A

Project Report

On

BEHAVIOUR OF THREE PHASE FLUIDIZED BEDS USING WOOD PARTICLES

Submitted by

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(109CH0477)

In partial fulfillment of the requirements for the degree in

Bachelor of Technology in Chemical Engineering

Under the guidance of

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CERTIFICATE

This is to certify that the project report entitled, ***"Bed Expansion Behaviour of Three Phase Fluidized Bed With Wood Particles"***, submitted by ***SiddharthMishra***(109CH0477) in partial fulfillment for the requirements for the award of Bachelor of Technology Degree in Chemical Engineering at National Institute of Technology, Rourkela is prepared by him under my supervision and guidance and this work has not been submitted elsewhere for a degree.

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ABSTRACT

The bed expansion behaviour for a co-current three phase fluidized bed with wooden cubes of 7mm dimensions has been investigated. Experiments were carried out using air, water and the wooden cubes as the gas, liquid and solid phases respectively. Water was used as the continuous phase and air as the discontinuous phase. Changes in bed expansion ratio with different system parameters such as gas and liquid velocities have been found out.

Bed expansion ratio shows an increment with increase in the gas and liquid velocities. Whereas the trend is reverse with increasing bed height.

Keywords: Three-phase fluidization, wooden particles, bed expansion ratio

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NOMENCLATURE

U_g	Superficial gas velocity, m/s
U_l	Superficial liquid velocity, m/s
U_{lmf}	Minimum liquid fluidization velocity, m/s
U_{gmf}	Minimum gas fluidization velocity, m/s
ΔP	Bed pressure drop, kPa
R	Bed expansion ratio
r	Bed fluctuation r
H_e	Expanded bed height, m
H_s	Static bed height, m
H_{max}	Maximum bed height, m
H_{min}	Minimum bed height, m
g	Acceleration due to gravity, m sec^{-2}
M_s	Mass of solids in the bed, kg
A	Area of the fluidizing column, m^2
D_p	Particle size, mm

Greek symbols

ρ	Density, kg m^{-3}
μ	Viscosity, Ns m^{-2}
ρ_s	Density of solid, kg m^{-3}
ρ_l	Density of liquid, kg m^{-3}
ρ_g	Density of gas, kg m^{-3}
ε_s	Solid holdup
ε_l	Liquid holdup
ε	Porosity

CHAPTER 1: INTRODUCTION

The course through which a bed of solid particles gets altered from immobile condition to active fluid-like state when a fluid (liquid, gas or a combination of these) is made to pass in between these solid particles, is known as fluidization. When any fluid passes between beds of small particles at a low flow rate, the fluid just percolates through the gaps amid the stationary solid particles without altering their dynamic properties and this state is referred to as a fixed bed. On increasing the fluid velocity, the particles move away from one another and some shake and change positions within limited regions. This state is known as expanded bed. When the velocity is further increased, a velocity is reached when all the particles are kept in a state of suspension by the upward moving fluid. At such velocity, the frictional force amongst the solids and fluids is in equilibrium with the particles' weight, the vertical part of the compressive force amongst neighbouring solids vanishes, and the pressure drop in anyportion of the bed about equalizes the weight of fluid/s and the solids in that portion. This bed is said to be just fluidized and is known as incipient fluidization (Chidambaram, 2011). At this condition, this bed is fluidized and would exhibit fluidic actions. In such a state, the bed will behave as a fluid, which may be like a liquid or gas.

1.1: Gas-Liquid-Solid Fluidized Bed

The solid-liquid-gas fluidized bed is simply a batch of solid particles suspended within a column by inserting liquid as well as gas. In the last decade, solid-liquid-gas fluidizing beds have come up as amongst the highly capable methods for three phase processes. They are being seen as highly essential in chemical as well as bio-chemical domain, treating dirty, unusable water and other biochemical processes. Due to its increasing importance, its hydrodynamic characteristics such as the pressure drop, minimum fluidization velocity, bed expansion and bed fluctuation have to be investigated in order to provide the basic information required for the design of such fluidized beds (Chidambaram, 2011).

1.2: Advantages of Three Phased Fluidized Reactor

- **Uniform Particle Mixing:** Due to the in built fluidic nature of the solid material, fluidized bed does not experience poor mixing like packed beds. This allows a uniform product that is rather hard to achieve in other reactor designs. The minimization of radial

and axial concentration gradients even leads to better fluid-solid contact, which is essential for reaction efficiency and quality.

- **Uniform Temperature Gradients:** Many chemical reactions need the addition or removal of energy. Local hot or cold spots within the reaction bed, generally a hindrance in packed beds, are kept at bay in a fluidized condition like as an FBR. In other reactor types, the local temperature differences, particularly hotspots, can lead to product degradation. Thus FBRs are quite properly suited to exothermic reactions. It is also learned that the bed-to-surface heat transfer coefficients for FBRs are more.
- **Ability to Operate Reactor in Continuous State:** The fluidized bed nature of these reactors does allow for the ability to constantly extract product and feed new reactants into the reaction chamber. Operating at a continuous process state allows manufacturers to produce their diverse products with greater efficiency because of the removal of startup conditions in batch processes.
- We can achieve a higher rate of reaction per unit reactor volume of the reactor.
- Fine catalyst particles can be used better; minimising the intra-particle diffusion. Lesser the particle size, more the corresponding surface area allowing greater and better contact of phases and improving the reactor's functioning.
- Can be effectively used for rapidly deactivating catalyst and three phase reactions where the catalyst and the reactant are both in solid phases. (e.g. catalytic coal liquefaction).

