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Effect of gas distributor on hydrodynamics of three phase inverse fluidized bed with batch liquid

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ABSTRACT

The influence of perforated plate and mesh gas distributor on the hydrodynamics of three phase inverse fluidized bed is studied in this work. Use of perforated plate gas distributor resulted in larger bubbles of wide size distribution with radial non uniformity inducing liquid circulations. When mesh gas distributor is used, radially uniform smaller bubbles of narrow size distribution and insignificant liquid circulations are observed. With perforated plate gas distributor lower pressure gradient is obtained. The effect of gas distributor on minimum gas fluidization velocity depends on static bed height and Archimedes number. For lower Archimedes number, higher gas holdup, lower liquid holdup and higher solid holdup is obtained when a mesh gas distributor is used.

Keywords: Inverse fluidized bed, distributor, perforated plate, bubble size, gas holdup.

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INTRODUCTION

Inverse fluidization is a mode of fluidization where low density solid particles are fluidized towards gravity by downward flow of continuous liquid phase. In the three phase operation, gas is dispersed upward countercurrent to downflowing liquid. The regimes of operation, advantages and applications of inverse fluidized bed (IFB) have been discussed elsewhere [1]. Several studies have been conducted on the hydrodynamics of three phase IFB covering different hydrodynamic aspects like flow regime [2] & [3], pressure drop [4], minimum fluidization velocity [1] & [4] and phase holdups [4] & [6]. However studies on the effect of gas and liquid distributor on the hydrodynamics are scanty. Only two studies in IFB use two different types of gas distributors [3] & [7]. The effect of perforated plate and membrane type gas distributor on uniform gas fluidization was studied by [7] while phase holdups using perforated rubber tube and perforated rubber disk as gas distributors was studied by [3]. A detailed study on the effect of type of gas distributor on the hydrodynamics of three phase IFB is lacking in the literature. Hence in the present work, the effect of gas distributor on hydrodynamic characteristics viz. pressure drop, minimum gas fluidization velocity and average phase holdups in three phase IFB under batch liquid condition is studied.

EXPERIMENTAL

A schematic of the experimental setup is shown in Fig.1. Air was distributed upwards from the bottom of the column through a gas distributor into batch liquid. Two types of gas distributors (No. 15 in Fig. 1) were used. The first one was a heat exchanger type perforated plate (1 mm hole, 2.3% free area) with air flowing upwards in the shell side. The second distributor was the heat exchanger type perforated plate completely covered with 25 μm stainless steel mesh. The characteristics of polyethylene/polypropylene particles used as solid phase are d_p (mm) (ρ_p (kg/m^3)): 2.34 (897), 2.89 (911), 6.1 (917), 5.0 (849), 6.1 (860), 8.0 (846). The particles were retained at the top by a mesh. Axial pressure profile was measured by differential pressure transducer and the liquid holdup was measured by conductivity method [6] using online data acquisition system.

