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Progressive Exapnsion of Particles in 3-Phase Inverse Fluidized Bed for Higher Archimedes Number

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Abstract: *Hydrodynamics of 3-phase Inverse fluidized bed are studied for three static bed heights with three particles which has higher Archimedes number. The gas velocities corresponding to the onset of fluidization (1st layer detachment), complete fluidization (last layer detachment), are identified. The variation of packed bed with gas, liquid velocity, static bed height and Archimedes number, gas distributor are presented.*

1. INTRODUCTION

Inverse fluidization is an operation in which solid particles having density lower than that of the liquid are fluidized by the downward flow of continuous liquid phase. In 3-phase inverse fluidized bed (IFB) gas is introduced counter currently to the liquid as dispersed phase [1]. Inverse fluidization has several advantages such as high mass transfer rates, minimum carry over of coated microorganisms due to less solids attrition and efficient control of biofilm thickness. The inverse fluidization can be also achieved with only upward gas flow and no net liquid flow (batch liquid) which depends on particle density and particle diameter/Archimedes number [2-6]. This operation has applications in biotechnology, wastewater treatment and catalytic chemical processes. One of the basic problems to understand the IFB was startup of the Fluidization of particles from packed condition where initially present. Transition of particles from packed bed to fluidized bed can be called as progressive expansion. Many authors observed these progressive phenomena in IFB and reported in literature [2, 7-10]. The study of Ibrahim *et al.*(1997) [7] first revealed that bottom most particles in the bed will be fluidizing and rest was in packed condition. Similar behavior was observed by Comte *et al* (1997), [3] for IFB with batch liquid also. The author's studied with three different types of distributors namely perforated and two membrane distributors. The progressive expansion behavior was more pronounced in perforated plate than membrane distributor. Buffiere *and Moletta* (1999) [8] studied the hydrodynamics of two different particles i.e one particle was pellet and another one was sphere with almost same Archimedes number but different diameter and densities. They reported the particles experience the onset of fluidization and transition to fluidization behavior. Choi and Shin (1999) [9] studied two different fluidized bed reactors for waste-water treatment and reported that the particles expands progressively. The study of Lee *et al* (2000) [10] has given some in-sights on transition of particles from packed to fluidized bed condition. The authors called these phenomena as partially fluidized bed regime. Information available on progressive expansion of particles was scanty and systematic study was also not available. The primary objective of present study is to characterize the hydrodynamic behavior of 3-phase IFB during the transition from packed to fluidized bed condition. The hydrodynamic parameters such as onset of fluidization, complete fluidization (minimum fluidization velocity) are measured. The variation of packed bed was also presented.

Experimental

A schematic diagram of the experimental setup is shown in Figure 1. The column is made up of acrylic material. Liquid flow rate was measured with calibrated rotameters.

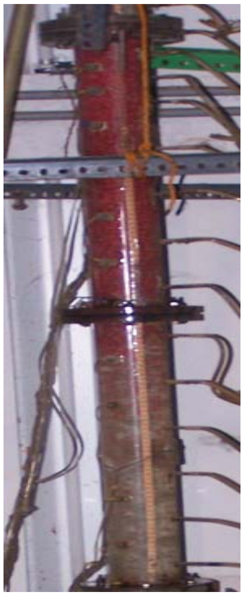

Fig. 1: Experimental setup.

Calibrated rotameters are used for measuring gas flow rate and it is dispersed at the bottom of the section. Provisions were made for particles should confine in the test section. Water, air and spherical polypropylene solid particles were used as liquid, gas and solid phases respectively. Three different static bed heights 15 cm, 30 cm, 45 cm are used for study of the effect of the bed height.

2. HYDRODYNAMIC BEHAVIOR

Initially pre measured solid particles are loaded to the column and filled up with liquid from the top of the test section. Under these conditions, the particles float at the top of test section as a packed bed with no liquid flow. The gas was dispersed at bottom of the column. At a particular liquid velocity and low gas velocities the gas slowly percolates through packed bed without disturbing the particles. As the gas velocity was increased the bottom layer of the particles detaches from the bed and attaining the fluidization condition. This was termed as onset of fluidization or 1st layer detachment from the static bed. With further increase in gas velocity more and more layers detaches or fluidizes, maintaining both fluidized and packed beds. The partially fluidized bed is now composed of a packed bed at the top and a fluidized bed at the bottom (Fan *et al.*, 1982a, Comte *et al.*, 1997, Buffiere and Moletta, 1999 and Choi and Shin, 1999). At some gas velocity at same liquid velocity, the last layer fluidizes maintaining the whole bed under fluidization condition. This gas velocity is termed as minimum gas fluidization velocity at that liquid velocity. With increased gas velocity the solids are uniformly distributed through out the bed. The gas velocity corresponding to this condition is termed as uniform fluidization gas velocity at that liquid velocity.