1.3: Applications of Three Phase Fluidized Beds

The three phase fluidized bed is emerging in the latest days as amongst the highly hopeful methods for three phase operations. In the latest decades, it has made inroads into numerous domains such as pharmaceuticals, chemicals, petrochemicals, biochemical processing, metallurgy. Fluidized beds perform various functions in the industries, like easing catalytic and non-catalytic reactions, mass as well as heat transfers, catalytic cracking, pyrolysis. Three-phase fluidized beds have been used effectively in various industrial functions like in Hydrogen oil operation for hydrogenation and hydro-desulphurization of residual oil, the H-coal process for coal liquefaction, and in Fischer-Tropsh process. Some more applications of fluidized bed are as follows:

- Turbulent contact absorption of flue gas desulphurization.
- Bio-oxidation process for wastewater treatment.

- Physical operations as drying and other forms of mass transfer.
- Biotechnological processes such as fermentation and aerobic wastewater treatment.
- Methanol production and conversion of glucose to ethanol.
- Pharmaceuticals and mineral industries.
- Oxidation of naphthalene to phthalic anhydride (catalytic).
- Coking of petroleum residues (non-catalytic) (Pandey, 2010).

1.4: Drawbacks of Fluidized Beds

- **Increased Reactor Vessel Size:** Due to the spreading out of the bed material components in the reactor, a large container is generally needed than that for a packed bed reactor. This large reactor means greater initial capital investments.
- **Pumping Requirements and Pressure Drop:** The necessities for the fluid to suspend the solid materials make it necessary that a higher fluid velocity be attained in the reactor. In order to achieve this, greater pumping power and hence more energy costs are required. Moreover, the pressure drop related with deep beds again needs further pumping power.
- **Particle Entrainment:** The high gas velocity present in such a style of reactor generally results in fines becoming entrained within the fluid. These entrained particles are then carried out from the reactor along with the fluid, where they are separated. This is a quite difficult and costly problem to address depending on the design and function of the reactor. This does generally continue to be a problem even with the presence of other entrainment minimising technologies.
- **Lack of Current Understanding:** Present understanding of the real behaviour of the materials in a fluidized bed is quite less. It is quite difficult to predict and calculate the complex mass and heat flows within the bed. Due to this lack of understanding, a pilot plant for new processes is required. Even with pilot plants, the scale-up can be very difficult and may not reflect what was experienced in the pilot trial.
- **Erosion of Internal Components:** The fluidic properties of the fine solids in the bed eventually lead to the wear of the reactor vessel. This can require expensive maintenance and upkeep for the reaction vessels and pipes.

- **Pressure Loss Scenarios:** If fluidization pressure is suddenly lost, the surface area of the bed may be at once minimised. This can either be a nuisance (e.g. making bed restart difficult), or may have more serious complications, such as runaway reactions (e.g. for exothermic reactions in which heat transfer is suddenly restricted).

CHAPTER 2: LITERATURE REVIEW

A lot of research has been carried out in the field of three phase fluidization especially because of their emergence as highly useful processes in various domains since the last one or two decades.

2.1: Modes of Operation of Solid-Liquid-Gas Fluidised Beds

Based on the differences in flow directions of gas and liquid and in contacting patterns between the particles and the surrounding gas and liquid, several types of operation for gas-liquid-solid fluidizations are possible. Gas-liquid-solid fluidization is classified mainly into four modes of operation.

- Co-current three phase fluidization with liquid as the continuous phase.
- Co-current three phase fluidization with gas as the continuous phase.
- Inverse three phase fluidization.
- Fluidization by a turbulent contact absorber (Jena et al., 2008).

2.2: Flow Regime

For the attainment of a steady process with various operating parameters, knowledge of the flow regimes attained in a fluidized bed is essential. The distinction between the flow regimes is still not identified appropriately. As of yet, seven distinct flow regimes for gas-liquid-solid co-current fluidized beds have been recognised,(Jena et al, 2009):

• **Dispersed bubble flow** – It often relates to slow gas rates and greater liquid rates. In this regime, tiny bubbles of uniform size are found. Bubble conjoining is less despite the great bubble frequency.

• **Discrete bubble flow** – It is the state in which low liquid and gas rates are found. In such a situation, bubble size is quite small with quite less bubble frequency.

• **Coalesced bubble flow** – It is the flow where low liquid rates and transitional gas rates function. In such a case, the bubble size gets larger with enhanced bubble coalescence.

• **Slug flow** – In this regime, bubbles appear in the form of large bullets with a diameter the same as that of the column and length greater than the column diameter. Few small bubbles can also be seen in the wakes of the slugs. This flow has quite few applications.

• **Churn flow** – It is similar to the slug flow regime. With an increase in the gas velocity, an increase in downward liquid flow in the vicinity of the wall is seen. It can be explained as the transition between bubbling and slug flow on the basis of two-phase fluidized systems.

• **Bridging flow** – It is a transitional regime between the churn flow and the annular flow. In this form of flow, solids and liquid form "bridges" in the reactor that is constantly broken and re-formed.

• **Annular flow** – At very high gas rates, an unbroken gas phase gets developed in the core of the column.