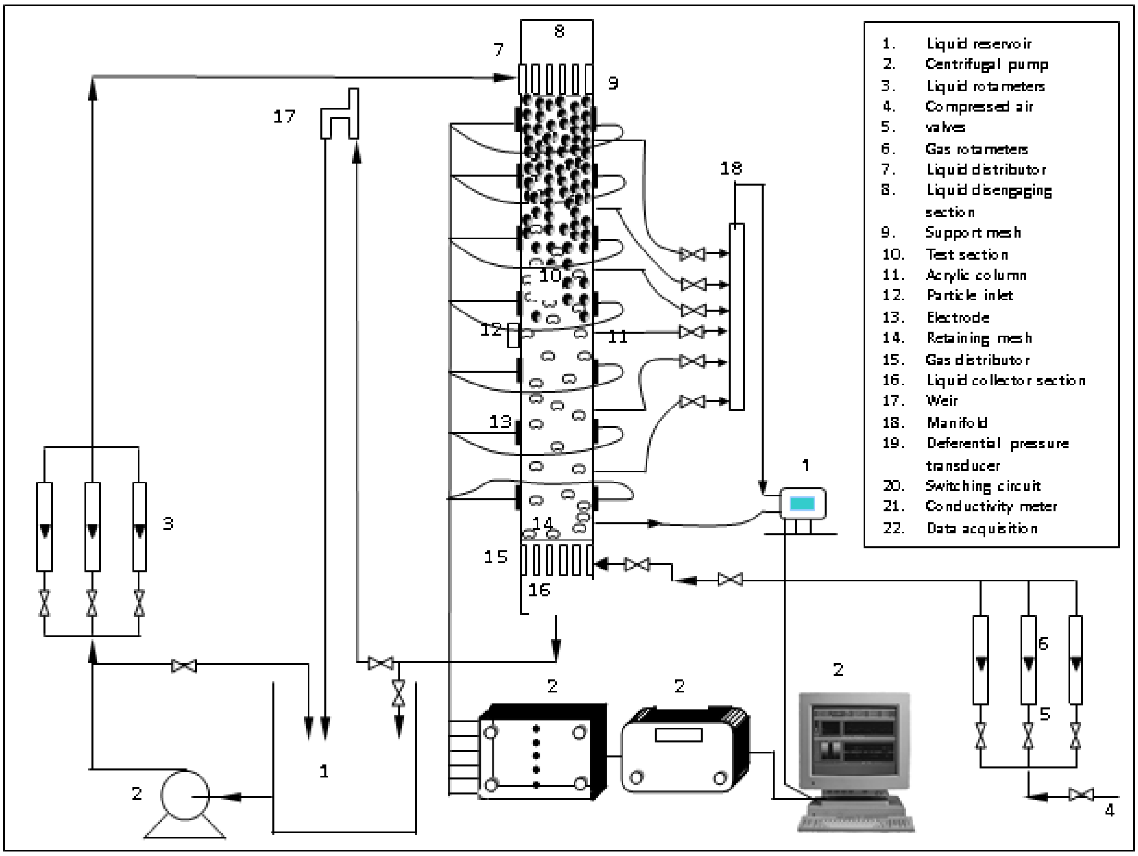

Fig. 1 Schematic Diagram of Experimental Setup

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In a typical experiment, for a given type of gas distributor, particles of chosen Archimedes number and static bed height were loaded and then filled with water. For a chosen air flow rate, after the system reached steady state, static pressure, conductance and bed height (visual) measurements were taken. The air flow rate was slowly increased till the bed is fully fluidized. This procedure was repeated for different static bed height, particle characteristics and gas distributor type. The liquid holdup ($\varepsilon_{l,cs}$), gas holdup ($\varepsilon_{g,cs}$) and solid holdup ($\varepsilon_{s,cs}$) at different axial positions were calculated using the following relations [1] & [6].

$$\varepsilon_{l,cs} = \gamma_{cs}^{m} \qquad (1)$$

$$\frac{dP}{dz} = \left(\varepsilon_{g,cs}\rho_g + \varepsilon_{l,cs}\rho_l + \varepsilon_{s,cs}\rho_s\right)g \qquad (2)$$

$$\varepsilon_{g,cs} + \varepsilon_{l,cs} + \varepsilon_{s,cs} = 1 \qquad (3)$$

In the above equations, γ_{cs}, m, ρ_g, ρ_l, ρ_s, P and z refer to normalized conductance, calibration constant, gas density, liquid density, solid density, static pressure and axial coordinate respectively. The axial profile of the cross sectional averaged phase holdups was averaged over the height of the bed to get the average phase holdups in the bed.

RESULTS AND DISCUSSION

As mentioned earlier, the objective of the present work is to study the effect of gas distributor on pressure drop, minimum gas fluidization velocity and average phase holdups. During the experiments, it was observed that when the perforated plate distributor was used, relatively large size bubbles were obtained. The bubble size distribution appeared to be wide. Further the bubbles were not uniform across the cross section of the column. On the other hand, when the mesh distributor was used, fine bubbles were obtained and the size distribution appeared to be narrow. Further the bubbles were uniform across the cross section of the column.

When liquid is in batch mode, the bed is in packed condition at low gas velocities. As the gas velocity is increased, bed expands layer by layer from the bottom due to increase in gas holdup in the bed keeping the top portion of the bed still in packed condition. This state is referred as semifluidization. As the gas velocity is further increased, the entire bed becomes fluidized at a particular gas velocity termed as minimum gas fluidization velocity [1]. In three phase IFB, fluidization can be achieved using gas alone with no liquid flow. Introduction of gas reduces the effective density of fluid mixture reducing the net buoyant force on the particle thus aiding fluidization. When the gas is passing through the bed, the gas holdup may not be uniform across the cross section inducing hydrostatic imbalance which created liquid circulations near the wall dragging the particles downwards. This effect also favours fluidization.