The cross sectional phase holdups are estimated using the following equations.

$$\varepsilon_l = \gamma^n \qquad \rightarrow (1)$$

$$\left(\frac{-dp}{dz}\right) = \left(\varepsilon_g \rho_g + \varepsilon_l \rho_l + \varepsilon_s \ \rho_p\right) g \qquad \rightarrow (2)$$

$$\varepsilon_g + \varepsilon_l \ + \varepsilon_s = 1 \qquad \rightarrow (3)$$

Eq. (1) is related with relative conductivity, □□which is measured experimentally and hence liquid holdup, □$_l$ can be calculated. The gas holdup □$_g$, solid holdup □$_s$, are calculated using Eq. (2) and (3) by knowing the liquid holdup.

3. RESULTS AND DISCUSSION

Calculation of % Packed bed: The percentage of packed bed calculated as specified in the formula

$$\% \, packed\, bed = \frac{packed\, bed\ height}{static\, bed\ height} \mathrm{X}100$$

This % packed bed provides a form of representing the progressive expansion of the bed till minimum fluidization condition. It is clearly showing the different stages from packed to fully fluidized state through partially fluidized regime. For example if the % packed bed height was 100% i.e the particles were completely under packed condition (packed bed), if it was 80% i.e. the packed bed was 80%, remaining fluidized condition (progressive expansion) and finally 0% represents to the complete fluidization.

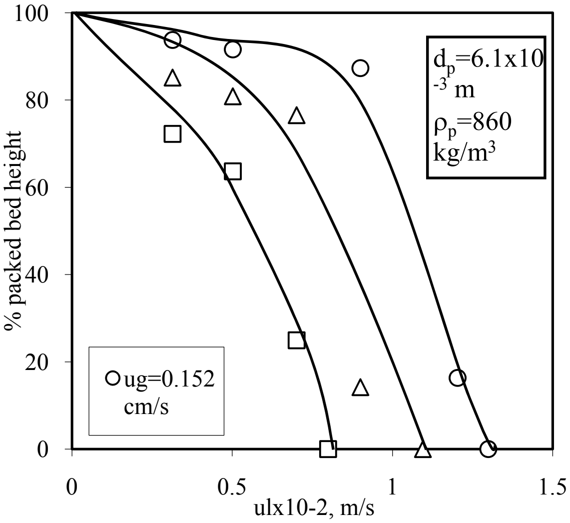

Fig. 2: Effect of liquid velocity on % packed bed

The effect of different operating and geometric parameters on % packed bed is discussed below.

Effect of liquid velocity

The effect of liquid velocity on % packed bed was shown in **Fig. 2** for Archimedes number of 311736 with a static bed height of 0.45 m with gas velocity as parameter. With increase in liquid velocity, the % packed bed decreases gradually for low liquid velocity as the bottom layers of bed start fluidizing and then steeply decreases as the liquid velocity approaches minimum liquid fluidization velocity at which the % packed bed finally becomes zero.

Effect of gas velocity

Figure 3 shows the effect of gas velocity on % packed bed for Archimedes number of 311736 with a static bed height of 0.45 m with liquid velocity as parameter. With increase in gas velocity, the % packed bed decreases finally reaching zero.

Unlike with the effect of liquid velocity, the decrease of % packed bed with gas velocity does not show two **regions**.

