HYDRODYNAMICS STUDIES ON SEMI-FLUIDIZED BED REACTOR USING INTERNALS

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ABSTARCT: Mixing is an important unit operation encountered in chemical and allied industries. It can be achieved by many ways. One such way is fluidization. The efficiency of conventional fluidized bed is enhanced by semi-fluidized bed reactor. It is a novel type of fluid-solid contacting device. The semi fluidized bed is characterized by a fluidized bed and a fixed bed in series with single contacting vessel. Any improvements that made in the fluidized section of semi fluidized bed will increase overall efficiency of semi fluidized bed. This can be achieved by employing mixing elements in fluidized section of semi- fluidized bed reactor. For this purpose, Experiments have been conducted in a 50 mm ID, 1m-height vertical glass column using water as liquid phase and glass beads, sand, quartz used as solid phase. kenics elements of different L/D ratios are used. It is found that pressure drop increases with increase in particle size and static bed height. The minimum liquid semi-fluidization velocity increases with particle size but is a weak function of static bed height. The height of top packed bed increases with liquid and but decreases with particle size and static bed height. Results are presented graphically.

Keywords: Semi-fluidized bed, Mixing, static elements, pressure drop, Minimum and Maximum Semi-fluidization velocity, packed bed formation

1. INTRODUCTION

A Semi-fluidized bed can be viewed as the combination of a batch fluidized bed at the bottom and a fixed bed at the top within a single vessel. A Semi-fluidization bed has the advantages of both the packed and the fluidized beds. It is a new and unique type of fluid-solid contacting technique which has been reported recently. In most of the chemical plants we come across situations where a solid phase has to be kept in contact with a fluid phase — for example diffusional operations like drying, adsorption, reaction kinetics, solid catalysed reactions, heat transfer, etc. In all these cases fluid-solid contacting is very essential and developments to increase the efficiency of contact and mixing are always welcome. Static elements incorporated in the fluidizing section helps to increase the mixing efficiency. The development and advantages of the semi-fluidized bed relating to studies on hydrodynamics, mass transfer, reaction kinetics and filtration [4]. Fixed bed or packed bed, batch and continuous fluidization and semi-fluidization all are two phase phenomena. In case of batch fluidization if the free expansion of the bed is restricted by the introduction of porous disc or sieve and the fluid velocity is increased the particles are fluidized and the expansion starts with further increase in velocity of fluid— the particles will be carried and the formation of a fixed bed results at the top. So by the introduction of restraint some of the particles are distributed to bottom section which is in the form of a packed bed. This is known as semi-fluidization which can be considered as a new type of solid-fluid contacting method which combines the features of both fixed and fluidized beds [7].

This type of technique overcomes the disadvantages of fluidized bed namely back mixing of solids, attrition of solids and problems involving erosion of surfaces. This also overcomes certain draw backs of packed bed, viz., Non-uniformity in temperature in the bed, channel flow and segregation of solids. Semi-fluidized bed are advantageous for fast exothermic reactions such as vapor phase oxidation and chlorination of hydrocarbons and used in the filtration operation for the removal of suspended solids and also used as bioreactors. Any improvements that made in the fluidized section of semi fluidized bed will increase overall efficiency of semi fluidized bed. For this purpose, an attempt was made to study the hydrodynamics of semi-fluidized bed with internals for liquid-solid systems.