Effect of gas distributor on bed pressure gradient

In Fig. 2, the pressure gradient across the bed is plotted as a function of gas velocity for perforated plate and mesh distributor. For both type of distributors, the pressure gradient increases with gas velocity due to increase in gas holdup and frictional losses. While in the packed bed regime (lower gas velocities), there is no influence of distributor on pressure gradient, in the fluidized bed regime the pressure gradient is higher for mesh distributor compared to perforated plate distributor. This is due to the higher gas holdup resulting from small bubbles when mesh distributor is used. The effect of distributor type on the hydrodynamics of bubble column and concluded that perforated plate distributor results in lower pressure gradient compared to membrane and porous plate distributors [8] similar to that observed in the present study for 3-phase IFB.

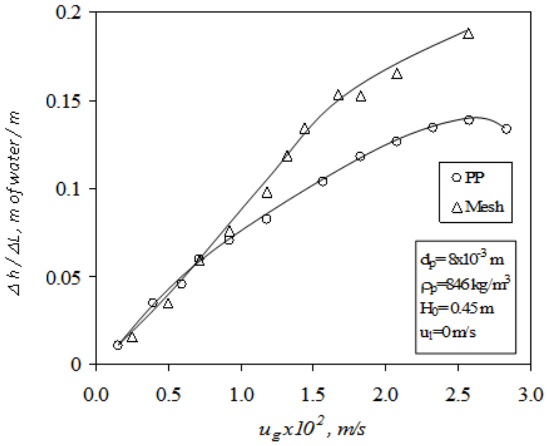

Fig 2: Effect of gas distributor type on pressure gradient

Effect of gas distributor on minimum gas fluidization velocity

The variation of minimum gas fluidization velocity with static bed height is shown for perforated plate and mesh distributor in Fig. 3. In the case of perforated plate distributor, it can be observed that the minimum gas fluidization velocity increases with static bed height. When shallow bed is compared with deeper bed, minimum gas fluidization velocity is less for shallow bed since gas induced liquid circulation can more easily penetrate and expand the bed. However for mesh type distributor, minimum gas fluidization velocity is almost independent of static bed height since gas induced liquid circulations are almost negligible because of uniform radial gas holdup.