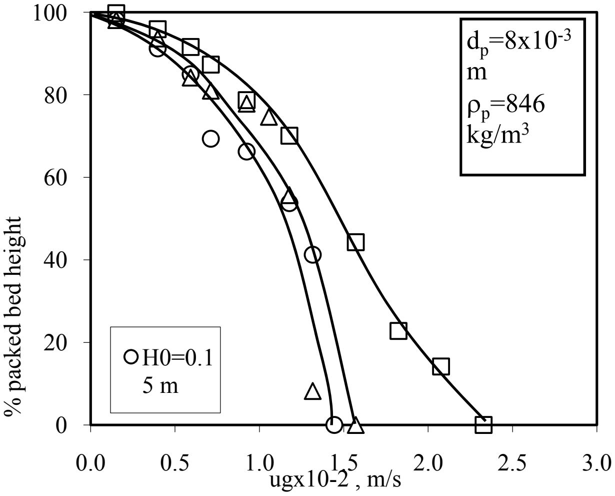

Fig. 4: Effect of static bed height on % packed bed

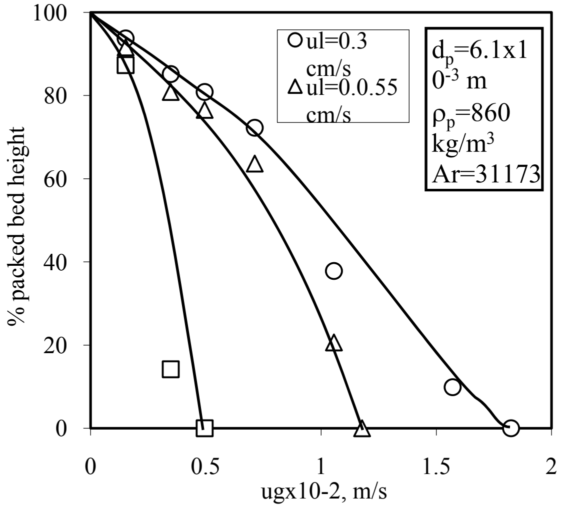

Fig. 3:Effect of gas velocity on % packed bed

Effect of static bed height

Figure 4 shows the effect of static bed height on % packed bed for Archimedes number of 311736 at a particular liquid velocity with gas velocity as independent variable. It can be observed from the below figure that, the % packed bed increases with increase in static bed height due to lower bed expansion for higher static bed heights.

Effect of Archimedes number

The effect of Archimedes number on % packed bed is shown in **Fig. 5** for a static bed height of 0.45 m at a particular liquid velocity with gas velocity as independent variable. For the given liquid and gas velocity, the % packed bed is higher for particles of higher Archimedes number due to lower bed expansion.

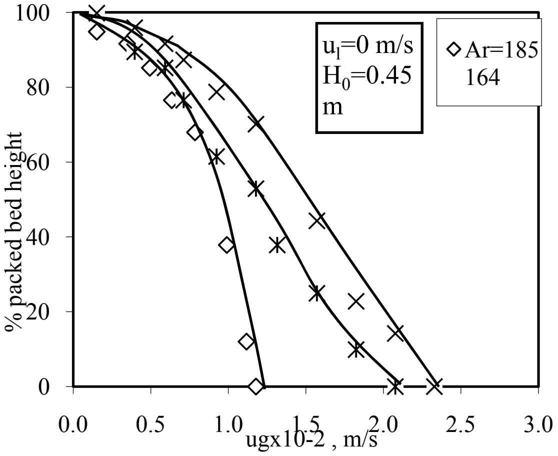

Fig. 5: Effect of Archimedes number on % packed bed

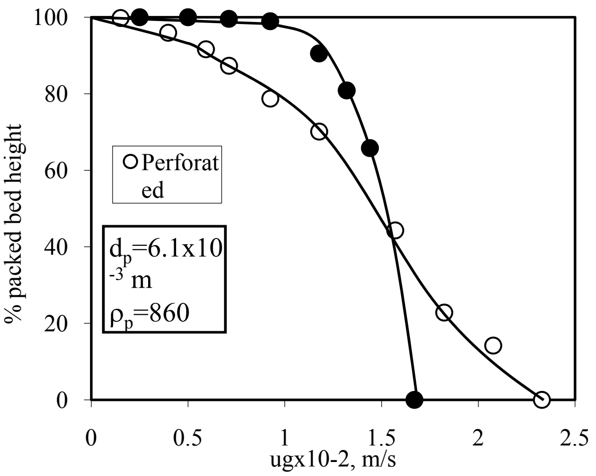

Fig. 6: Effect of type of gas distributor on % packed bed height

Effect of gas distributor type

Figure 6 shows the effect of gas distributor type on % packed bed for Archimedes number of 311736 with a static bed height of 0.45 m at zero liquid velocity with gas velocity as independent variable. In the case of mesh gas distributor, the decrease of % packed bed with gas velocity is steeper compared to that for perforated plate gas distributor. Therefore, the % packed bed for mesh gas distributor is higher than that of perforated plate gas distributor for lower gas velocity and the reverse is true for higher gas velocity. Similar behavior was observed in the studied of Comte et al (1997). The mesh gas distributor used to give uniform gas bubble distribution and perforated gas distributor used to give non uniform gas bubbles. This gas bubble distribution leads to radial non uniformity of gas holdup and fluidizes the bottom layer.

Axial variation of solid holdup

The progressive expansion also can be seen from axial solid hold up profile and shown in Fig. 7. At low liquid (0.55 cm/s) and gas velocity (0.15 cm/s) the axial solids holdup upto 45 cm was 0.6, it shows the particles are in packed bed condition. At same liquid velocity and increase in gas velocity to 0.924 cm/s the lower layer of particles start fluidizing and can be seen in figure as axial solid holdup 0.6 till 30 cm, beyond that the particles fluidized and solids holdup became 0.4 at 40 cm and at 0.09 at 50 cm i.e the particles progressively fluidizing. Further increase in gas velocity slowly the fluidized bed height increased and reduces the packed bed height. At some gas velocity (u_{gmf}) the entire particles became fluidized, this velocity was called minimum gas fluidization velocity at that liquid velocity [3, 9].