2. EXPERIMENTAL SECTION

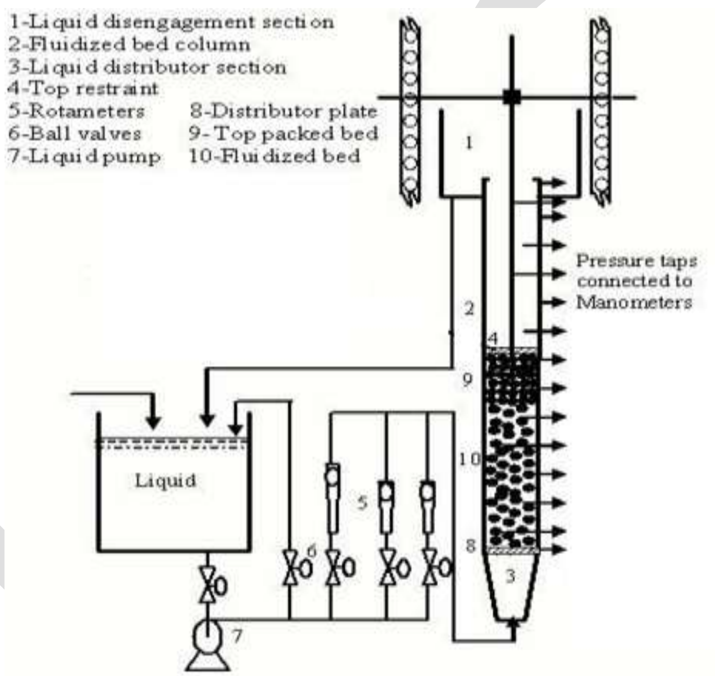

Fig 2.1 Experimental setup **Fig 2.2 Kenics element**

A schematic representation of the experimental setup is shown in Fig. 2.1. The experimental semi-fluidized bed consists of a fluidized bed assembly, a top restraining plate with fixture, and a pressure measuring arrangement. The fluidized bed assembly consists of a fluidizer, liquid distributor, liquid storage tank, calibrated liquid rotameter. The fluidizer is a vertical cylindrical glass column of 0.05m internal diameter and 1m height. The liquid distributor is located at the bottom of the fluidized bed column and is designed in such a manner that uniformly distributed liquid enters the fluidized bed column. The higher cross-section end is fitted to the fluidized bed column, with a perforated distributor plate made of G.I. sheet of 0.001 m thick, 0.05m diameter having open area equal to 20 % of the column cross-sectional area with a 16 mesh (BSS) stainless steel screen in between. The size of the holes has been increased from inner to outer circle. The top restraining plate is made from Perspex sheet of 0.05m diameter and 3 mm thick containing 3 mm holes with approximate total open area of 40%. There is a minor clearance between the plate and the inner wall of the column, which facilitated the free movement of the plate in the column, restricting the particle entrainment. A BSS 16 mesh screen is attached to the bottom of the plate and the plate is supported by a Perspex slotted support from the top. The whole assembly is fitted to an iron rod of 5 mm diameter with nut bolt arrangement.

Four Particles of different sizes and water have been used as the solid and the liquid phases respectively. Kenics elements employed as mixing element shown in Fig2.2. The scope of the experiment is presented in Table 2.1 and 2.2. Accurately weighed amount of material is fed into the column, fluidized and de-fluidized slowly and adjusted for a specified reproducible initial static bed height. Liquid is pumped to the fluidizer at a desired flow rate using liquid rotameter. Approximately five minutes are allowed to make sure that the steady state has been reached. The readings of the manometers and the expanded bed heights or the top packed bed height (as the case may be) are then noted. The procedure has been repeated by varying the particle size, particle density bed expansion ratio(R) and initial static bed height (H_s) and internals L/D ratio.

Table 2.1 Characteristics of particle-liquid system used in the study

Solid –liquid Systems	**D_p, mm**	**ρ_p, (kg/m^3)**	**ε_s**	**ρ_l, (kg/m^3)**	**μ_l x10^3, Pa.s**
Sand-Water	1.1	2644.35	0.452	995.7	0.789
Quartz- water	3	2830	0.503	995.7	0.789
Glassbeads-Water	2.18	2470	0.425	995.7	0.789
Glassbeads-Water	5	2470	0.526	995.7	0.789

Table 2.2 Range of Variables

Variables	Range
Particle size (d_p)	1.1, 2.18, 3, 5 (mm)
Particle hardness	5.5, 7, 69
Initial static bed height (h_s)	12.7, 15.2 (cm)
Bed expansion ratio(R)	1.5, 2, 2.5, 3
Internals L/D ratio	2, 3, 4

3. RESULTS AND DISCUSSIONS

The experiments were conducted by varying the flow rate of 0.0333 m^3 /s to 0.5334 m^3 /s. Pressure drop across the entire bed was measured using U-tube manometer and also top packed bed height height were noted for each flow rate. Minimum and Maximum Semi-fluidization velocity were observed visually and graphically.

