PROJECT REPORT ON

HYDRODYNAMICS STUDIES OF INVERSE FLUIDISED BED

A Report Submitted In partial fulfillment of the requirements of

Bachelor of Technology (Chemical Engineering)

Submitted by

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CERTIFICATE

This is to certify that the project report entitled **"Hydrodynamics Studies of Inverse Fluidized Bed"** submitted by **Gangadhar Hota, Roll No: 110CH0445** in partial fulfillment of the requirements for the award of B.Tech Degree in Chemical Engineering at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the report has not been submitted to any other University/Institute for the award of any Degree.

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ACKNOWLEDGEMENT

I feel immense pleasure and privilege to express my deep sense of gratitude and feel indebted towards all those people who have helped, inspired and encouraged me during the preparation of this report. I wish to express my sincere thanks and gratitude to my supervisor **Prof. Abanti Sahoo** for suggesting me the topic and providing me the necessary guidance, motivation and constructive criticism throughout the course of the project. I am also grateful to **Prof. R. K. Singh**, Head of the Department, Chemical Engineering for providing me the necessary opportunities for the completion of my project. I am also thankful to all the staff and faculty members of Chemical Engineering Department, National Institute of Technology, Rourkela for their consistent encouragement.

Thanking You,

Gangadhar Hota

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ABSTRACT

Fundamental research in hydrodynamic behavior of inverse fluidization are carried out in a laboratory unit and effects of different parameters on three-phase inverse fluidization systems are studied in this work. Poly Propylene beads of different sizes are fluidized in the inverse fluidized bed with counter current flow of water and air as fluidizing medium. The hydrodynamic characteristics are observed by measuring the pressure drop, bed expansion and minimum fluidization velocity as a function of flow rate and bed height with tap water and air as fluidizing medium. Attempt has been made to develop correlation for pressure drop using the observed data on the basis of statistical analysis. The observed pressure drop and bed expansion ratio indicate the application of inverse fluidized bed as the bio-reactor which can further be modified for the design of large scale effluent treatment for various industries.

Key words: inverse fluidization, hydrodynamics, bed expansion

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CHAPTER: 1

INTRODUCTION

1. **FLUIDIZATION :**

Fluidization is a technique through which fine solid particles behaves like a fluid through contact with liquid or gas or both. Under the fluidized state, the fluidized state, gravitational pull force on solid particles is offset by the fluid drag force. In fluidized condition particles remain in a semi-suspended condition.

The term 'fluidization' is usually associated with two or three phase systems, in which solid particles are fluidized by a liquid or gas stream flowing in the direction opposite to that of gravity. In these classical fluidized bed systems, the solid particles have a higher density than the fluid. Fluidization where the liquid is a continuous phase is commonly conducted with an upward flow of the liquid in liquid-solid systems or with an upward co-current flow of the gas and the liquid in gas-liquid-solid systems.

1.1 Inverse Fluidization:

When the density of the particles is lower than that of the liquid and the liquid is in continuous phase, Fluidization can be achieved by down flow of liquid, it called Inverse Fluidization. Considering a bed of solid particles floating on a fluid surface, when a liquid or a gas is passed at a very low velocity down through the bed of particles, the particles start to move and there is a pressure drop. Increasing the fluid velocity steadily, the pressure drop and the drag on the individual particles increases and eventually the particles move more vigorously and get suspended in the fluid. The particles float or sink depending on their density relative to the fluid. If the density of solid particles and continuous liquid phase is almost same then fluidization is only achieved by counter-current flow of gas and this type of fluidization is called solid-liquid-gas inverse fluidized bed.

1.2 Advantages of Inverse Fluidization Process:

1.2.1 Low energy consumption**:**

The inverse fluidization is achieved by a stream of fluid falling from the top and it is fluidizing in the direction of gravity against buoyancy. Hence not a very high velocity of inlet flow is required as in case of traditional fluidization. The minimum fluidization velocity is lower in this case. Also it takes lesser energy to pump a fluid to force the particles in this case. Hence viewing on a larger scale, at the industrial level, it can save a lot of energy. Such energy efficient processes are the need of today when energy crisis is at its peak.

1.2.2 High turbulence:

In inverse fluidization, a big advantage is the achievement of higher turbulence, which is aided by an initial collision of fluid inlet with the bed particles, leading to foaming. This higher turbulence is the key in better mixing, and more solid randomness which leads in higher heat transfer rates. Better the turbulence better will be mass transfer rates between solids and gases (3-phase inverse fluidization) which improve the performance of a chemical reactor.

1.2.3 Gas-solid contact in gas-liquid-solid inverse fluidization:

The traditional fluidization is inefficient for the gas solid cases of mass transfer or mixing and often many alternatives have to be used for the purpose. Inverse fluidization can promote contacting of solid and gas. A better mass transfer between gases and solids is expected in a 3-phase setup, improving the performance of the chemical reactor.

1.2.4 Erosion of vessel:

Inverse fluidization was seen to be achieved at a lower velocity of the inlet flow, comparative to traditional fluidization, it can be directly predicted that the equipment parts will definitely have a longer life in the case of inverse fluidization. This helps in reducing run-time costs to industries.

1.2.5 Economical:

The above four advantages show the efficiency of the process. Yet there are a few more ways how this process becomes economical. Firstly particles of the bed have to be lighter than the medium fluid. That does not mean particles of heavy materials cannot be used. A simple way is to use hollow particles, this gives a lighter particle and also the surface area available for a particle is more than that of a solid particle from a given amount of material. These hollow catalysts or bed particles can make the process further economical and useful for a wide range of fluid; especially lighter fluids with lesser viscosity.

In spite of the various advantages, the efficiency and quality of fluidization is adversely affected in cylindrical beds due to the particle size reduction results in entrainment, limitation of operating velocity in addition to other demerits like slugging, non-uniform fluidization associated with such beds.