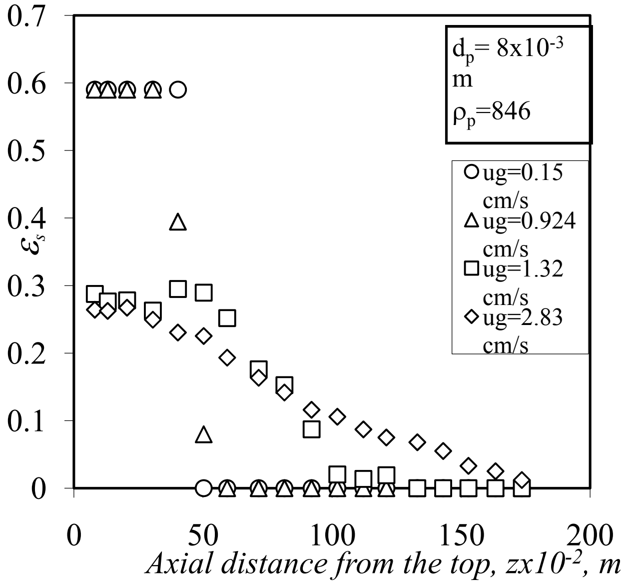

Fig. 7:Axial variation of solid holdup

4. CONCLUSIONS

The following conclusions drawn from the present study

1) The fluidization occurs layer by layer with increase in gas velocity in 3-phase IFB for batch and continuous flow of liquid.
2) The gas velocity corresponding to complete fluidization increases with increase in static bed height..
3) The liquid velocity corresponding to complete fluidization increases with increase in static bed height.
4) Perforated type gas distributor is more pronounced effect than mesh type gas distributor on % packed bed.
5) Progressive expansion can also be seen from axial solid holdup profile.

Nomenclature

Ar	Archimedes number (d_p^3g□□)/□^{2})
d_p	diameter of particle (mm)
dp/dz	pressure gradient (N/m^3)
H_0	Initial bed height (cm)
g	acceleration due to gravity, m2/s
n	constant in equation (1)
u_g	gas velocity, cm/s
u_{gmf}	complete fluidization gas velocity, cm/s
u_l	liquid velocity, cm/s

Italics

ε	hold up
γ	relative conductivity
ρ_p	particle density (Kg/m^3)
□	viscosity (Pa.s)

subscript

g	gas
l	liquid
s	solid

5. ACKNOWLEDGMENT

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REFERENCES

[1] Fan, L. S., K. Muroyama and S. H. Chern, "Hydrodynamic Characteristics of Inverse Fluidization in Liquid-Solid and Gas-Liquid-Solid Systems", *Chem. Eng. J.,* 24, 143-150 (1982).

[2] Roustan, M., R. Y. Wang and D. Wolbert, "Modeling Hydrodynamics and Mass Transfer Parameters in a Continuous Ozone Bubble Column", *Ozone Sci. Eng.*, 18, 99-115 (1996).

[3] Comte, M. P., D. Bastoul, G. Herbrard and M. Roustan, "Hydrodynamics of a Three-Phase Fluidized Bed – the Inverse Turbulent Bed", *Chem. Eng. Sci.,* 52, 3971-3977 (1997).

[4] Subbarao, B. V. V., M.Tech. Thesis, "Bed expansion of three phase Inverse Fluidized Bed with batch liquid", Indian Institute of Technology madras, Chennai, India (1998).

[5] Renganathan, T. and K. Krishnaiah, "Pridiction of minimum fluidization velocity in two and three phase Inverse Fluidized Beds”, *Can. J. Chem. Eng.*, 81, 853-860 (2003).

[6] Krishna, B.S.V.S.R. and K. Krishnaiah, The Minimum and Uniform Fluidization velocity of Inverse Fluidized bed*, Int. J. Chem. Sci., 5(4), p1733* (2007).

[7] Ibrahim, Y. A. A., C. L. Briens, A. Margaritis and M. A. Bergongnou, "Hydrodynamic Characteristics of a Three-Phase Inverse Fluidized Bed Column", *A.I.Ch.E.J.,* 42, 1889-1900 (1996).

[8] Buffiere, P. and R. Moletta, "Some Hydrodynamic Characteristics of Inverse Three Phase Fluidized-Bed Reactors", *Chem. Eng. Sci*. 54, 1233-1242 (1999).

[9] Choi, H. S. and M. N. Shin, “Hydrodynamics Study of Two Different Inverse Fluidized Reactors for the Application of Wastewater Treatment” *Korean J. Chem. Eng.* 16, 670-676 (1999).

[10] Lee, D. H., N. Epstein and J. R. Grace, “Hydrodynamic Transition from Fixed to Fully Fluidized Beds for Three-Phase Inverse Fluidization”, *Korean J. of Chem. Eng.* 17, 684-690 (2000).