3.1 Effect of bed expansion ratio (R)

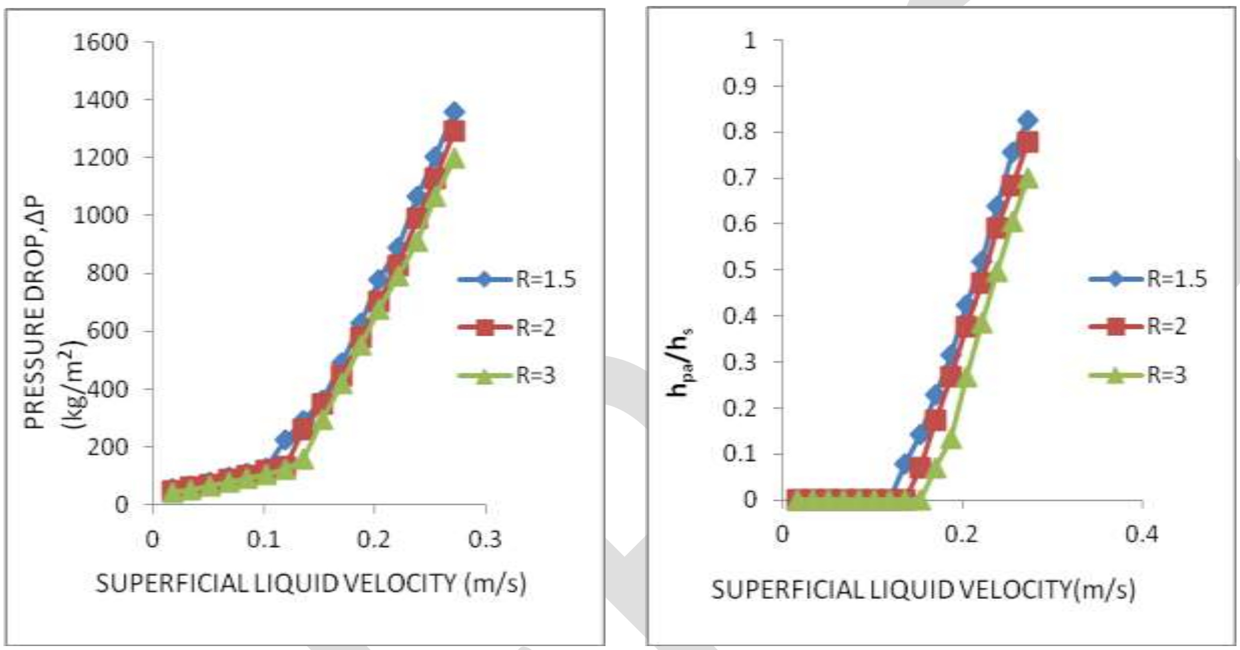

Fig 3.1.1 Effect of superficial liquid velocity on bed pressure drop and h_{pa}/h_S for 0.003m particles (Quartz) in water at different R without internals with hs=0.127 m

International Journal of Engineering Research and General Science Volume 3, Issue 2, Part 2, March-April, 2015
ISSN 2091-2730

