PRESSURE DROP THROUGH A FIXED BED OF PARTICLES WITH DISC PROMOTER

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CERTIFICATE

This is to certify that the project entitled, "PRESSURE DROP THROUGH A FIXED BED OF PARTICLES WITH DISC PROMOTER" submitted by Mr.ARPIT SRIVASTAVA and Mr. DEEPTI RANJAN NAG in partial fulfillment of requirements for the award of Bachelor of Technology Degree in CIVIL Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the project has not been submitted to any other University/ Institute for the reward of any Degree or Diploma.

Date 2-05-07

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ABSTRACT

In the present work, Hagen-Poiseuille's equation for laminar flow through a circular pipe has been used to formulate fixed/packed bed pressure drop equations by introducing characteristics of the bed and the porous medium. The values of constant of the modified Hagen-Poiseuille's equation have been obtained using experimental data of fixed bed pressure drop collected with the system variables. Two equations: one for unpromoted bed and another for the case of bed with disc promoters, have been proposed to predict fixed bed pressure drop in the respective cases. The experimental data of bed pressure drop collected with system variables such as initial static bed height, bed material of different sizes and densities and different promoter blockage volume have been used in the investigation. The predicted values of fixed bed pressure drops using developed correlations have been found to agree fairly well with the corresponding experimental ones. the conclusion has also been derived for the effect of promoter parameter on packed bed pressure drops.

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CHAPTER 1

INTRODUCTION

Introduction

The use of a suitable promoter in gas-solid fixed bed has been found improve heat and mass to transfer rates and quicksand condition. Although, a lot of literatures are available on the dynamics and applications of unpromoted packed beds, no investigation has been made on the dynamic behaviour of a promoted packed bed. In gas-solid fluidized beds, promoters are used to dampen fluctuation and to improve fluidization quality. For economic considerations, the studies on the effect of promoters on pressure drop are necessary as the change in bed pressure affects the flow homogeneity in the bed. Decrease in pressure drop causes development of channels reducing thereby the particles contact while increase in pressure drops improves particles contact at the cost of increased power consumption.

In the present investigation, packed bed pressure drop data have been analyzed to: (i) develop correlations for the pressure drop in the line of Hagen-Poiseuille's equation, and (ii) study the effect of disc promoter on the bed pressure drop. Gas-solid fluidized beds have found more industrial applications compared to fixed beds due to low pressure drop and good solid-fluid mixing. Some of the important applications of gas-solid fluidized beds are in the dairy, cement industries, food and pharmaceutical industries for drying, cooling, coating and agglomeration. The important advantages of the gas-solid fluidized beds are smooth, liquid-like flow of solid particles. This permits a continuous automatically-controlled operation with ease of handling and rapid mixing of solids leading to near isothermal conditions throughout the bed. This results in a simple and controlled operation with rapid heat and mass transfer rates between gas and particles, thereby minimizing overheating in case of heat sensitive products. Albeit the above-mentioned advantages of gas-solid fluidized beds, the efficiency and the quality in large diameter and deep beds suffer seriously due to certain inherent drawbacks such as channeling, bubbling and slugging. These result in poor homogeneity of the fluid and ultimately affect the quality of fluidization. The formation of bubbles and their ultimate growth to form slugs and the collapsing of bubbles cause erratic bed expansion with intense bed fluctuation. The excessive bed expansion and fluctuation result in increased Transport Disengaging Height (TDH) of the fluidizer and hence becomes uneconomical from the point of view of system design. Formation of large scale bubbles also reduces the heat and mass transfer rate which affect the output of the system. Hence persistent efforts have been made by the investigators to improve the quality of gas-solid fluidization by promoting bubble breakage and hindering the coalescence of bubbles which result in reduced bed expansion and fluctuation and better gas-solid mixing.

CHAPTER 2

EXPERIMENTAL ASPECTS

Experimental Set-up

The experimental set-up consists primarily of the following major components

1. Air compressor
2. Air receiver
3. Constant pressure tank
4. Silica-gel column
5. Rota meters
6. Calming section
7. Air distributor
8. Fluidizer
9. Manometer
10. Pressure gauge
11. Promoter

Air compressor

It is a K.G. type stationary water-cooled air compressor, driven by 5.5 kW 3-phase inductions motor.