1.3 Application of Inverse Fluidization:

1. An important application of liquid-solid fluidized beds has been developed recently in biotechnology, namely, immobilized biocatalyst bioreactors.

2. Inverse fluidization finds main application in environmental engineering for waste water treatment and in biochemical engineering.

3. Environmental engineering in biological reactors

4. Efficient control of bio film thickness and ease of re-fluidization in case of power failure. These significant advantages found many applications of inverse fluidized beds in biochemical processes like ferrous iron oxidation and aerobic and anaerobic biological wastewater treatment like treatment of wine distillery waste-water.

5. Minimum carryover of coated microorganisms due to less solids attrition.

6. The application of inverse fluidization technique in biotechnology is one of the most important areas in bioreactor engineering. The various advantages of IF lead to its application in Waste Water treatment. IF has been a powerful tool in the treatment of waste water from various wine, distillery and sugar industries.

1.5 Objective:

a) To study the effect of different system parameters on hydrodynamic behaviors of the inverse fluidized bed by taking tap water as fluidizing medium in three phase Inverse Fluidized bed.
b) Study of bed hydrodynamics includes calculation of the minimum fluidization velocity and pressure drop for different heights throughout the column and the bed expansion of inverse liquid fluidization.
c) Experimentally find the pressure drop variation and bed expansion for different heights of the column, with varying liquid flow rate.
d) To develop correlation for pressure drop using the observed data and basis of statistical analysis

CHAPTER: 2

LITERATURE REVIEW

2. LITERATURE REVIEW:

From the available literature it is observed that only limited studies are reported in inverse fluidized bed reactor with reference to bed expansion and pressure drop studies.

2.1 Bed Expansion:

- Three types of model has been suggested by Fan et al. (1982), First type correlations for the bed expansion are expressed as a relationship between U_a and e, which is theoretical, semi-theoretical or empirical in nature.
- Second type correlations for the bed expansion have been developed by modifying the relation between the drag coefficient and Reynolds number for a single particle.
- Third type of correlation for bed height has been directly correlated with operating liquid velocity, particle diameter and density.
- The bed expansion in the down comer has been investigated by Han et al. (2000).
- There are different models for the correlation of bed expansion with the superficial liquid velocity. Among all these correlations, the model proposed by Richardson and Zaki (1954) is being used.

2.2 Minimum Fluidization Velocity:

It is defined as the lowest superficial velocity at which the downward weight of the particles the drag force due to downward flow of the liquid just counters the upward buoyancy force of the solid particles, i.e., the net upward force is equal to the net downward force. It is observed that as the bed weight increases the pressure drop increases but the minimum inverse fluidization velocity is almost constant and is independent of bed weight. Basically two factors affecting the minimum inverse fluidization velocity namely the particle density and size.

- For each gas velocity the minimum liquid fluidization velocity corresponds to the velocity of liquid at which the pressure gradient within the bed is minimum (Ibrahim et al. 1996).
- The minimum liquid fluidization velocity is obtained from a plot of pressure gradient vs. liquid velocity at a constant gas velocity (Krishna et al., 2007).
- As the gas velocity is increased, the liquid velocity required for maintaining the bed under minimum fluidization conditions is reduced as observed by several other authors (Buffiere and Moletta, 1998; Ibrahim et al., 1996; Lee et al., 2000; Legile et al., 1992; Renganathan & Krishnaiah, 2004).

2.3 Previous Works on Inverse Fluidized Bed Bioreactor:

1. Sokol & korpal (2006) investigated in the inverse fluidized bed bio-film reactor (IFBBR) in which polypropylene particles of density 910 kg/m^3 were fluidized by an upward co-current flow of gas and liquid. Measurements of chemical oxygen demand (COD) versus residence time t are performed for various ratios of settled bed volume to bioreactor volume (V_B/V_R) and air velocities u to determine the optimal operating parameters for a reactor, that is, the values of (V_B/V_R) ,u and t for which the largest reduction in COD occurred. The biomass loading in a reactor depended on the ratio (V_B/V_R) and an air velocity u. In the cultures cultivated after change in (V_B/V_R) at a set u, the steady-state mass of cells grown on the particles was achieved after approximately 3 days of operation. With change in u at a set (V_B/V_R), the new steady-state biomass loading occurred after cultivation for about 2 days.
2. Sowmeyan & Swaminathan (2007) worked to evaluate the feasibility of an inverse fluidized bed reactor for the anaerobic digestion of distillery effluent, with a carrier material that allows low energy requirements for fluidization, providing also a good surface for biomass attachment and development. Inverse fluidization particles having specific gravity less than one are carried out in the reactor
3. Gomez et al. (2006) immobilized derivatives of soybean peroxides in a laboratory scale fluidized bed reactor to study their viability for use in phenol removal. The influence of the different operational variables on the process is also studied a reactor model based on the experimental results that predicts the system's behavior both in steady and transient state is developed. The model considers the fluidized bed reactor as a plug flow reactor in series with an ideal mixer and follows a kinetic law based on the observed external mass transfer resistances in order to work out the process rate.
4. Bendict et al. (2006) conducted experiments using 6 mm diameter spherical particles of low-density polyethylene (LDPE) and polypropylene (PP) with water and aqueous solutions of Carboxy methyl cellulose (CMC). It was found that the minimum fluidization velocity, U_{mf} decreased with an increase in CMC concentration and solid density. A dimensionless correlation was proposed for the prediction of bed height at fully fluidized conditions.
5. Vijaya Lakshmi et al. (2005) studied the hydrodynamic characteristics (bed expansion and pressure drop) of low-density polyethylene (LDPE) and polypropylene (PP) (4, 6 and 8 mm) in a liquid-solid inverse fluidized bed reactor as a function of particle

diameter, liquid viscosity and density. The bed expansion and pressure drop data are used to determine the minimum fluidization velocity in the particle diameter and a decrease in solid density and was independent of initial bed height.