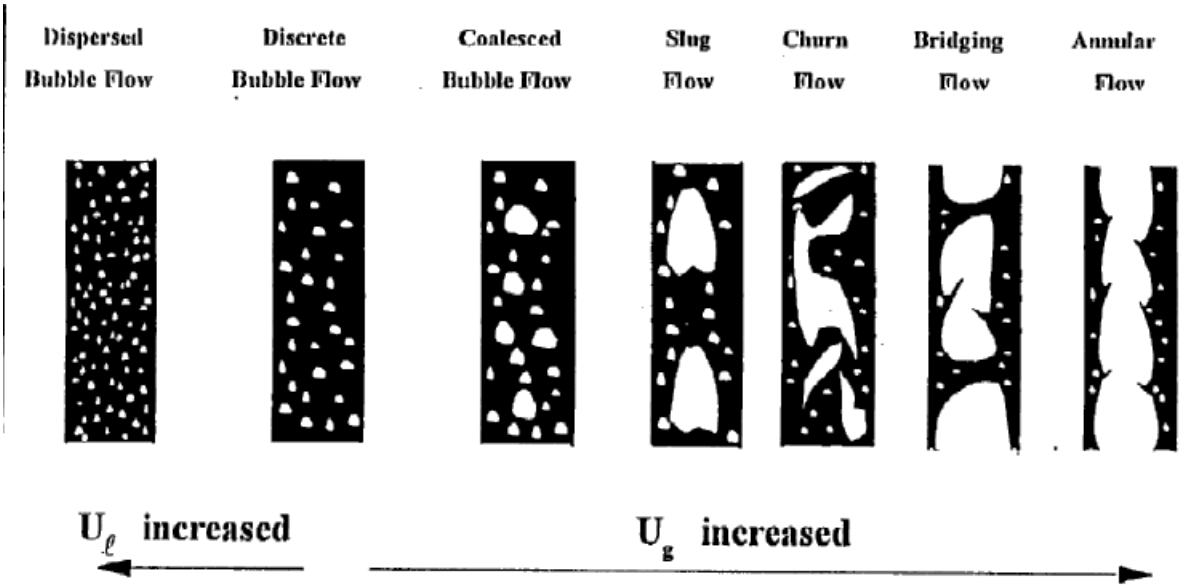

Figure 2.1 Various Flow Regimes

2.3: Variables Affecting the Quality of Fluidization

The quality of fluidization is determined by the following variables (Chidambaram, 2011):

- **Fluid flow rate** – Flow rate ought to be sufficient to keep the solids in a suspended state, but not too high resulting in fluid channelling.
- **Fluid inlet** – Inlet has to be designed in such a way to provide uniform distribution of the fluid entering the bed.

- **Particle size** – The quality of fluidization is to a large extent determined by the particle size. Particles of different sizes have been grouped into Geldaart's categorisation of particles. Particles that have a wider range are easier to fluidize than the particles of even size.

- **Gas, liquid and solid densities** –Smooth fluidization is easily maintainable when the relative density of the gas and the liquid and the solid are nearer.

- **Bed height** – With increase in the bed's height, it is tough to sustain effective fluidization.

2.4: Some definitions in fluidization phenomena

1. Minimum Fluidization Velocity (U_{mf}) – The minimum fluid velocity at which the bed just gets fluidized. At this velocity, the weight of the bed just gets counterbalanced by the pressure of the fluid.

2. Bed Pressure Drop (ΔP) – Measures the total weight of the bed in combination with the buoyancy and phase holdups.

3. Bed Expansion Ratio (R) – It the ratio of fluidized bed height to the initial static bed height.

$$R = He/Hs \quad (1)$$

4. Bed Fluctuation Ratio (r) – It is the ratio of maximum and minimum heights of the bed attained during fluidization.

$$r = Hmax/Hmin \quad (2)$$

4. Gas Holdup (ε_g) – It measures the volume fraction of gas. It is the ratio of volume of gas to the total volume of bed.

$$\varepsilon_g = \frac{VolumeOfGas}{Total\ Volume\ Of\ The\ Bed} \quad (3)$$

5. Liquid Holdup (ε_l) – It measures the volume fraction of liquid. It is the ratio of volume fraction of liquid to the total bed volume.

$$\varepsilon_l = \frac{VolumeOfLiquid}{Total\ Volume\ Of\ The\ Bed} \quad (4)$$

6. Solid Holdup (ε_s) – It measures the volume fraction of solid. It is the ratio of volume fraction of solid to the total volume of bed.

$$\varepsilon_s = 1 - \varepsilon_g - \varepsilon_s \quad (5)$$

7. Porosity (ε) – It is the volume occupied by both liquid and gas (Jena, 2009 b).

$$\varepsilon = 1 - \varepsilon_s = \varepsilon_l + \varepsilon_g \quad (6)$$

2.5: Experimental survey

The first fluidized bed was for the first time, developed by Winkler in 1921 and was industrially used for the first time in large-scale as Winkler gassifier in 1926 (Kunii and Levenspiel, 1991). Fluidized bed catalytic cracking of crude oil to petrol (FCC) was commercialized in 1942, and till date remains the greatest use of fine-powder fluidization. Numerous catalytic functions such as accrylonitrile manufacture, phhthalic anhydride and Fischer-Tropsch synthesis of liquid fuels derived from coal-based gas further enhanced the range following the FCC (Jena et al.,2009). Lurgi for the first time, made commercial use of the circulating fluidized bed (CFB) in the 1970's for rough powders that could function at more than the terminal velocity of all the bed particles. Polyethylene hence came to be manufactured in a fluidized bed, and this technique is till date, widely employed in industry. Circulating Fluidized beds were commercialised in 1980's for the combustion and producing polypropylene in fluidized beds. New domains where fluidization came to be used in producing semiconductors and ceramic materials by chemical vapour deposition and in biological applications the use of liquid fluidized beds (Jena H. M ,2009).

Analysis on literature on hydrodynamic properties of solid-liquid-gas fluidization reveals that a lot of work has been done, and the in detail research studies were based on experiments performed in small columns.

Many bed expansion data are accessible in the literature because of the significance of this design parameter and to the comparative simplicity of obtaining its measurement. Three measurement methods have been used to obtain the data required for the development of bed height vs. gas and liquid velocity curves: (1) visual examination of the expansion, (2) estimation from the breakpoint in the static pressure profile,

and (3) analysing the photographs taken with a high resolution camera. The expanded bed height shows an increase with gas and liquid flow rates once the velocity exceeds the minimum fluidization velocity (Handl, 1976; Zhivaikin et al., 1967), and the fact that two regions of bed expansion exist has also been reported(Balabekov,1969a, 1971; Gelperin and Kruglyakov, 1979; Handl, 1976;Tichy and Douglas, 1972) . Theory regarding bed expansion is as of yet, quite limited so that data are correlated in terms of simple empirical correlations (Mu-royama and Fan, 1985).