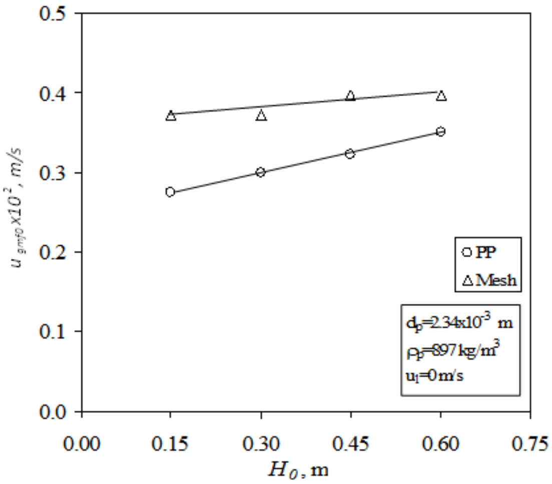

Fig 3a: Variation of minimum gas fluidization velocity with static bed height

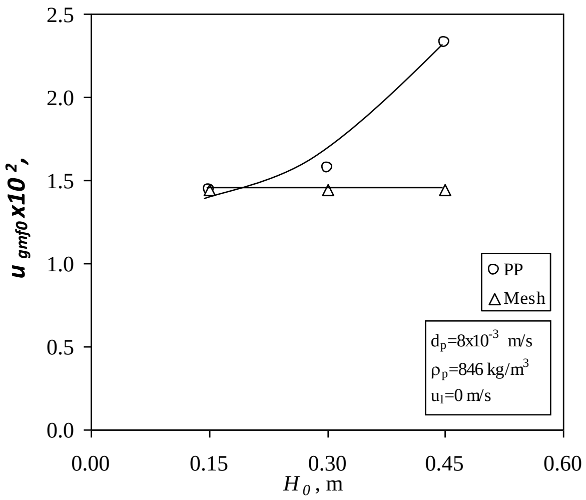

Fig 3b: Variation of minimum gas fluidization velocity with static bed height

It can be observed from Fig. 3a that, for low Archimedes number (<1.8 x 10^5), the minimum gas fluidization velocity for perforated plate distributor is lower than that for mesh distributor. The minimum gas fluidization velocity in inverse fluidization under batch liquid condition is due to the gas holdup in the bed and due to the drag on the particles exerted by the liquid circulations near the wall created by gas flow through the bed. The relative contribution of these two effects is to be considered. It is known that mesh distributor results in more gas holdup reducing the effective fluid density which will help expand the bed easily in spite of liquid circulations being almost negligible when mesh distributor is used. In the case of perforated plate, even though the gas holdup is less, liquid circulations will aid fluidization by dragging the particles down. Hence at lower gas velocities itself the bed will fluidize when perforated plate is used.

Figure 3b presents the variation of minimum gas fluidization velocity with static bed height for higher Archimedes number (>1.8 x 10^5). Particles with higher Archimedes number are difficult to fluidize. This is the reason for the higher gas velocities in Fig. 3b. At lower static bed height, minimum gas fluidization velocity is almost same for perforated plate and mesh distributor, which may be due to higher gas holdup when mesh distributor is used and higher liquid circulations when perforated plate is used. As the static bed height increases, even though the gas holdup may distribute uniformly through the bed, liquid circulations may not be able to penetrate till the top of the bed. Hence more gas is required to expand the entire bed in the case of perforated plate.

Effect of gas distributor on phase holdups

In Fig. 4a, the average gas holdup is plotted as a function of gas velocity for perforated plate and mesh distributor. It can be seen that the gas holdup increases with gas velocity for both type of distributors due to higher gas input. It can be seen that the average gas holdup is higher in the case of mesh distributor. Use of mesh distributor results in smaller bubbles resulting in higher gas holdup due to their lower rise velocity and hence larger residence time. Higher gas holdup because of fine bubble size with membrane spargers has also been observed [8] in bubble columns.

Figure 4b shows the variation of average liquid holdup with gas velocity for perforated plate and mesh distributor. For both type of distributors, with increase in gas velocity, the average liquid holdup does not change appreciably till minimum gas fluidization velocity is reached. Beyond minimum gas fluidization velocity, the average liquid holdup increases sharply with increase in gas velocity which may be due to increase in gas holdup that reduces the effective gas-liquid mixture density. Increasing the gas velocity results in more bed expansion resulting in more liquid holdup. Beyond this velocity, the average liquid holdup gradually decreases with increase in gas velocity since the solid holdup is constant and the gas holdup increases with gas velocity. It can be observed from Fig. 4b that in the packed bed condition, both type of distributors give rise to the same liquid holdup. However, in the fluidized bed condition, more liquid holdup is observed with perforated plate distributor due to higher bed expansion obtained for lower Archimedes number.