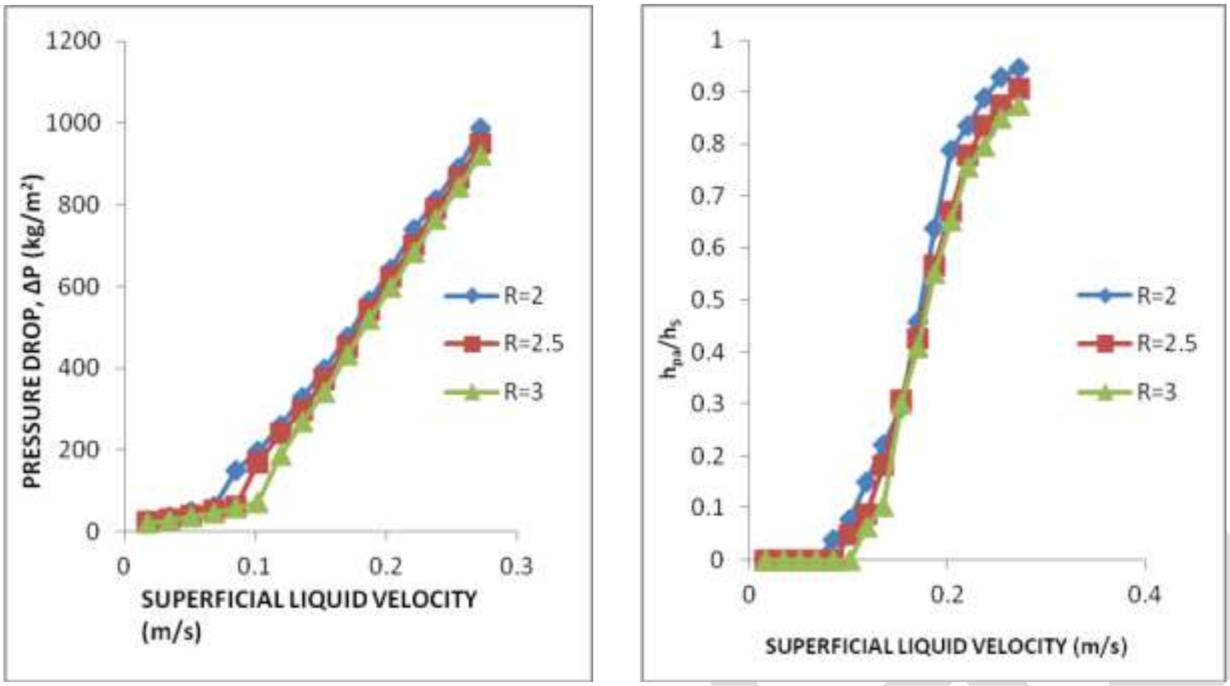

Fig 3.1.2 Effect of superficial liquid velocity on bed pressure drop and h_{pa}/h_S for 0.0011m particles (sand) in water at different R using internals with hs=0.127 m and $(L/D)_I$ =3

From these above figures, it can be observed that pressure drop across the bed and top packed bed formation decreases with increasing the bed expansion ratio for both with and without internals. The minimum Semi-fluidization velocity also called onset velocity of semi-fluidization (U_{osf}) is the superficial liquid velocity at which a bed particle of the expanded fluidized bed first touches the top restraint of the semi-fluidizer. Experimentally the minimum Semi-fluidization velocity can be determined by the following methods[11]. (1) From the plot of the ratio of the height of the top restraint to the height of the expanded fluidized bed (h_t/h_f) Vs the superficial liquid velocity(U_l). (2) From the plot of pressure drop across the bed Vs the superficial liquid velocity. The bed expansion ratio has a stronger effect on the minimum Semi-fluidization velocity as illustrated in fig 3.1.1 and 3.1.2. The reason is the requirement of higher fluid velocity to lift the particle to the higher position of the top restraint in the bed. U_{osf} increases with the increase in bed expansion ratio. The same behavior has been observed by other investigators also[10].

