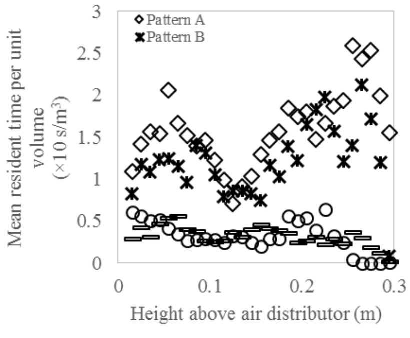

Fig. 4. Mean residence time per entrance per unit volume.

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