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Effect of Fluid Flow Rates on Hydrodynamic Characteristics of Co-Current Three Phase Fluidized Beds with Spherical Glass Bead Particles

A.Sivalingam[1]* and Dr.T.Kannadasan[2]

[1] Selection Grade Lecturer, Department of Chemical Engineering, Coimbatore Institute of Technology, Coimbatore – 641 014, India.
[2] Professor in Chemical Engineering, Coimbatore Institute of Technology, Coimbatore – 641 014, India.
and on other duty as Director (Research), Anna University Coimbatore, Academic Campus, Jothipuram, Coimbatore – 641 047, India.

Corres.author: as_sabhari@rediffmail.com.
Mobile Number: +919865020076

Abstract: The study of hydrodynamics plays an important role in the economical design and operation of a three phase fluidized bed. The present work is an experimental investigation on the hydrodynamic behavior of a co-current three phase fluidized bed with liquid as a continuous phase in a 54 mm id Perspex (Acrylic column) with particle size of 4.38 and 1.854 mm glass beads. Based on the experimental work, the effect of fluid rates on the various parameters such as pressure drop, porosity, gas and liquid holdups were studied and the observed data was reported.

Key words: Hydrodynamics, fluid rates, fluidization bed design, gas and liquid holdups.

1.0 INTRODUCTION

The three phase fluidized bed is a device in which the gas phase moves in the form of bubbles relative to the liquid phase, and eventually reactive solid is fluidized in the liquid phase[7]. The commercial application of three phase fluidization systems are in heavy oil, synthetic crude processing, coal liquefaction in the presence of catalyst, biological waste water treatment and fermentation. The hydrodynamic behavior of gas-liquid-solid fluidized bed is a complex subject and one of the most important for basic understanding of certain refinery and petrochemical industrial applications[3].

Gas-liquid fluidization is defined as an operation in which bed of solid particles are suspended in gas and liquid, which is due to the net drag force of the gas and or liquid flowing opposite to the net gravitational force or the buoyancy forces on the particles[10]. Gas-Liquid-Solid systems are one of the most important multiphase systems for physical, chemical and bio-chemical processing[4]. Such an operation generates considerable intimate contact among the gas, liquid and solid particles[5]. If gas is introduced in liquid-solid fluidized bed, it is possible to disperse the gas in the form of small bubbles and there by obtain a good contact between the gas, the liquid and the solids[1]. It is called as Three phase or Gas-Liquid-Solid fluidized beds[6]. An interesting phenomenon, in three-phase fluidization is the expansion or contraction of bed, due to the introduction of gas in the bottom of a bed of solids fluidized by a liquid, at a constant liquid flow rate[11]. It depends on the nature of solids; particularly inertia. With large particles, the bed height increases monotonically as gas velocity increases. However, an initial decrease of bed height exists if small particles are used. It is believed to be caused by the wake trailing behind the bubble[12].

The successful design and operation of a gas-liquid fluidization bed system depends on the ability to accurately predict the fundamental characteristics of the system[8]. The hydrodynamics, the mixing of individual phases and the heat and mass transfer characteristics can be accurately determined[9]. Knowledge of minimum fluidization velocity is essential for the successful operation of three phase fluidized beds[2].Based on experiment, the various parameters such as pressure drop, porosity, gas and liquid holdups can be calculated for the studies on residence time distribution of liquid and gas phases.

2.0 MATERIALS AND METHODS

2.1 Experimental Studies

2.1.1 Experimental Setup: The Perspex fluidized bed column used was 1.6m high and 0.054m in diameter as shown in fig 1. The liquid and gas flow rate were measured. The gas and liquid streams were merged and passed through a quick closing valve, a 3 mm thick perforated grid before entering the bed. The calming section and the grid ensured that the liquid and gas were well mixed and evenly distributed into the bed, the grid was also used to retain the solid particles. A tee joint at the top of the column allowed gas to escape and liquid to be recirculated to the reservoir. Pressure tappings were provided at the top and bottom of the test section.