3.2 Effect of particle diameter and hardness

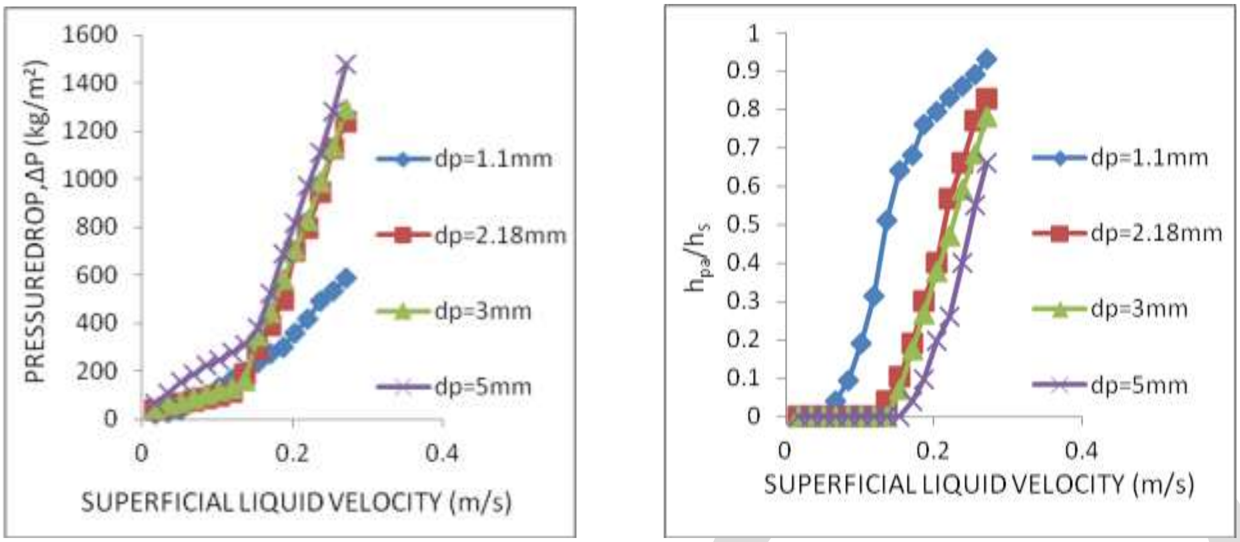

Fig 3.2.1 Effect of superficial liquid velocity on bed pressure drop and h_{pa}/h_S at different d_p particles in water without internals with R=2 and h_s =0.127m

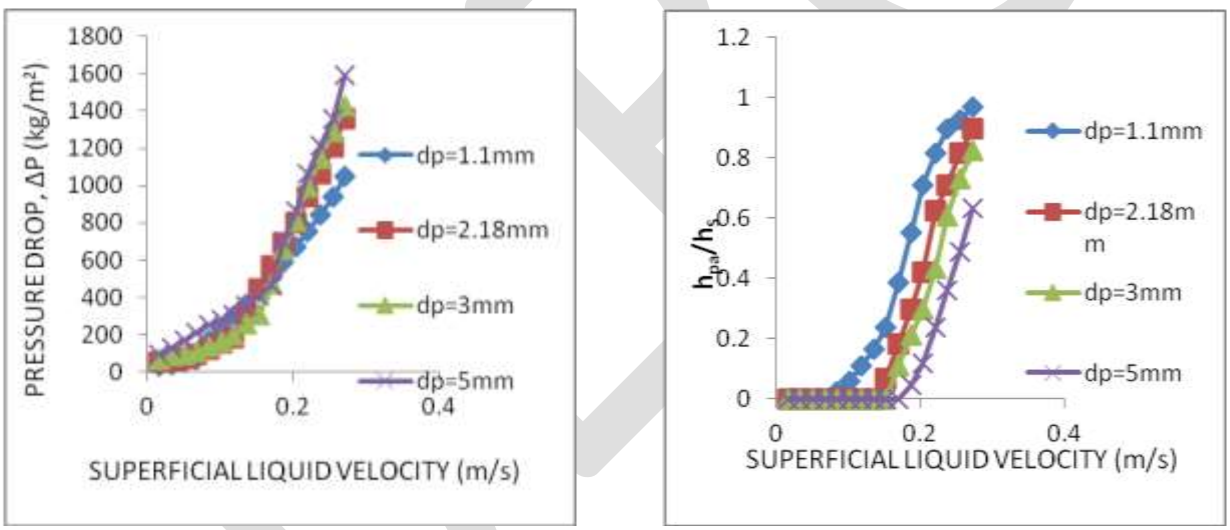

Fig 3.2.2 Effect of superficial liquid velocity on bed pressure drop and h_{pa}/h_S at different dp particles in water using internals with R=2, h_s =0.152m and $(L/D)_I$=3

From the above figures, it can be observed that increases the particle size, pressure drop across the bed increases but the top packed bed formation decreases with the increase the particle size and hardness for both with and without internals. The effect of particle size on U_{osf} is presented in fig 3.2.1 and fig 3.2.2. This shows that larger the particle size and hardness higher is the minimum semi-fluidization velocity. This is true as higher drag force and ultimately the higher fluid velocity is required to lift the bigger size particle which bears a higher mass. The same behavior has been observed while using internal elements of different L/D ratio.