Air receiver

It is a horizontal pressure vessel provided with a pressure gauge of range 0 to 7.0 kg/cm (686.7 kPa) and a safety valve.

Constant pressure tank

It is of the same size as that of the receiver, with flat ends. The purpose of using this tank in the line is to dampen the pressure fluctuations and to supply compressed air to the system at a constant pressure. It is also provided with a pressure gauge of range 0 to 5.6 kg/cm (549.36 kPa). Constant pressure tank used in the set up maintained a constant pressure of 2.8 kg/cm (274.68 kPa).

Silica-gel column

The compressed air from the constant pressure tank is passed through this column, fitted with silica-gel to dry the air before being used in the system.

Rotameters

Two rotameters -one for the measurement of lower range (0 to 8 kg/hr) and the other or the higher range of flow (beyond that of lower range rotameter) have been used.

(a) Lower range

It is graduated to read the maximum flow rate of 3960.86 kg/(m- hr) as against 100% range of the rotameter.

(b) Higher range

It is graduated to read the maximum flow rate of 6250.57 kg/(m - hr) as against 50% range of the rotameter.

Calming section

The compressed and dried air from the rotameters is passed through a conical section filled with 5 mm diameter glass-balls, supported on a coarse screen which serves as the calming section. This dampens the turbulence in flow and helps smoothening of pressure fluctuations in the inlet air.

Air distributor

The calming section is followed by a GI plate of 1 mm thickness having 37 nos. of orifices placed in an equilateral triangular pattern at a pitch of 7.5 mm to act as an air distributor which facilitate uniform air entry to the fluidizer. A mild steel wire mesh is placed over the distributor to prevent the entry of materials into the calming section.
Altogether five distributors (Fig. 3.2 and Plate 3.2) with opening area of 12.9%, 8.96%, 5.74%, 3.23% and 1.43% of the column section have been used in the experiment.

Fluidizer

It is a cylindrical column of 5.08 cm I. D. and 100 cm. length made up of perspex material. It is provided with flanges of the same material. Three pressure tappings-two just below and above the distributor, and the third from the top of the bed, have been taken.

Manometers

Two differential manometers with carbon tetra-chloride as the manometric liquid have been used to record the distributor and the total (bed + distributor) pressure drop.