CHAPATER: 3

MATERIALS AND METHOD

3. EXPERIMENTATION:

The setup of Inverse fluidized bed (IFB) can be operated in different modes. In 2-phase IFB, the solids are fluidized using only liquid (no gas phase) flowing from the top of the column. The 3-phase IFB can be operated with dispersed gas phase sent from the bottom of the column through the liquid phase which can be either in batch or continuous mode. In 3-phase IFB with liquid in batch mode, the solid particles are maintained in a fluidized condition by means of gas flow only with no net liquid flow .In the continuous mode of operation, both liquid and gas phases contribute to the downward fluidization of the particles.

3.1 Experimental set up

The column is made of Perspex and has the dimension of 10 cm diameter with a maximum height of 1.240 m and a wall thickness of 3 mm.

The column consisted of three sections, namely,

• Conical liquid distribution section:

This section consists of a cone with angle of 30^0 whose large base diameter is same as the diameter of the column i.e. 10 cm and small base diameter is 3 cm. At the top of the cone a vent or exit is provided for the inlet gas. The distributor is also kept at the top of the column; ball valves are there to control the incoming water flow rate.

• Test section:

The test section is made up of column of height 1 meter. 10 number of pressure tapping are provided at equal distance of the column. The pressure tapping are connected with manometers with help of pipes.

• Conical liquid discharge section:

This section consists of exit outlet for the water; at the bottom of the column another distributor is given to prevent the particles from escaping the bed. This distributor also works as sparger of air .A non returning control valve is there to let the air in. A control valve is also provided in the discharge line to adjust the flow rate.

• Four numbers of manometers (1 meter) are used to measure the bed pressure drop. These manometers are filled with carbon tetra chloride of density 1590 kg/m^3.

The conical head liquid distributor located at the top of the column is designed in such a way that uniform liquid distribution across the column cross section could be ensured. A wire mesh is also provided at the top of the column to prevent the particles to escape out from bed. Liquid is pumped to the top of the column through the calibrated Rota meters. The column could be loaded with solid particles from the top of the column. In this work water is to be used as the fluidizing liquid. The pressure taps are evenly spaced at 10 cm intervals on the wall of the test section and connected to carbon tetrachloride manometers. The liquid discharge section connects a pipe to the reservoir; which transfers the liquid to the tank so that it is re-circulated.

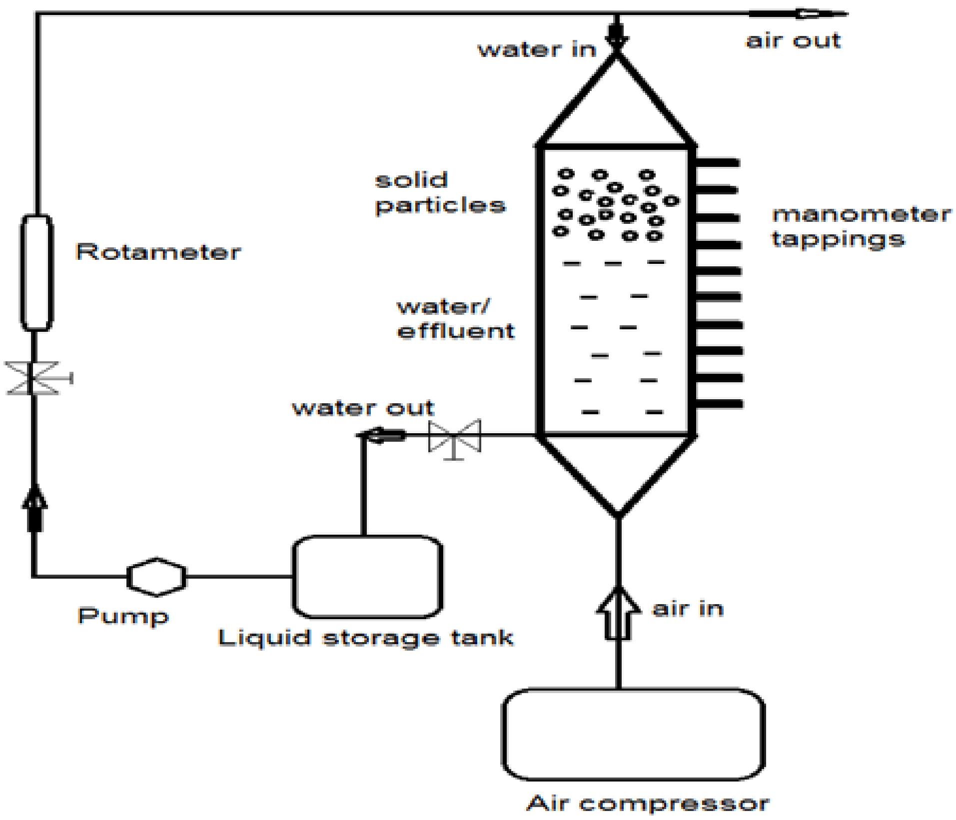

Fig.1: Schematic Diagram of Inverse Fluidized Bed

3.2 Parts of Setup:

1. The fluidized bed consists of a perplex column of height 1.024 m, diameter 10 cm and thickness 3 mm.
2. A Centrifugal Pump is used for pumping water. (Power=0.5 HP, Head=14 ft.)
3. Calibrated water Rota-meter of capacity 0-100 LPM is used to measure the flow rate of water.
4. Four numbers of manometers with standard length of 1.0 m are used to measure the pressure drop.
5. Circular pitch distributed plates with different pitch diameters are used.
6. Two Conical heads with apex angle of 60^0 are used at top and bottom of the column. (Inner base diameter = 10 cm, height = 30 cm)

Fig.2: Setup of inverse fluidized bed.