3.3 Effect if initial static bed height (h_s)

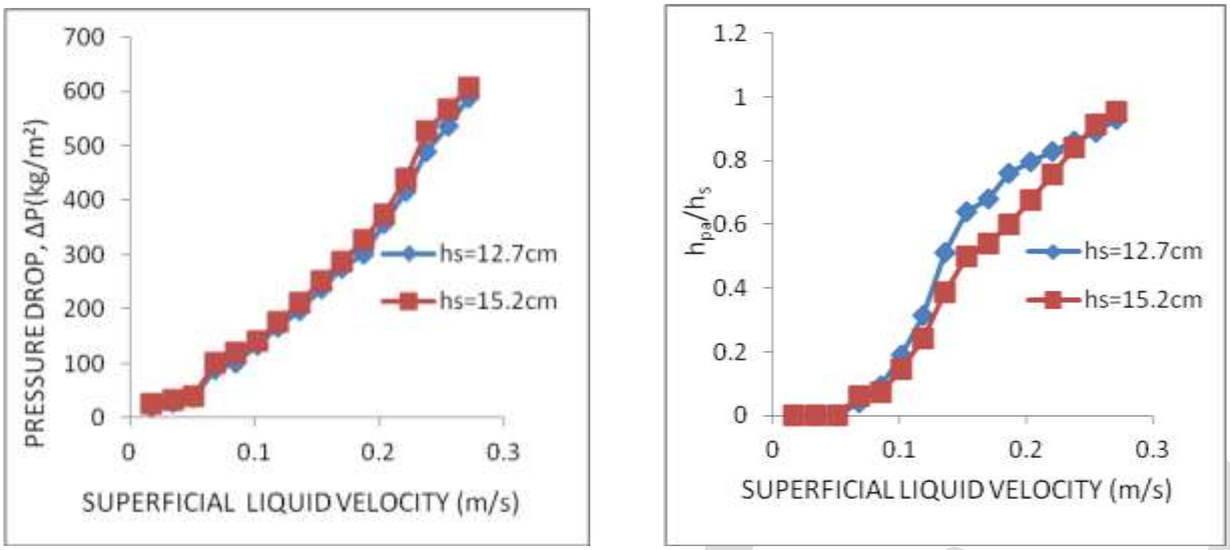

Fig 3.3.1 Effect of superficial liquid velocity on bed pressure drop and h_{pa}/h_S for 0.0011m particles (sand) in water at different h_s without internals with R=2

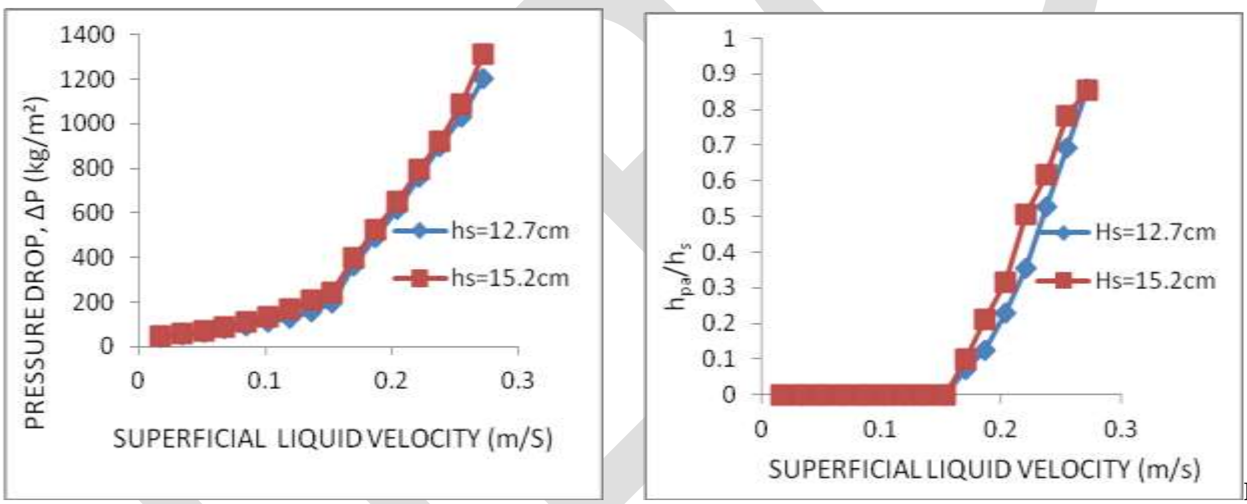

Fig 3.3.2 Effect of superficial liquid velocity on bed pressure drop and h_{pa}/h_S for 0.00218m particles (glass beads) in water at different h_s using internals with R=3 and $(L/D)_I$=3