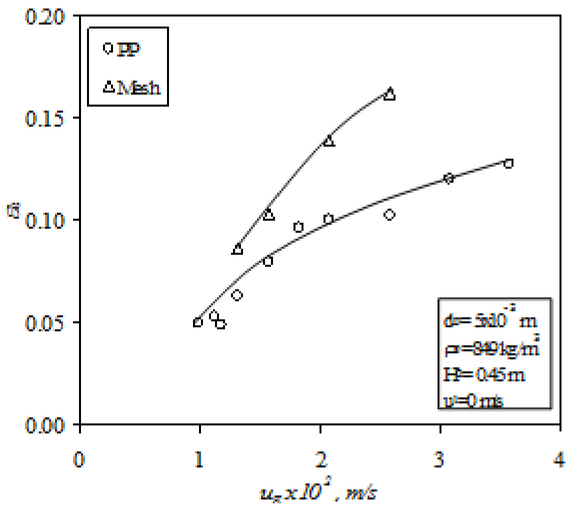

Fig 4a: Effect of gas distributor type on average gas holdup

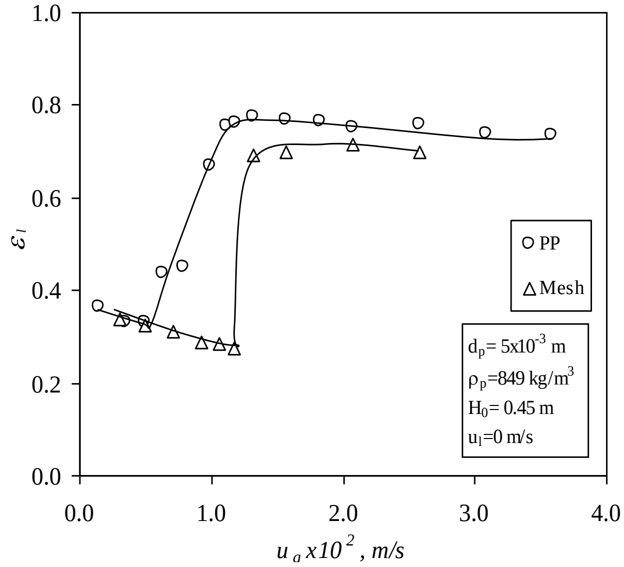

Fig 4b: Effect of gas distributor type on average liquid holdup

In Fig. 4c, the average solid holdup is plotted as a function of gas velocity for perforated plate and mesh distributor. For both type of distributors, with increase in gas velocity, the average solid holdup does not change appreciably till minimum gas fluidization velocity. Beyond minimum gas fluidization velocity, the average solid holdup decreases sharply with increase in gas velocity in contrast to liquid holdup till the bed expands to cover the entire column. With increase in gas velocity, more bed expansion is obtained resulting in lower average solid holdup. Beyond this velocity, the average solid holdup remains constant with increase in gas velocity since the bed expansion is limited by the available column height. While the solid holdup is almost same for both types of distributors in the packed bed region, perforated plate distributor gives rise to lower solid holdup in the fluidized bed region due to higher bed expansion obtained for lower Archimedes number. Similar observation of higher bed expansion with perforated plate distributor has also been reported in [7] for lower Archimedes number.

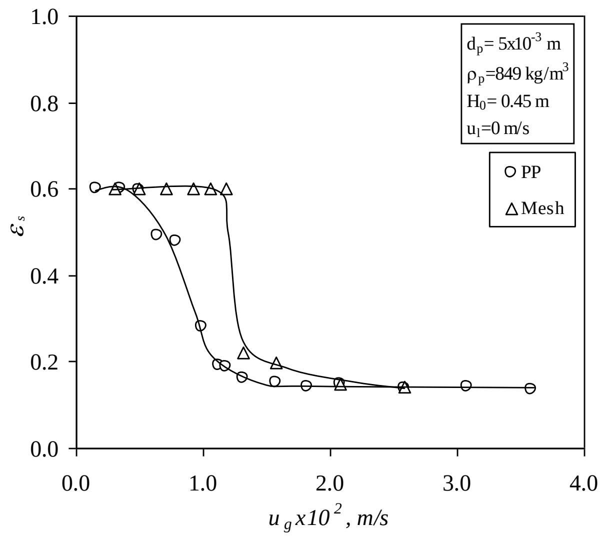

Fig 4c: Effect of gas distributor type on average solid holdup

CONCLUSIONS

The following conclusions can be drawn for the two types of gas distributors viz. perforated plate and mesh. The perforated gas distributor gives rise to larger pressure gradient compared to mesh distributor. More gas hold up with uniform bubble size is obtained in the case of mesh distributor, whereas less gas holdup with distribution of bubble sizes is observed in the case of perforated plate distributor. The minimum gas fluidization velocity increases with static bed height for perforated plate distributor, but in general it is independent of static bed height for mesh distributor. For low Archimedes number, minimum gas fluidization velocity is lower for perforated plate distributor. For higher Archimedes number, minimum gas fluidization velocity is higher for perforated plate distributor at high static bed heights. At lower Archimedes number, higher liquid holdup and lower solid holdup is obtained by using perforated plate distributor.

NOMENCLATURE

ε Holdup
Cs cross sectional
m constant
γ conductivity
g acceleration due to gravity
g- gas
l- liquid
s- solid
ρ- density
d_p diameter (m)
u – velocity (m/s)
dP/dZ- pressure drop over the height of dZ length (N/m^3)
Δh/ΔL – water column height over the height of ΔL (m of water column/m)

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