Three models for bed expansion in fluidized beds have been put forward in the literature (Levsh et al., 1970; O'Neillet al., 1973; Tichy and Douglas, 1972). The model proposed by Levsh et al. (1970) is inadequate due to its inclusion of the gas fraction in the bed, for which no relationship was satisfactorily given .O'Neill et al. (1973) based their study on a hydrodynamic model that comprises of two regimes of fluidization. But, their model does not go hand in hand with experimental data due to the supposition that conditions of incipient fluidization, if there in the bed at umF, are upheld all through the entire range of fluidization flow rates. Tichy and Douglas (1972) have used an equation for flow in between porous media for analyzing bed expansion behaviour. The deficiencies of this method are the utilization of an equal diameter of gas channels,

2.6: Scope and objective of the present investigation

The objective of the current work is as follows:

- To study the change in bed expansion ratio with change in the bed height.
- To study the change in bed expansion ratio with changes in the liquid and gas flow rates.

The current effort is directed on comprehending the bed expansion behaviour in a three phase fluidized bed. Experiments were done in a fluidized bed of channel height 1.4 m and diameter of 0.1 m. Wooden cubes of dimensions 7 mm are used as the solid phase. The fluidization procedure has been carried out with co-current inclusion of liquid (water) as the continuous phase and gas (air) as the discrete phase. Velocities of both liquid and gas have been varied in a wide range of 0-0.0678 m/s and 0-0.0212 m/s respectively. The static bed heights of the solid phase in the fluidized bed used are taken as 0.13 m, 0.18 m, 0.23 m .

CHAPTER 3: EXPERIMENTATION

Experiments were carried out with the procedure as has been explained below to study the effects of various parameters on bed expansion behaviour. The description for the various parts of the experimental set up is also given below.

3.1: Experimental Setup

A fluidized bed assembly comprises of three portions, namely, the test section, the liquid-gas distributer portion, and the gas-liquid separation section. Figure 3.1 gives a schematic diagram of the experimental setup while Fig. 3.2 is a photograph of the testing section. The test section is the most important part of the fluidized bed where fluidization occurs. It is an upright cylindrical Pllexi glass tube of 0.1 m diameter and 1.4 m height comprising of two sections of persprex columns. The liquid-gas distributor is present at the base of the test section and is constructed in a manner such that evenly mixed liquid-gas mixture goes into the test section. The distributor portion is made from Perspex sheet and is frucctoo-conical of 0.31 m in length, has a divergence angle of 4.5^{o}. The liquid inlet of 0.01252 m in internal radius is present centrally at the lower end. The higher end is fitted to the test section, with a perforated distributor plate made of G.I. sheet of 0.001 m thick, 0.12m diameter. The perforations were triangular in pitch. To prevent the uneven dispersal near the entry of the test section, the distributor plate is such constructed that comparatively even flow can be attained all through the cross-section. An antenna-kind air sparger of 0.045 m radius with 50, 0.001 m holes is installed beneath the distributor plate with a few layers of plastic and glass globules in the midst for producing fine bubbles evenly distributed within the column cross-section of the apparatus. The liquid-gas separation portion at the uppermost point of the fluidizer is a cylindrical portion of 0.13 m internal radius and 0.34 m height, gathered to the testing portion with 0.08 m of the testing portion inside it, that lets the gas escape and liquid circulating through the outlet of 0.0254 m internal diameter at the bottom of this section.

Oil free pressurized air from a centrifugal compressor (1 phase, 1 Hp, 1420 rpm)is employed to provide the air at almost unchanging pressure change as the fluidizing gas. The air was inserted into the column by the help of the air sparger at the required velocity by taking the use of two calibrated rotameters. Water was forced into the fluidizer at the desired velocity by the means of two water rotameters. Centrifugal pump of capacity (Texxmo, singlephase, 1 HP, 2900 rpm, discharge capability of 130 lpm); was employed to convey water to the

fluidizer. Water rotameters that were employed were of the range 0-10 lpm to 10-100 lpm. Air rotameters were of the range 0-10lpm to 4.15-41.5 lpm.(Figure-3.3)

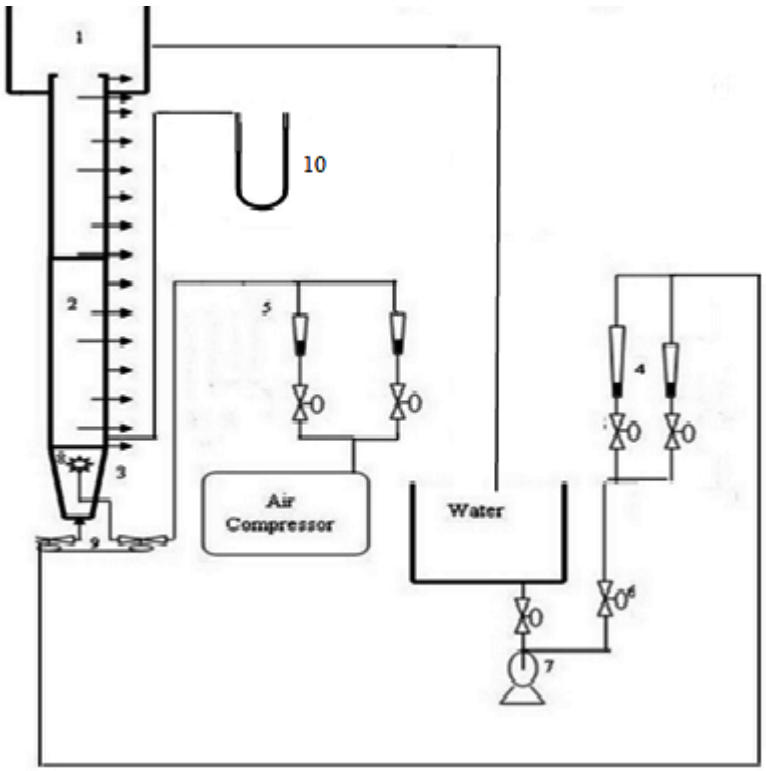

Figure 3.1:Schematic Diagram of the Experimental Setup

The Components of the setup are

1. Gas–liquid disengagement section,
2. Test section,
3. Gas–liquid distributor section,
4. Water rotameters,
5. Air rotameters,
6. Ball valves,
7. Liquid pump,
8. Air sparger,
9. Two way quick closing valves
10. U tube manometer