From these above figures, it can be noted that the pressure drop increases with the increase in initial static bed height and top packed bed formation decreases with initial static bed height. The minimum semi-fluidization velocity being partially unaffected by the initial static bed height is indicated in fig 3.3.1 and fig 3.3.2. The maximum semi-fluidization velocity (U_{msf}) is the fluid velocity at which the entire bed of solid particles is transferred to the top packed bed. There are two methods used for the prediction of the maximum semi-fluidization velocity from extrapolation of the experimental data. (1) By extrapolation of the porosity of the fluidized section (ε_f) vs superficial liquid velocity curve to ε_f =1 or (2) By extrapolation h_{pa}/h_s vs superficial liquid velocity curve to h_{pa}/h_s =1. In the present study, second method has been used to determine the maximum semi-fluidization velocity. From the figures 3.1.1. to 3.3.2, it can be noted that maximum semi-fluidization velocity has been found to increase with the static bed height, the particle size and the bed expansion ratio.

3.4 Effect of (L/D) ratio of internal elements

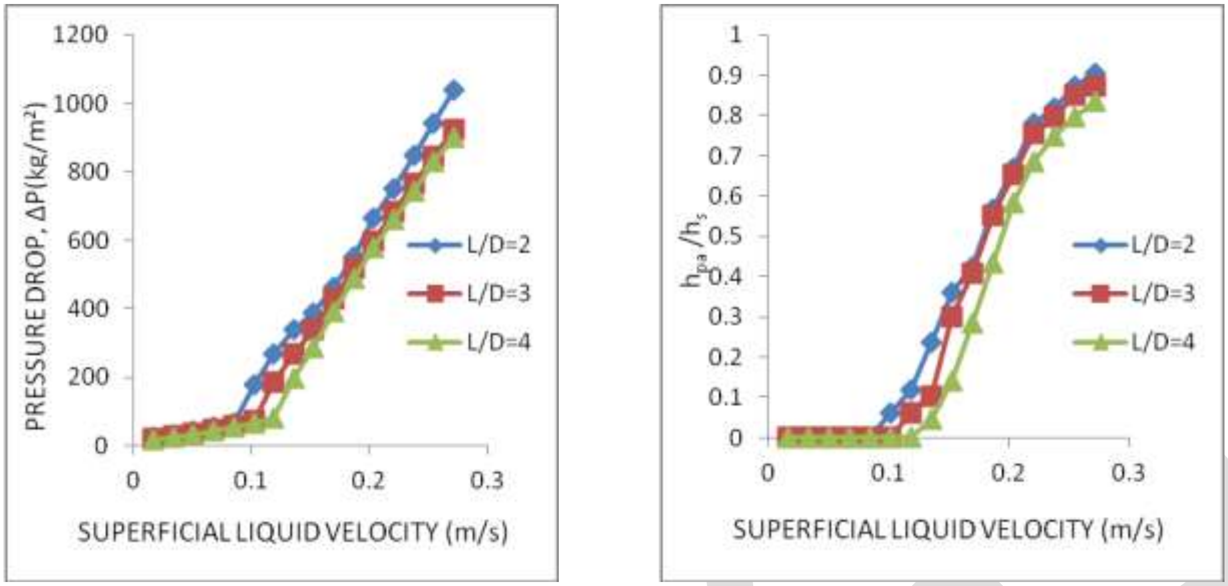

Fig 3.4.1 Effect of superficial liquid velocity on bed pressure drop and h_{pa}/h_S for 0.0011m particles (sand) in water at different (L/D) ratio of internal elements with R=3 and h_s=0.127m

From the figure 3.4.1, it can be found that pressure drop across the bed and top packed bed formation increases with the decrease in L/D ratio of internals from 4 to 2. And the minimum semi-fluidization velocity increases with increasing the L/D ratio of internals from 2 to 4. This shows that larger the L/D ratio of elements, it restricts the free motion of particles. Hence, higher fluid velocity is required to lift the particle to the top restraint plate.