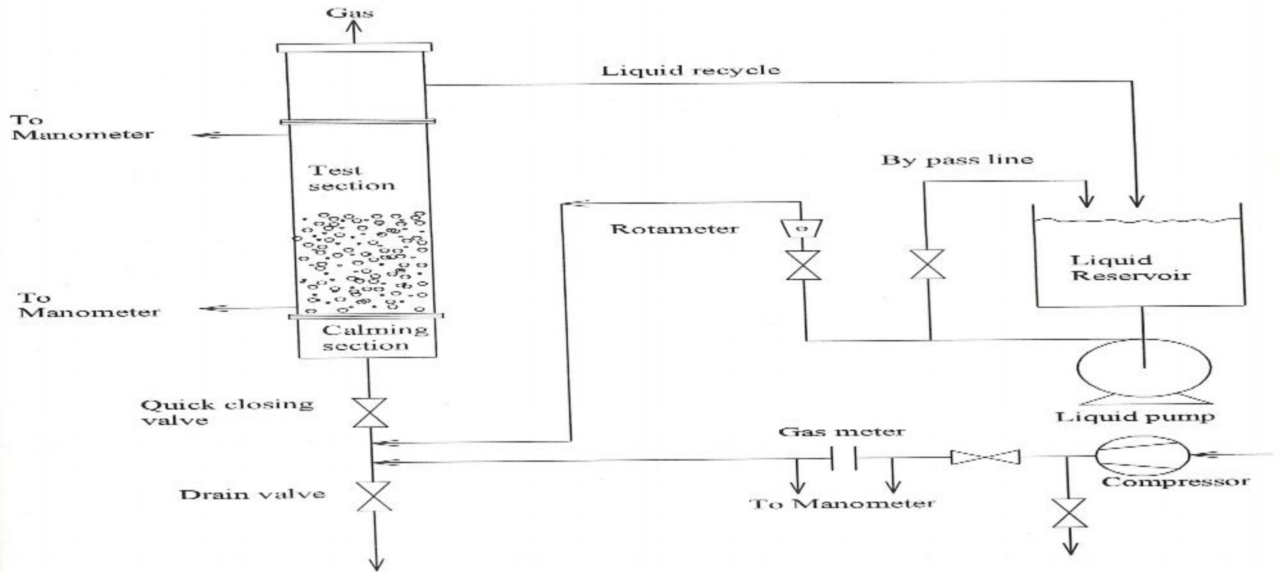

Fig 1: Schematic diagram of the experimental setup

2.1.2 Experimental Procedure

The experiment was conducted using two different sizes of glass bead particles 4.38 mm and 1.854 mm with liquid as a continuous phase. Two sets of operating conditions were used. One by maintaining the gas phase flow rates constant and the other by keeping the liquid flow rates as constant. For measuring the fluidized bed height, a scale arrangement was made at the column. The height of the expanded bed was noted, when the steady state conditions were attained. In the case of particulate fluidization, the bed was homogeneously distributed after attaining the steady state. It was noted visually by taking the average of the difference of heights. The pressure drop across the fluidized bed was noted using the manometric method. Using the difference of heights, the pressure drop is calculated. The liquid holdup and gas holdup were calculated by measuring the gas-liquid and liquid fluidized bed heights. The liquid holdup was calculated experimentally by closing the inlet and outlet of the test section by quick closing valves and finding the amount of liquid retained on the test section.

3.0 RESULTS AND DISCUSSIONS

The pressure drop, bed porosity, gas holdup and liquid holdup were calculated using the experimental data.

3.1 Gas Holdup: From the fig 2 and 4, for beds of particle size 4.38 mm and 1.854 mm, the gas holdup increases with increasing superficial gas velocity and decreases with increasing superficial liquid velocity. The holdup was very high in low liquid flow rates and high gas rates, the influence of liquid velocity was more on gas holdup and the bed expands with increasing gas flow rate and large slugs were formed in the higher gas velocities and liquid flow rates.

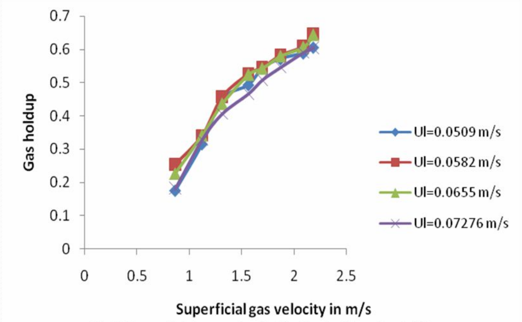

Fig:2.Superficial gas velocity Vs Gas holdup for 4.38 mm particle

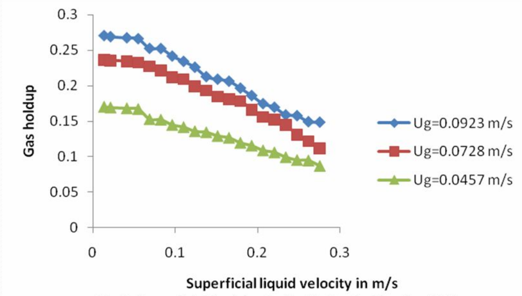

Fig:3. Superficial liquid velocity Vs Gas holdup for 4.38 mm particle

From the fig 3 and 5, for beds of particle size 4.38 mm and 1.854 mm, the holdup obtained was less when compared to that obtained increasing the gas flow rates. The gas velocity plays more predominant role in gas holdup.