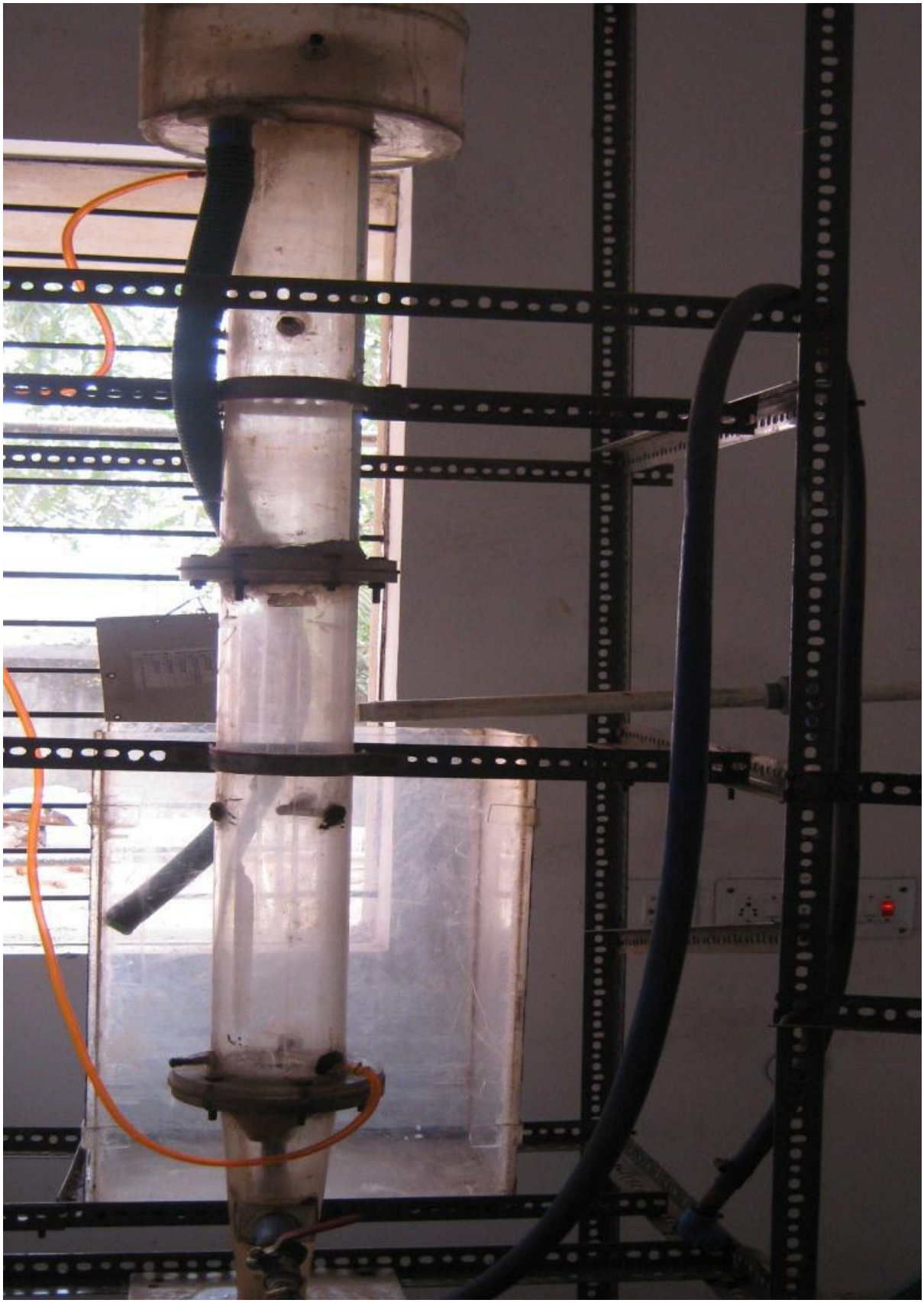

Figure 3.2 :Photographic View ofthe Test Section

Figure 3.3 :Photographs of (a) the disengagement section, (b) the gas-liquid distributor