3.5 Effect of with and without internals

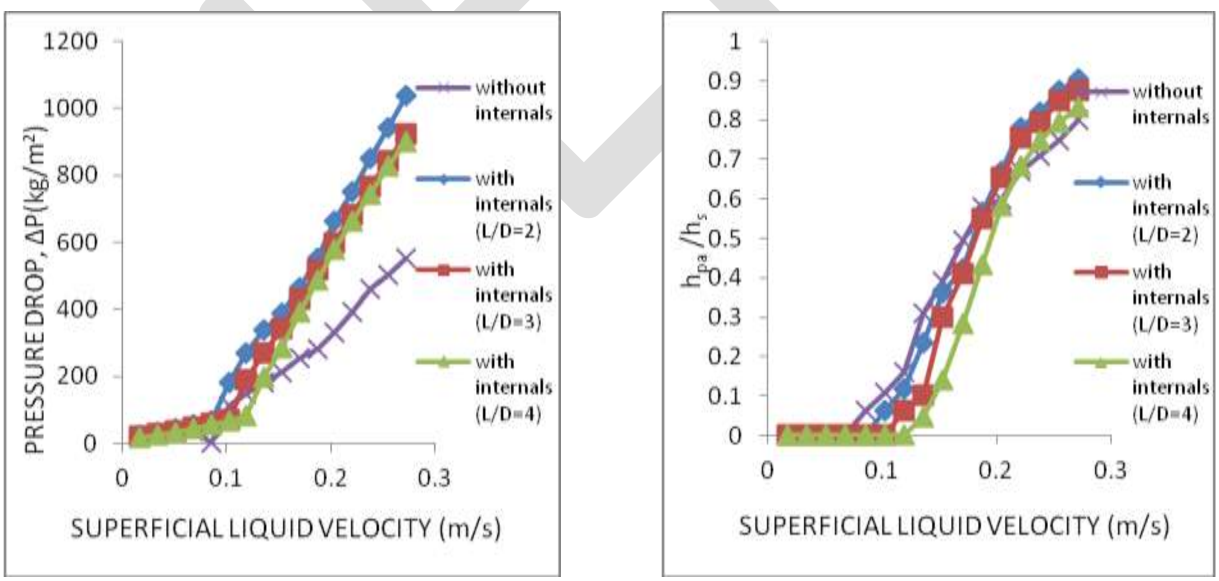

Fig 3.5.1 Effect of superficial liquid velocity on bed pressure drop and h_{pa}/h_S for 0.0011m particles (sand) in water at different (L/D) ratio of internal elements with R=3 and h_s=0.127m

From the figure 3.5.1, it can be observed that bed pressure drop and top packed bed formation increases while using internal elements. With internals, Minimum semi-fluidization velocity increases and the top packed bed formation initially decreases and after reaching the minimum semi-fluidization velocity h_{pa} increases when compared with the experiments without internals. Due to the presence of elements, the free motion of particles being affected so higher fluid velocity are required. Once it reaches the U_{osf}, elements enhance the mixing and accelerates higher packed bed formation.

4. ACKNOWLEDGEMENT

We take this opportunity to express our thanks to department of chemical engineering, kongu engineering college to undertake this work and allow us to present our findings as our contribution to the development of knowledge in the field of chemical reaction engineering and also wish to express my sincere thanks to my parents and all my friends for their support

5. CONCLUSION

The present study of the liquid-solid semi-fluidized bed hydrodynamics has been resulted with following conclusions. Both the minimum and maximum semi-fluidization velocities increase with the increase in particle size and bed expansion ratio and also increases while using internals than without using internals. The minimum semi-fluidization velocity is independent of the variation of initial static bed height, but the maximum semi-fluidization velocity increases with increase the static bed height. When using internals with lesser L/D ratio, bed pressure drop and packed bed formation increases. The efficiency of semi-fluidized bed reactor was enhanced by using internals of smaller L/D ratio.

Nomenclature

D_p Mean particle diameter, m

h_f Height of the expanded fluidized bed, m

h_{pa} Height of the top packed bed, m

h_s Height of initial static bed height, m

h_t Height of the top restraining plate, m

ΔP_{sf} Pressure drop across the semi-fluidized bed, Kg/m^2

R Bed expansion ratio, dimensionless

U_{osf} Minimum semi-fluidization velocity, m/s

U_{msf} Maximum semi-fluidization velocity, m/s

ε_f porosity of the fluidized bed, dimensionless

ε_{pa} porosity of the packed section, dimensioless

μ_l viscosity of the liquid, Pa s

ρ_s density of solid, kg/m^3

ρ_l density of liquid, kg/m^3

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