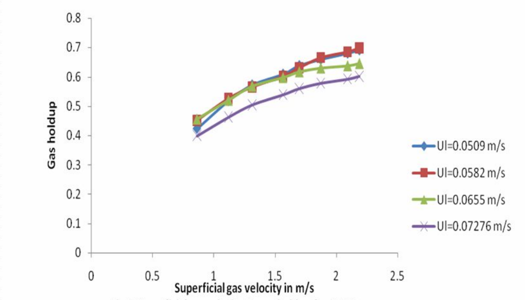

Fig:4.Superficial gas velocity Vs gas holdup for 1.854 mm particle

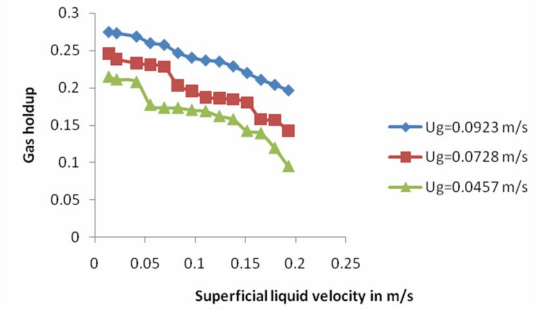

Fig:5. Superficial liquid velocity Vs Gas holdup for 1.854 mm particle

3.2 Liquid Holdup: From the fig 6 and 8, for beds of particle size 4.38 mm and 1.854 mm particles, the liquid holdup increases with increasing superficial liquid velocity and decreases with increasing superficial gas velocity. The holdup was very high in low gas flow rates and high liquid flow rates. The influence of liquid velocity was more on liquid holdup and the bed expands with the increasing liquid flow rates.

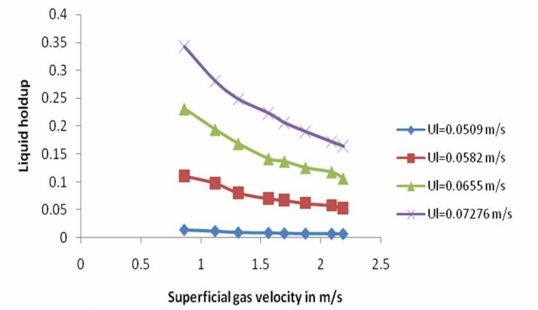

Fig:6.Superficial gas velocity Vs liquid holdup for 4.38 mm particle

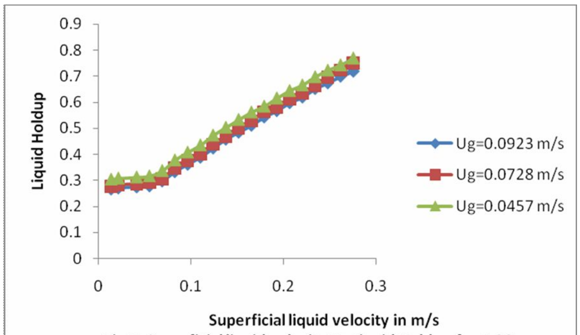

Fig:7. Superficial liquid velocity Vs Liquid Holdup for 4.38 mm particle

From the fig 7 and 9, for beds of particle size 4.38 mm and 1.854 mm, the liquid holdup was more than that obtained by increasing the gas flow rate.. The liquid velocity plays more predominant role in liquid holdup.