Experimental Procedure:

1. First, the column is loaded with solid particles of a particular size and density to a specific bed height.
2. Water is fed to the column at a known flow rate, the system is allowed to attain steady state by adjustment of inlet and discharge flow rate.
3. The manometers are to be filled with carbon tetrachloride and the pressure drop across the test section is to be noted from the manometers by visual inspection.
4. Water flow rate is increased gradually in steps till the bed is completely fluidized. Depending on the flow rate of liquid through the column, a packed bed or a partially packed and fluidized bed should be encountered. These bed heights are to be measured by visual inspection.
5. The pressure drop is plotted against the distance between the tapping along the entire column for the different flow rates taken (3-15 LPM).
6. The velocity at which the entire bed just becomes fluidized is to be noted as the minimum fluidization velocity.

3.4 Method for Hydrodynamic Studies:

Initially tap water is used as the fluidizing medium. Then various hydrodynamic behaviors are to be studied (parameters like water flow rate, pressure drop and static bed height). The effects of these parameters over bed pressure drop are to be analyzed. Static bed height is varied keeping all three parameters constant. Similarly experiments are conducted by changing one parameter and keeping all other three parameters constant.

3.5 **Different Flow Regimes**:

Fig-3: Packed bed condition.

At low liquid velocities, the particles at the top of the column are supported by the distributor mesh. As the liquid velocity increased bottom layer of the particles starts to fluidize and the rest remains in packed condition. With further increase in velocity, more particles at the bottom of the packed bed are fluidized and the bed height gradually increases.

Fig-4: Bed under minimum fluidized condition

At some particular velocity the entire bed becomes just fluidized. The velocity corresponding to this condition is the ‘minimum fluidization velocity’. Though the entire bed is fluidized, the concentration of solids is still not uniform along axis of the bed. Generally near the liquid distributor; high concentration of solids is observed and for further increase in velocity; the material distribution becomes uniform throughout the bed. This velocity is the ‘uniform fluidization velocity’.

Fig-5: uniform fluidization condition

CHAPTER: 4

RESULTS AND DISCUSSION

4.1 Observations:

Polypropylene beads of 6 mm and 10 mm diameter are taken in the Inverse Fluidized bed at different static bed heights and the bed expansion is observed by varying different parameters.

4.1.1 Effect of water flow rate on bed expansion:

Expanded bed height is observed by visual inspection with the increase in flow rate. Thus the bed expansion ratios are calculated for different static bed heights in Table-1 and Table-2. Also the values of the minimum fluidization velocities are shown in Table-3.

Bed expansion ratio= (average of maximum and minimum expanded bed height)/static bed height

Table-1: Effect of flow rate on bed expansion (particle size: 6 mm)

Sl no	Flow rate (lpm)	Bed height (cm)	Bed expansion ratio	Bed height (cm)	Bed expansion ratio
1	0	8	2.8	12	2.01
2	0.5	8		12	
3	1	8		12	
4	2.5	8		12	
5	5	15.1		14.8	
6	7.5	19.3		17.2	
7	10	26.5		23.5	
8	12.5	35.7		32.5	

Table-2: Effect of flow rate on bed expansion (particle size: 10 mm)

Sl no	Flow rate (lpm)	Bed height (cm)	Bed expansion ratio	Bed height (cm)	Bed expansion ratio
1	0	9	2.7	12	2
2	0.5	9		12	
3	1	9		12	
4	2.5	9		12	
5	5	9		12	
6	7	16.2		16.4	
7	7.5	17.1		17	
8	10	28.9		26.4	
9	12.5	38.6		33.5	

Table-3: Minimum Fluidization Velocity for different static bed heights:

Sl.No.	Particle dia (mm)	Initial bed height(cm)	Min. fluidization Velocity (m/sec.)(u_{mf})	Bed height (cm) at u_{mf}
1	6	8	0.011	15.1
2	6	12	0.011	14.8
3	10	9	0.0148	16.2
4	10	12	0.0148	16.4

4.1.2 Effect of flow rate on pressure drop:

Due the counter current flow of water and air in the bed, changes in the height of CCl_4 level in manometers are observed. Thus the pressure drop values are calculated and shown in Table-4 and Table-5.

Table-4: Effect of flow rate on pressure drop at different levels of column (6mm particle):

Sl no	Flow rate(lpm)	Pressure drop across the bed (Pa)			
		1	2	3	4
1	2	312.4	755	1031.2	1862.5
2	4	578	795.9	1171.5	2010.14
3	6	531	868.2	1046.5	2375
4	8	546.5	784	1359	2190.7
5	10	703	815.1	1508	2240.2
6	12	634.2	898	1388	2156.3
7	15	686.2	885.7	1562	2066.5
8	18	750	912	1698.4	2248.6
9	20	848.7	1022	1845	2406.2

TABLE-5: Pressure drop at different expanded bed heights (6mm particle)

⇩ Bed expansion (cm)	Pressure drop across the bed (Pa)		
Water Flow rate(lpm) ⟹	5	10	15
8	0	0	0
15	300	477	953
30	389.7	663	1108
45	417	716	1340
60	495	884	1586
75	543.5	1044	1795

TABLE-6: Comparison of pressure drop across the bed using different size beads (Hs=8cm)

⇩ Bed expansion(cm)	Pressure drop across the bed(Pa)	
particle diameter ⟹	6mm	10mm
10	495	774
20	890	971
30	976	1092
40	1088	1563
50	1349	1756
60	1723	2079
70	2038	2346
80	2411	2629

Table- 7: Effect of liquid velocity on pressure drop for 10mm particles at H_S=12 cm

Liquid velocity (m/sec)	Pressure drop(Pa)
	H_S=12 cm
0.00532	467.9
0.0106	790.8
0.0159	1091.8
0.0212	1177.6
0.0266	1136.3
0.0319	1160.2

4.2 Results and Discussions:

4.2.1 Minimum Fluidization Velocity**:**

- The minimum fluidization velocity (U_{mf}) does not depend on the initial bed height (from table-3).
- From table-3 it is also clear that the minimum fluidization velocity depends on the size (density) of particles, for higher size (lower density) particles the minimum fluidization velocity is higher than the lower size (higher density) particles. As the particle density decreases, the upward buoyancy force increases and a higher downward force (consequently liquid flow rate) is required to reach the condition of minimum fluidization.