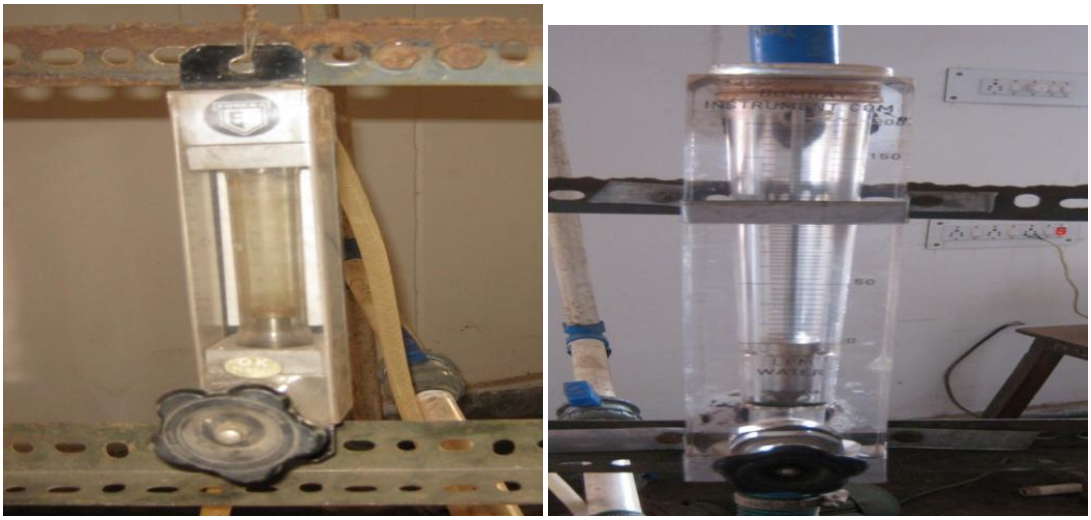

Figure.3.4: Photographic view of (a) air rotameter, (b) water rotameter

Figure.3.5: Photographic view of (a) air sparger, (b) distributor plate.

3.2: Experimental Procedure

- The three phases that were employed within the column were wooden cubes of dimensions 7mm, normal water as well as pressurised air.
- Wooden strips were first chopped into cubes of 7mm dimensions by careful and accurate measurement and cutting.
- They were then put in water for about three to four days to let them get absolutely wet and hence get denser than the water so that they could be used for the experiment.
- At the initial stage, wooden cubes were loaded into the column and were suitably packed to get a desired initial bed height.
- The water-air movements were co-current and bottom to top.
- The air flow rate was fixed at a specific flow rate and monitored continuously and maintained at a constant rate to avoid fluctuations in the flow rate and hence, the distortions in the readings.
- The water flow rate was then varied at regular intervals with each interval lasting about five-six minutes to let the fluidized bed attain steady state.
- The expanded bed height was then measured visually and noted down.
- Hence, for a particular air flow rate, the bed expansion ratios for various water flow rates were noted down.
- After that, the air flow rate was changed and the same procedure was repeated.
- Since the experiment involved more than a single bed height, the bed height too was changed and the above procedure repeated for the new bed height.

3.3: Scope of the Experiment

The scope of the experiment for the present work is described by the following tables.

Table 1: Properties of Bed Material

Material	**ρ ($kg.m^{-3}$)**
Wet Wooden Cubes	**1110**

Table 2:Properties of Fluidizing Medium

Fluidizing Medium	ρ ($kg.m^{-3}$)	μ (Ns/m^2)
Air at 25ºC	1.168	0.00187
Water at 25ºC	997.0479	0.095

Table 3: Operating Conditions

Gas Velocity Range	(m/s)	0-0.0212
Water Velocity Range	(m/s)	0-0.0721
Static Bed Heights	(m)	0.13,0.18,0.23

CHAPTER 4: RESULTS AND DISCUSSION

In the present work, bed expansion behaviour of the solid-liquid-gas fluidized bed was examined. Wooden Cubes of 7mm dimension, normal water and pressurised air were employed as the solid, liquid and the gas phase respectively. In the study, we have tried to gain appropriate information regarding the bed expansion behaviour of fluidized bed through changes in certain operating parameters like liquid flow rate, gas flow rate and bed height. The bed expansion ratio has been studied and discussed in this chapter.

4.1: Bed Expansion Ratio

In the current project, expanded bed height was determined via visual examination. In visual survey, a quite dilute bed appearing at the topmost of the three-phase zone has been overlooked and the height of the comparatively denser bed has been reported as expanded bed height. The bed expansion experiment as carried out by changing liquid speed (at a constant gas speed) and particle sizes have been presented in terms of bed expansion ratio which is the ratio of the expanded bed height to the static bed height.

The same procedure was repeated after varying the bed height and data collected. Observed data were plotted and the plots are shown below through Figures No. 4.1 to 4.3.