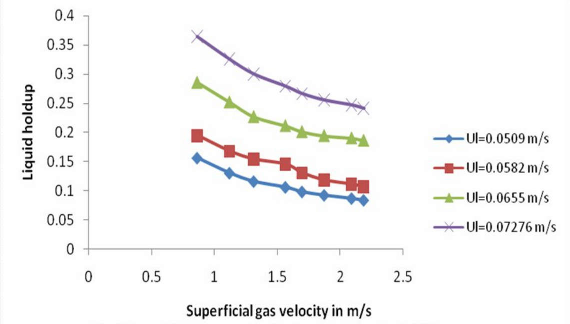

Fig:8.Superficial gas velocity Vs Liquid holdup for 1.854 mm particle

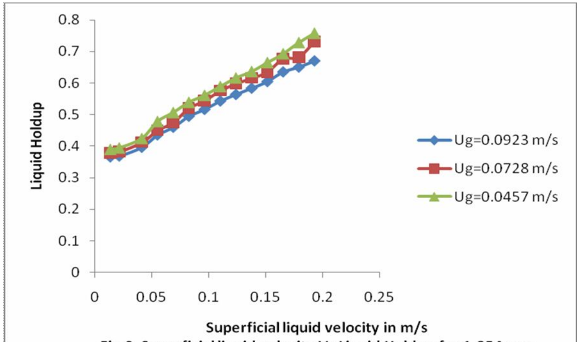

Fig:9. Superficial liquid velocity Vs Liquid Holdup for 1.854 mm particle

3.3 Porosity: From the fig 10,11,12,13, it can be inferred that the bed porosity increases with the increase in gas velocity for the same size particles. It was found that the increase in bed height increases the bed porosity. From the experimental results, in gas – liquid fluidized beds the porosity was high in small particles. While comparing the effect of liquid flow rate on bed porosity with the effect of gas flow rate, it was observed that the porosity is higher with the increased gas flow rates than the increase in the liquid flow rates.

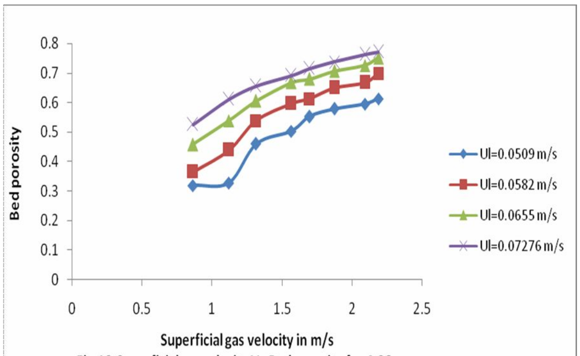

Fig:10.Superficial gas velocity Vs Bed porosity for 4.38 mm particle

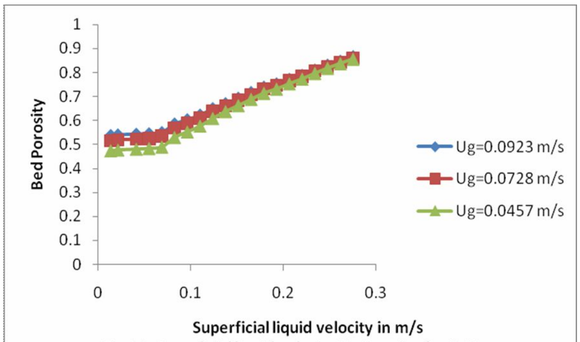

Fig:11. Superficial liquid velocity Vs Porosity for 4.38 mm particle

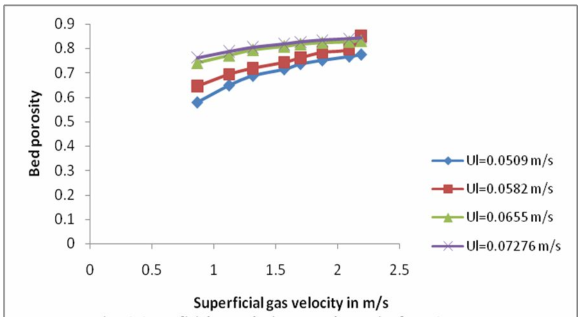

Fig:12.Superficial gas velocity Vs Bed porosity for 1.854 mm particle

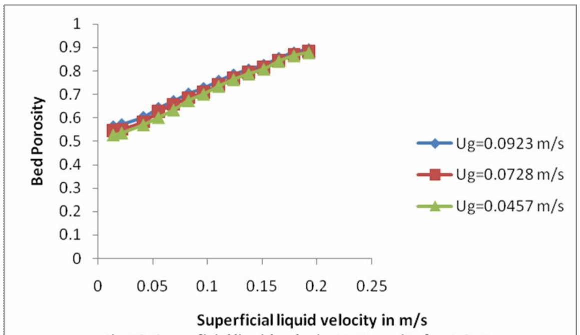

Fig:13. Superficial liquid velocity Vs Porosity for 1.854 mm particle

3.4 Pressure Drop: From the fig 14,15,16,17, it can be inferred that the pressure drop is high for smaller size particles compared to the larger size particles. It was observed that with increase in superficial liquid velocity the pressure drop decreases. This is due to the expansion of the bed at higher liquid flow rates.