4.2.2 Bed Expansion**:**

- The bed expands only if the flow rate is above the minimum fluidization velocity (table-3).
- It is observed from the figure-5 and figure-6 that the bed height remains unaffected (fixed) up to a certain liquid flow rates and there-after varies linearly with flow rates. It is also observed that bed height variation depends on solid densities. It is because of the fact that at low flow rates the force due to the downward flow of liquid is less than the net buoyancy force of the particles acting in the opposite direction.

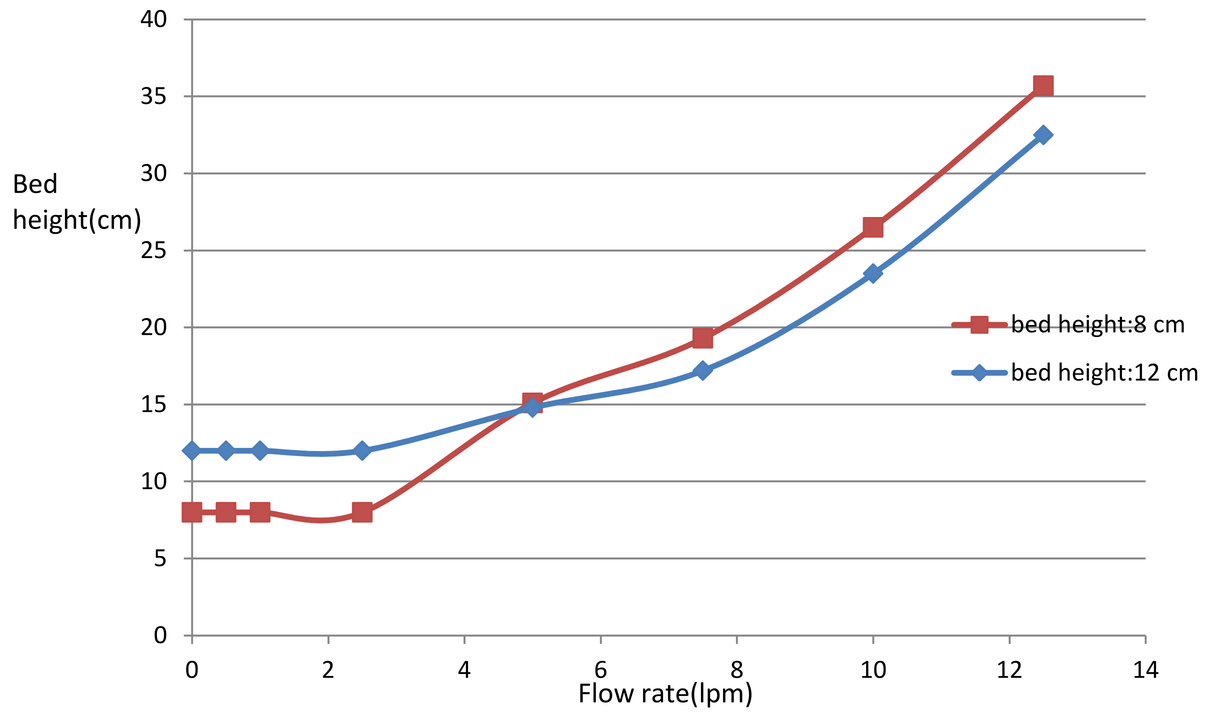

FIGURE:6 -FLOW RATE vs BED HEIGHT FOR PARTICLE DIA : 6 CM

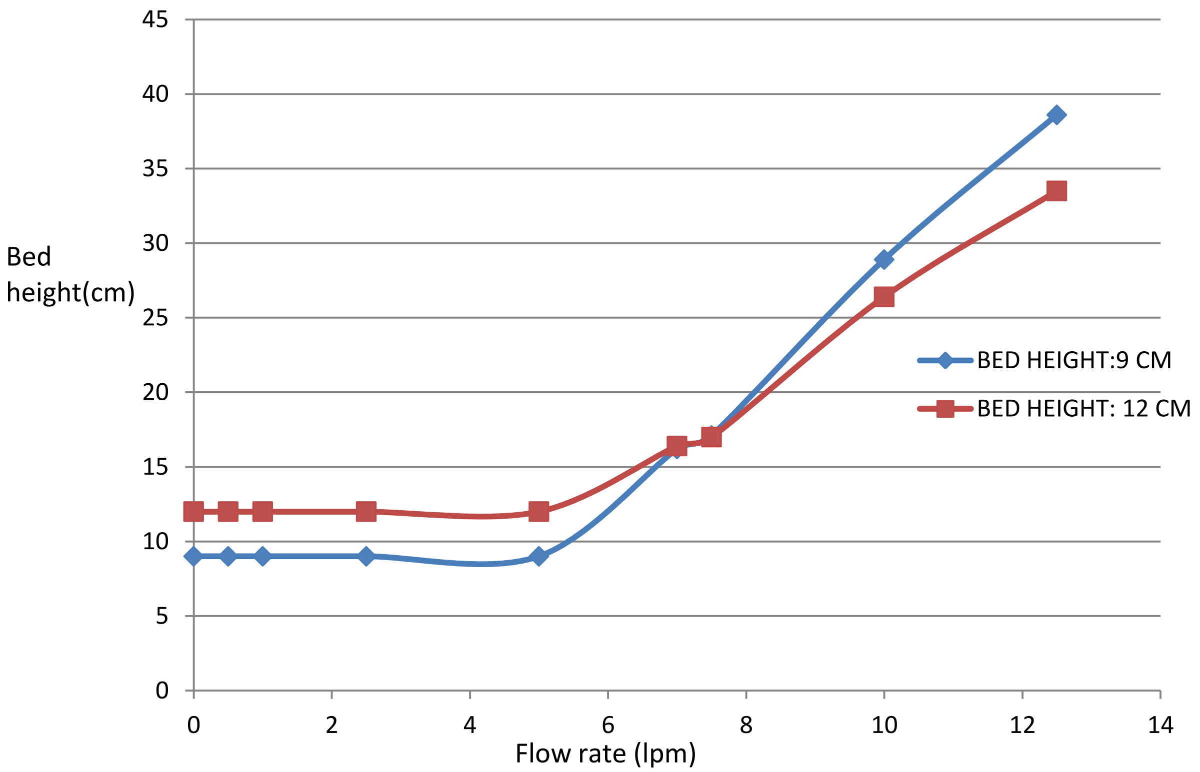

FIGURE:7 - FLOW RATE vs BED HEIGHT FOR PARTICLE DIA:10 CM

4.2.3 Pressure Drop**:**

The determination of pressure drop in helps to determine the energy loss and conditions of stable flow regimes of inverse fluidized bed reactor for the given operation.