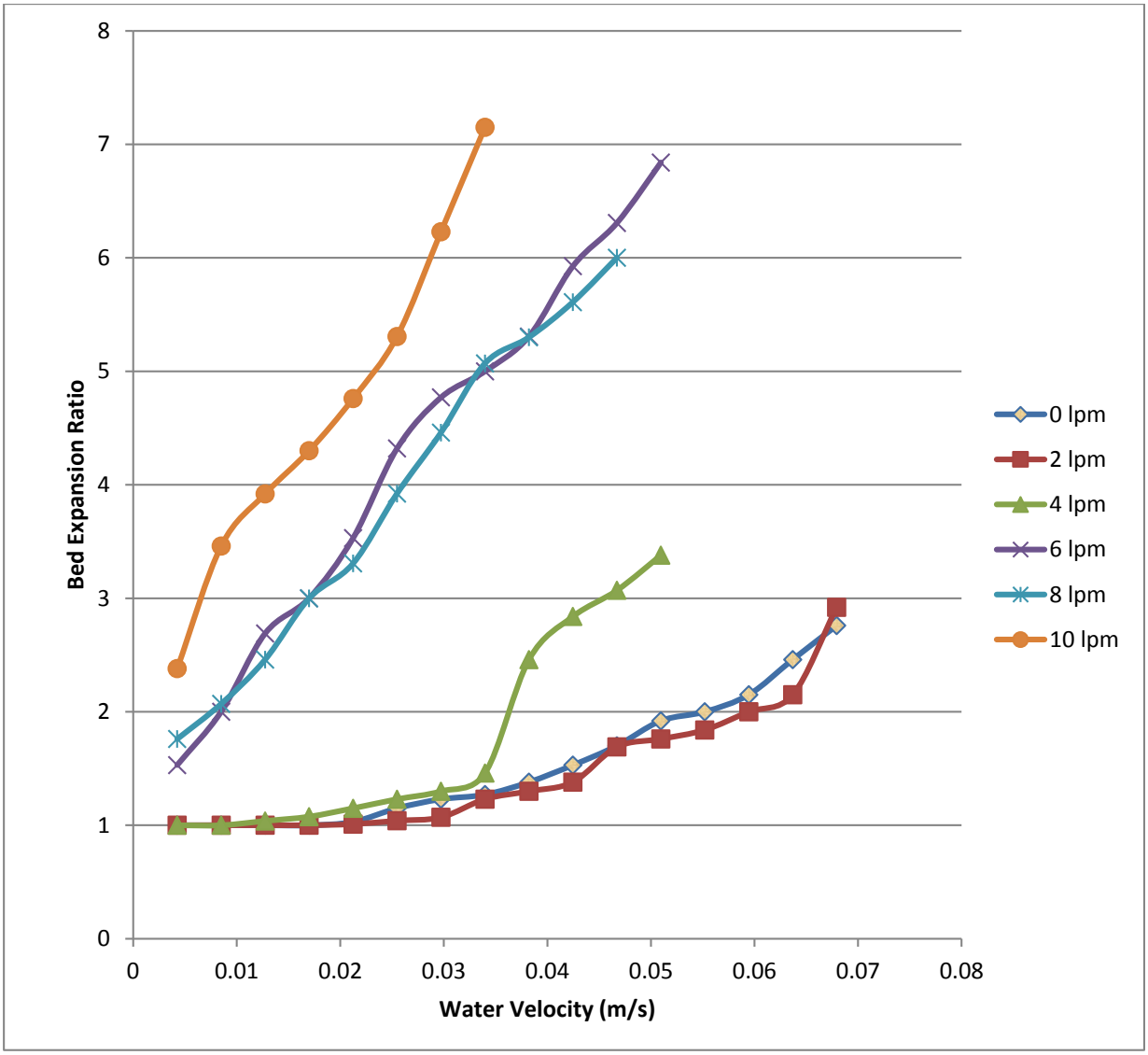

Figure 4.1 :Plot of Bed Expansion Ratio vs Liquid Flow Rate for Bed height of 13cm

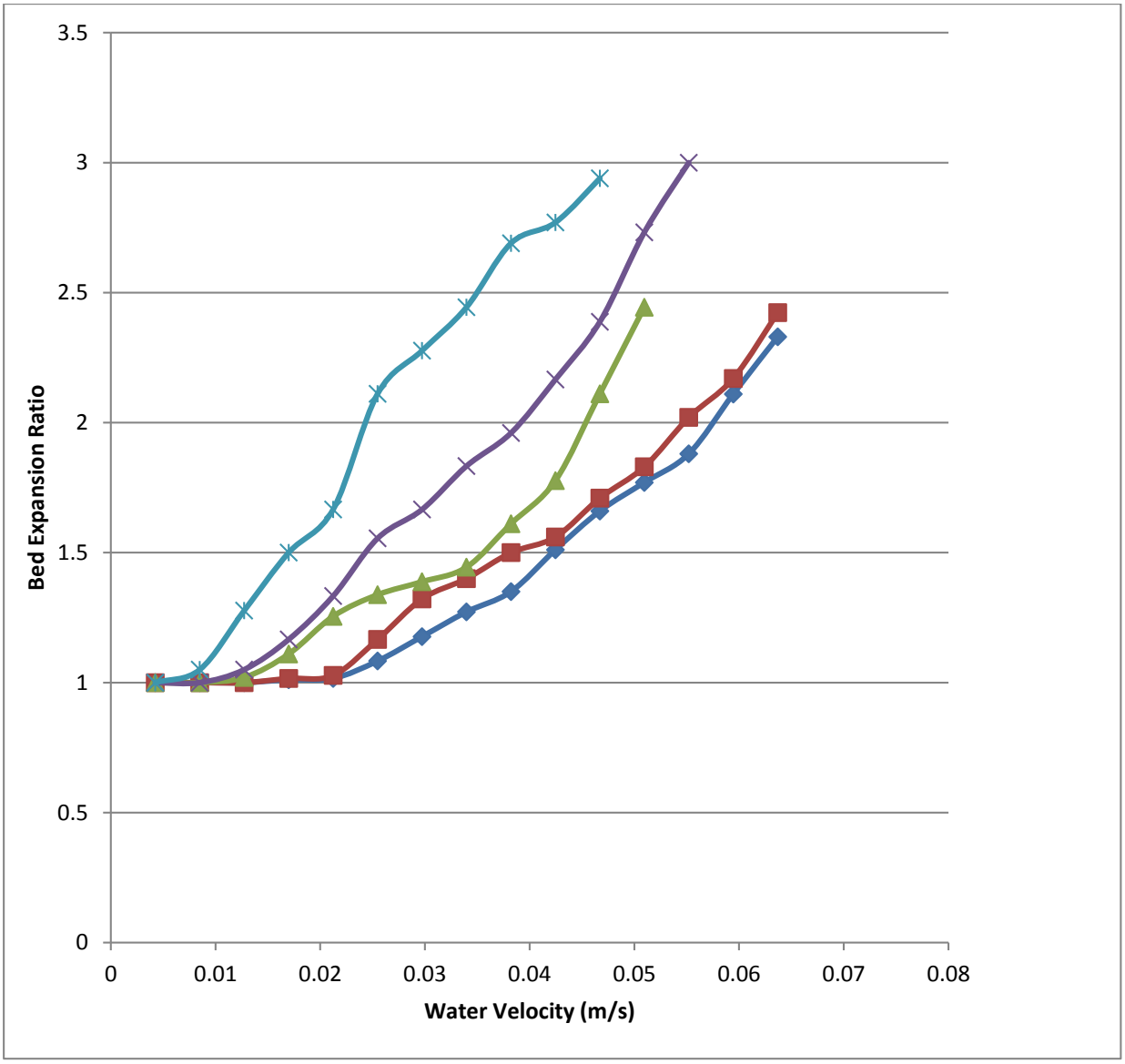

Figure 4.2 :Plot of Bed Expansion Ratio vs Liquid Flow Rate for Bed Height of 18cm