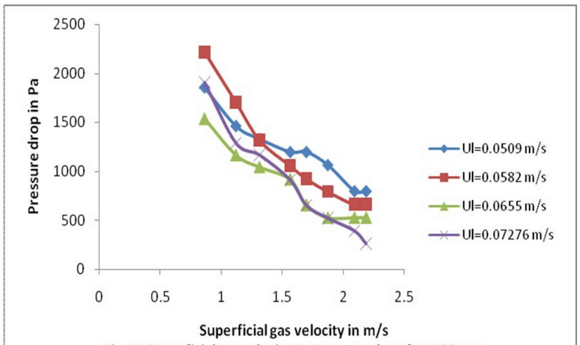

Fig:14.Superficial gas velocity Vs Pressure drop for 4.38 mm particle

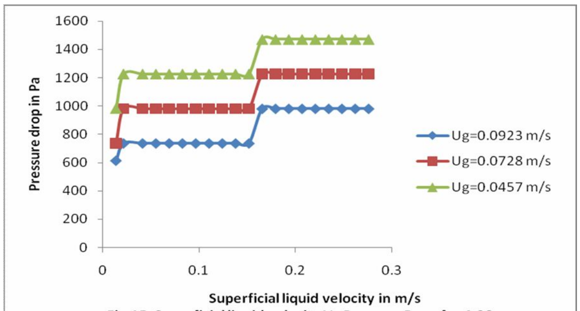

Fig:15. Superficial liquid velocity Vs Pressure Drop for 4.38 mm particle

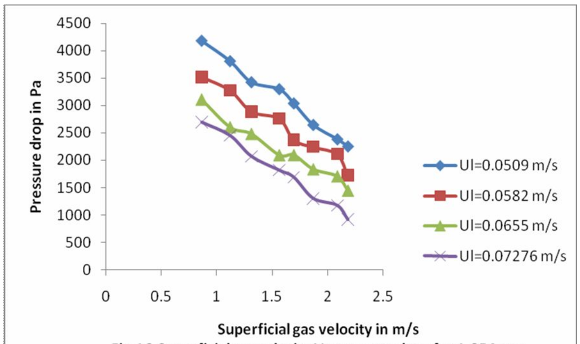

Fig:16.Superficial gas velocity Vs pressure drop for 1.854 mm particle

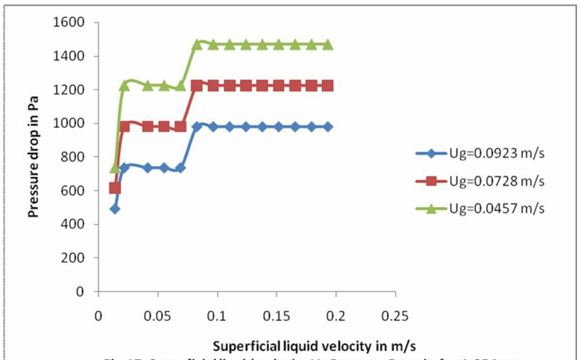

Fig:17. Superficial liquid velocity Vs Pressure Drop in for 1.854 mm particle

4.0 CONCLUSION

Experiment was conducted using the Perspex fluidized bed column, for the two operating conditions. Hold-up, bed porosity and pressure drop in gas-liquid–solid fluidized bed showed a marked variation with particle size and gas flow rates at constant liquid flow rates when compared to results obtained at constant gas flow rates . Bubble break-up occurs in beds of large solid particles at high gas flow rates and low liquid flow rates. In the break-up regime, the gaseous phase forms a uniform dispersion of small bubbles. The gas hold up and bed porosity increases with increasing gas flow rate. From the comparison of the effect of gas flow rates and liquid flow rates on the hydrodynamic characteristics we could infer that the influence of the gas flow rate on the various parameters is more when compared to that of the liquid flow rates. So the gas flow rate plays a predominant role in the design of the fluidized bed. The system mainly depends on good contact between solid and liquid.

5.0 NOMENCLATURE

ε = Porosity ‘or’ voidage
ε_g = Gas holdup
ε_l =liquid hold up
ε_0 =initial bed porosity
ε_s =Solid holdup
ε_{mf} =Bed porosity at minimum fluidization velocity
ρ =Density of liquid, kg/m^3
ρ_f =Effective density of the fluidized bed
ρ_g =Gas density, kg/m^3
ρ_l =Liquid density, kg/m^3
ρ_m =Density of manometric liquid, kg/m^3
ρ_s =Density of solid particles, kg/m^3
μ =Viscosity, poise

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