The data obtained in table-4 and table-5 is plotted in a graph to show the variation in pressure drop (figure-8 and figure-9 respectively).

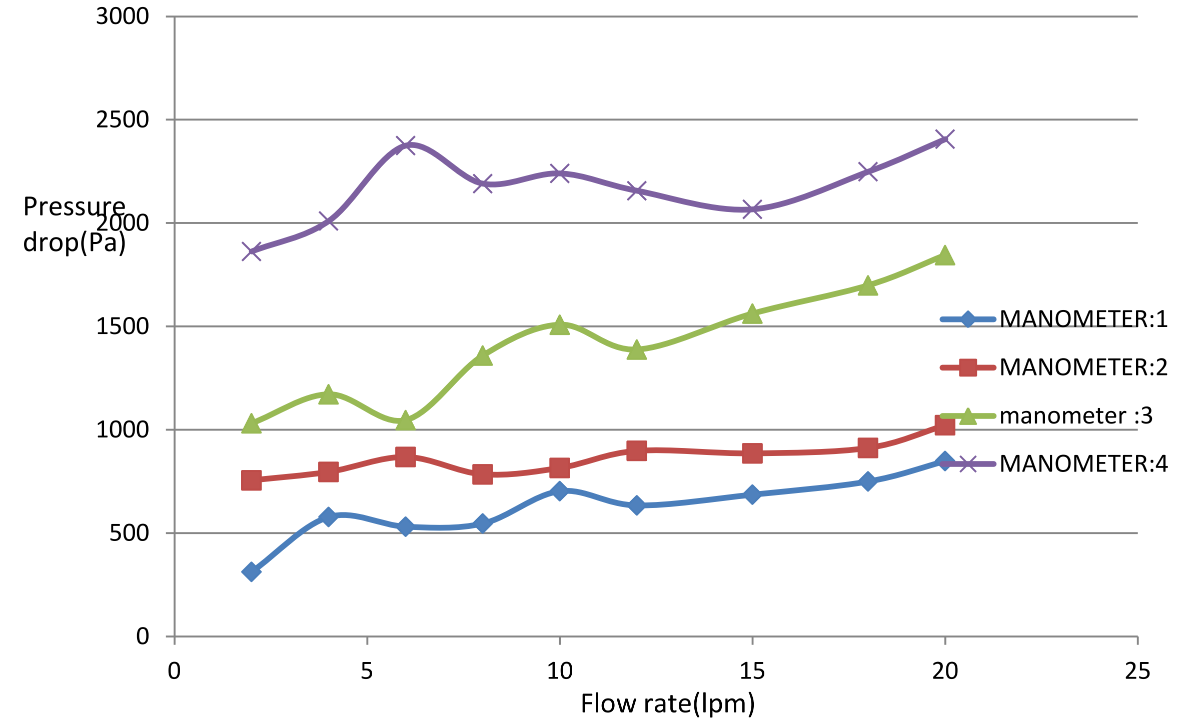

FIGURE:8- PRESSURE DROP vs FLOW RATE (water as fluidising medium)

Manometer1 = The Pressure difference between 2nd and 3rd tapings.

Manometer2 = The Pressure difference between 4th and 5th tapings.

Manometer3 = The Pressure difference between 6th and 7th tapings.

Manometer4 = The Pressure difference between 8th and 9th tapings.