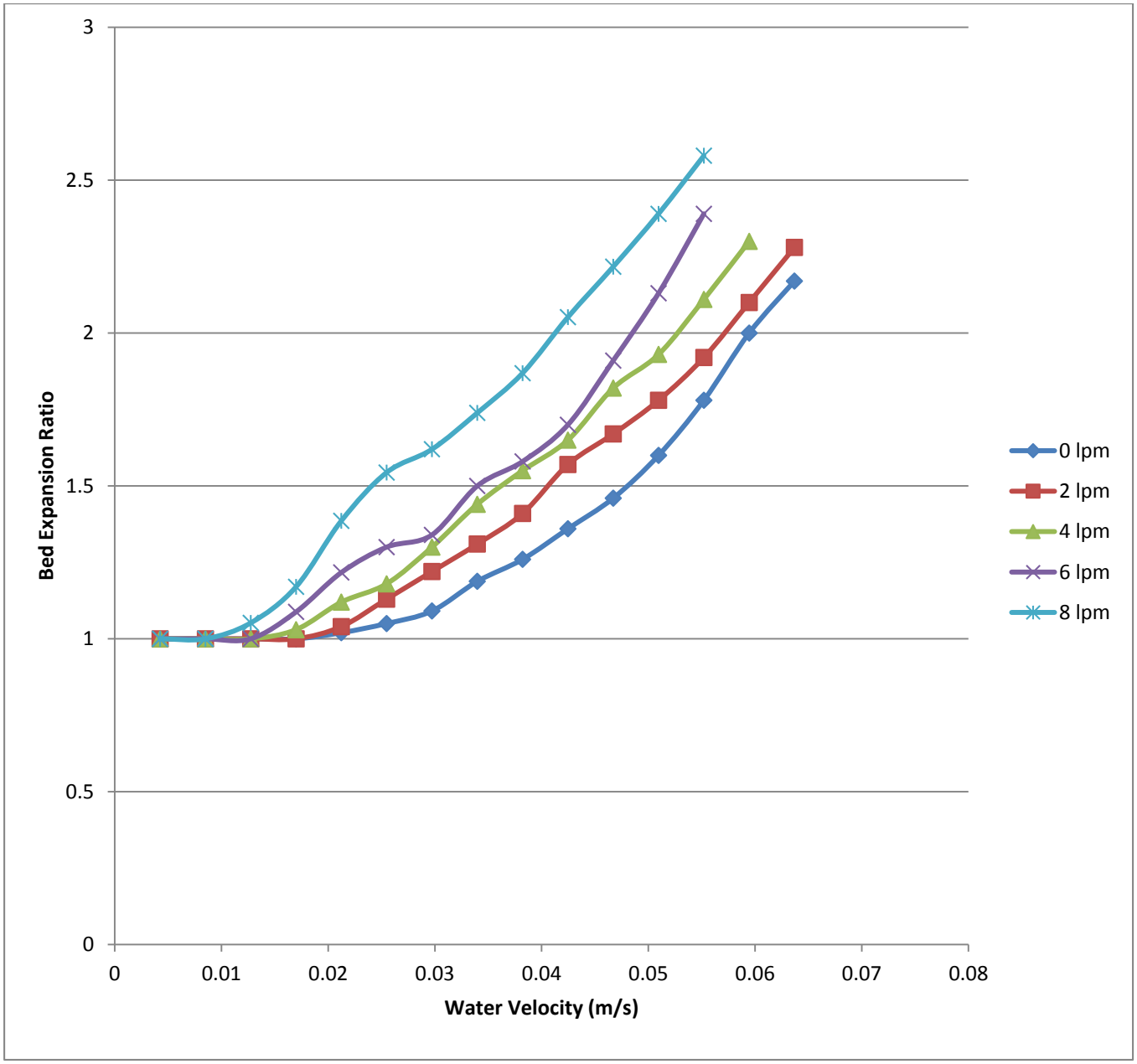

Figure 3.3 :Plot for Bed Expansion Ratio vs Liquid Flow Rate at Bed Height of 23 cm

The above plots clearly depict the fact that not only is fluidization achieved faster with a greater gas velocity at the same liquid flow rate but also that bed expansion ratio is greater for higher gas velocities as well as for higher liquid flow velocities. This can be attributed to the fact that with increased speed, the liquid hold up also increases as a result of which the spacing between the solid particles also increases and hence, the greater degree of expansion leading to a higher ratio.

We also notice that with increase in the bed height of the particles, the expansion ratio decreases (depicted by the fall in slope of the respective graphs and also decrement in the final value obtained for the same liquid and gas flow rate). This trait can be attributed to the fact that as there is an increase in the bed height, so is an increase in the weight of the objects to be fluidized and hence the comparative degree of fluidization is lesser and the ratio falls for successive increase in the bed height.

CHAPTER 5: CONCLUSION

From the experiments performed, the effects of the different parameters on bed expansion ratio have been found out to be-

- Increasing the gas velocities leads to an increase in the expansion ratio.
- Increasing the liquid velocities leads to an increase in the expansion ratio.
- Increasing the bed height leads to a decrease in the expansion ratio.

5.1: Scope of the work

- To examine the phase holdups of the three phase fluidized bed with wood or other materials' cubes of varying dimensions.
- Contrasting the bed behaviour of regular and irregular particles.
- To examine the heat and mass transfer phenomena with regular cube particles.

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