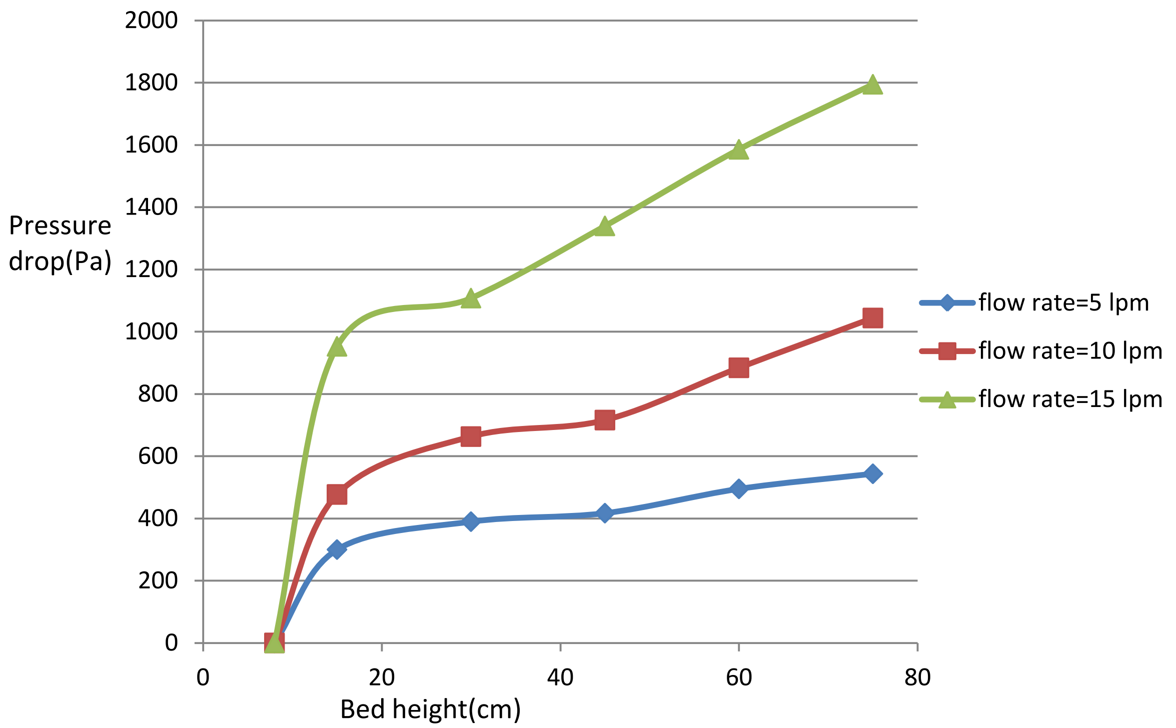

FIGURE-9 : PRESSURE DROP VARIATION AT DIFFERENT BED HEIGHTS

The pressure drop at various heights across the bed are noted down in table-5 at different flow rates and It is clear from fig-9 that pressure drop increases across the bed as the bed expands with the increase in flow rate.

4.2.4 Comparison of pressure drop across the bed using different size beads**:**

It is evident from table-6 that the pressure drop across the bed is higher at different bed heights for larger particles than that of smaller particles which is made clear by plotting a graph between pressure drop and bed expansion for both size materials (Figure-10).

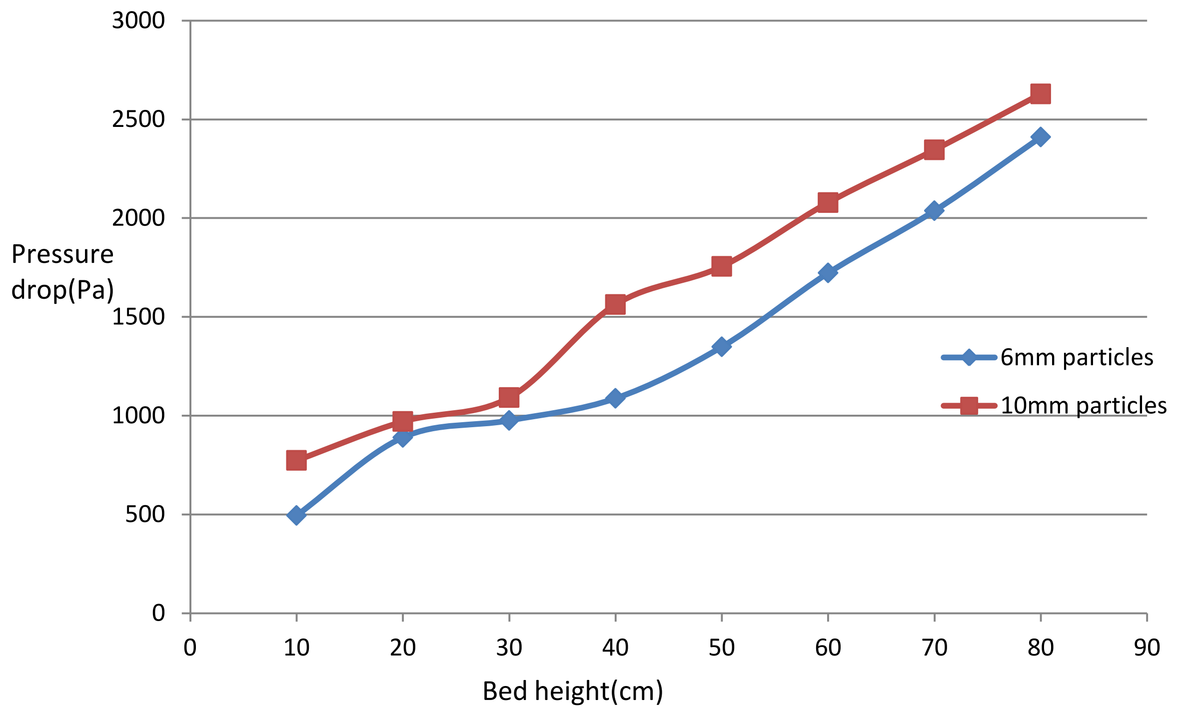

FIGURE:10 -COMPARISON OF PRESSURE DROP USING 6MM AND 10 MM DIA POLYPROPYLENE BEADS

4.2.5 Effect of liquid velocity on pressure drop for 10mm particles at H_S=12 cm:

From the plot Experimental value of minimum fluidization velocity is found to be 0.0212 m/sec.

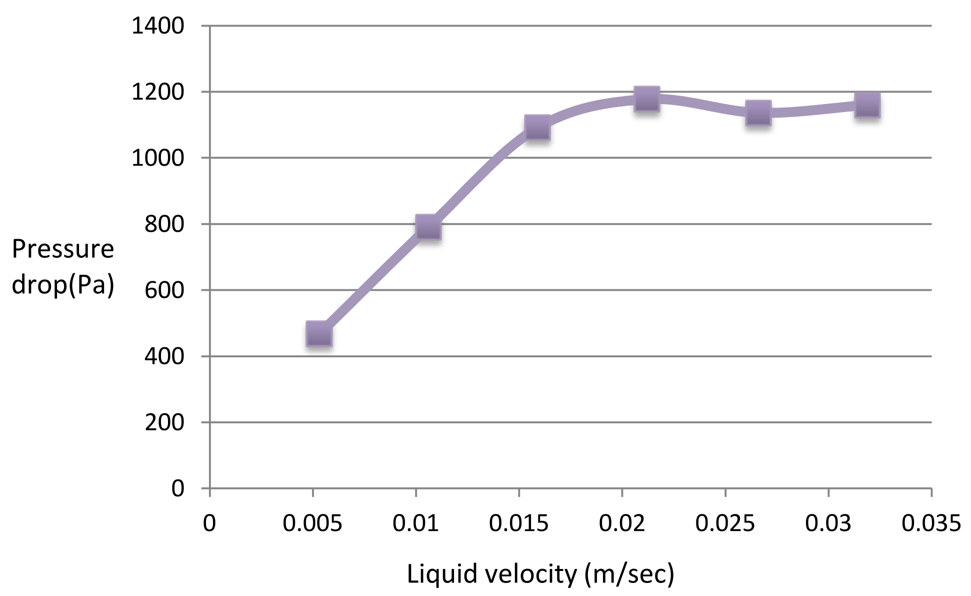

Fig. 11 : PRESSURE DROP VS LIQUID VELOCITY

4.2.6 2^3 Statistical Analysis:

Salient features of 2^k factorial design (where k is the no. of variables) are:

- Require relatively few runs per factor studied.
- Very widely used in industrial experimentation.
- Interpretation of data can proceed largely by common sense, elementary arithmetic, and graphics.
- For quantitative factors, can't explore a wide region of factor space, but determine promising directions.
- Designs can be suitably augmented due to sequential assembly.

In our case there are three variables: static bed height, particle size and liquid velocity, Hence the effects are studied using statistical analysis of 2^3 Factorial Design for pressure drop across the bed taking static bed height, particle size and liquid velocity as parameters.

Notations:

H_S=A

U=B,

D_P=C

AB=interacting effect of A&B

AC=interacting effect of A&C

BC=interacting effect of B&C

ABC=interacting effect of A, B &C

Table-7: Effect of Parameters

H_S	U	D_P	ΔP	A effect	B effect	AB effect	C effect	AC effect	BC effect	ABC effect
0.08	0.0106	0.006	697	-	-	+	-	+	+	-
0.12	0.0106	0.006	685	+	-	-	-	-	+	+
0.08	0.0266	0.006	1040	-	+	-	-	+	-	+
0.12	0.0266	0.006	1004	+	+	+	-	-	-	-
0.08	0.0106	0.01	896	-	-	+	+	-	+	+
0.12	0.0106	0.01	901	+	-	-	+	+	-	-
0.08	0.0266	0.01	1297	-	+	-	+	-	+	-
0.12	0.0266	0.01	1157	+	+	+	+	+	+	+

Table-8: Analysis of Data

HS	U	DP	ΔP	A	B	AB	C	AC	BC	ABC	ΔP_{cal}
0.08	0.0106	0.006	697	-1	-1	1	-1	1	1	-1	577.625
0.12	0.0106	0.006	685	1	-1	-1	-1	-1	1	1	581.625
0.08	0.0266	0.006	1040	-1	1	-1	-1	1	-1	1	983.625
0.12	0.0266	0.006	1004	1	1	1	-1	-1	-1	-1	904.375
0.08	0.0106	0.01	896	-1	-1	1	1	-1	-1	1	769.625
0.12	0.0106	0.01	901	1	-1	-1	1	1	-1	-1	809.625
0.08	0.0266	0.01	1297	-1	1	-1	1	-1	1	-1	1339.625
0.12	0.0266	0.01	1157	1	1	1	1	1	1	1	1219.625

The correlation formulated for pressure drop is as follows,

$$\Delta P = 959.625 + (-183 * H_S) + (1319 * U) + (-169 * H_S * U)$$

$$+ (825 * D_P) + (-87 * H_S * D_P) + (-5 * U * D_P) + (-121 * H_S * U * D_P)$$

(Equation 1)

Table-9: Comparison of Experimental and Calculated Values of Pressure Drop

HS	U	DP	ΔP	A	B	AB	C	AC	BC	ABC	ΔP_{cal}
0.08	0.017	0.006	876	-1	-0.2	0.2	-1	1	0.2	-0.2	720.025
0.12	0.017	0.006	691	1	-0.2	-0.2	-1	-1	0.2	0.2	547.225
0.08	0.0212	0.006	946	-1	0.325	-0.325	-1	1	-0.325	0.325	837.85
0.12	0.0212	0.006	921	1	0.325	0.325	-1	-1	-0.325	-0.325	814.65
0.08	0.017	0.01	923	-1	-0.2	0.2	1	-1	-0.2	0.2	817.625
0.12	0.017	0.01	918	1	-0.2	-0.2	1	1	-0.2	-0.2	803.625
0.08	0.0212	0.01	1079	-1	0.325	-0.325	1	-1	0.325	-0.325	1147.25
0.12	0.0212	0.01	1048	1	0.325	0.325	1	1	0.325	0.325	1118.75

CHAPTER: 5

CONCLUSION

4.3 Conclusion:

The bed height is obtained by visual observations and pressure drop by manometers.

- The bed remains packed until the minimum fluidization velocity is reached.
- At the minimum fluidization velocity the lower particles just start to move.
- At higher flow rates, particles start rotational and wavy motion. This process gives rise to turbulence fluidization and better mixing.
- The minimum fluidization velocity does not depend on the static bed height.
- With increase in particle size, the minimum fluidization velocity also increases. It is also observed that the height at which the bed comes to minimum fluidization condition is higher for larger particles.
- It is concluded that the bed expands with the gradual increase in liquid flow rate. It is also observed that higher static bed height expands less in comparison to the lower static bed height.
- Pressure drop variations across bed height are compared using different size materials and it is concluded that pressure drop at a particular bed height is higher for larger particles than that of smaller particles.
- The minimum fluidization velocity is experimentally found to be 0.0212 m/sec.

4.4 Future scope of work:

- Further results can be obtained by varying the air flow rate.
- Also statistical analysis for bed expansion can be carried out.

NOMENCLATURE:

H_S: Initial Static Bed Height (m)

D_P: Particle Diameter (m)

U: Liquid Velocity (m/Sec)

ΔP: Pressure drop across the bed (Pa)

U_{mf}: Minimum Fluidization Velocity (m/sec)

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