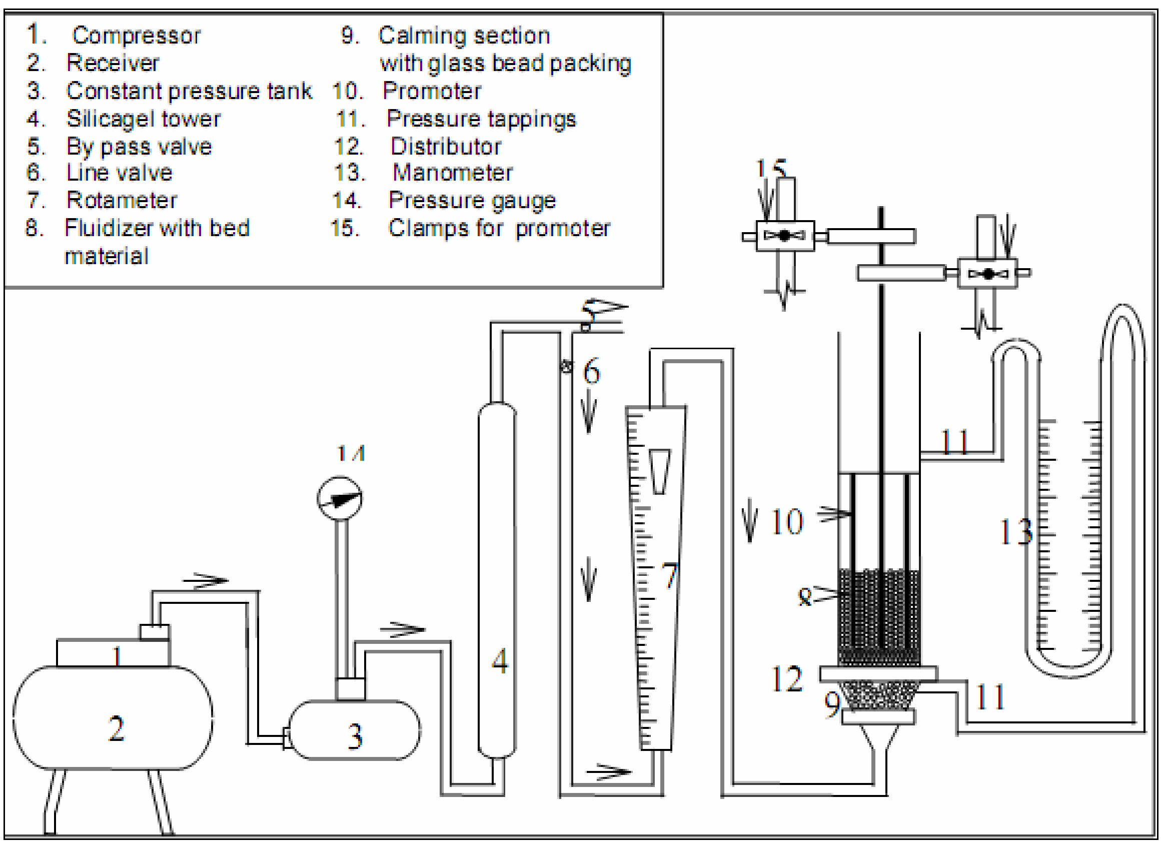
Promoter

Three types of promoter viz. rod, disk and blade have been used in the study. The promoters are placed at one cm above the distributor level with the help of two clamps fixed in the opposite directions at the top of the fluidizer. The details of promoter details are as under

Disk promoters

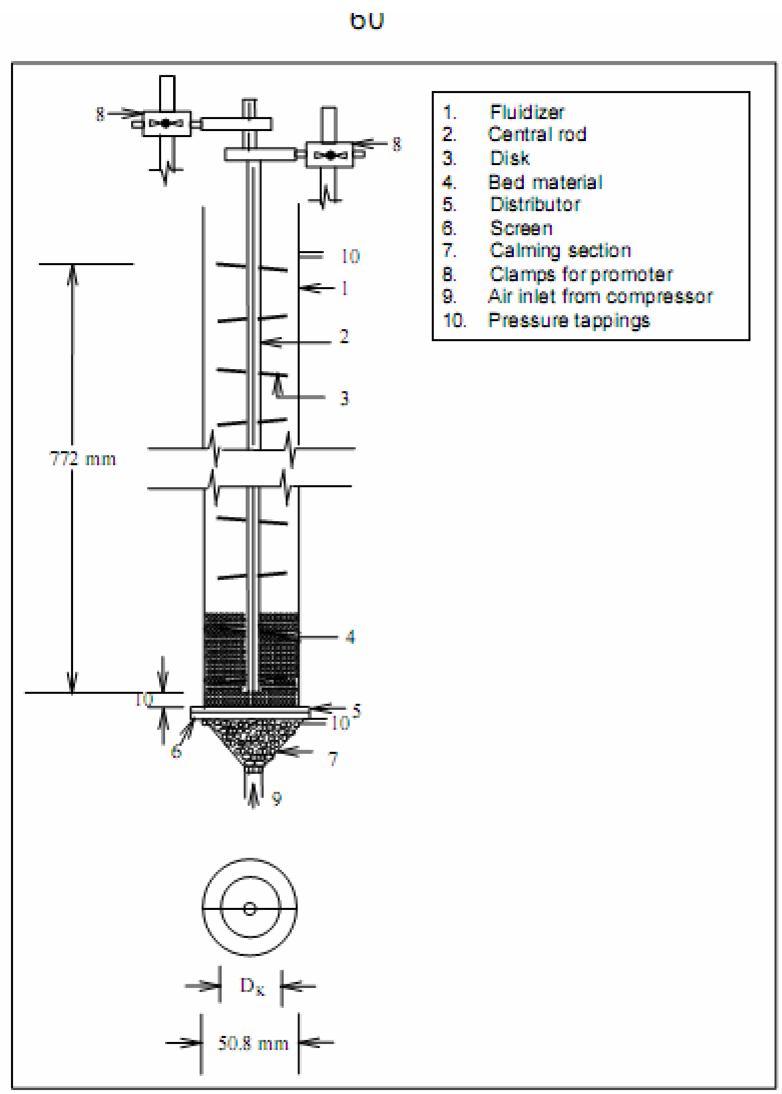
Seven number of disk promoters with varying disk thickness and disk diameter have been used. The disks of each disk promoter have been fixed to a 6.1 mm diameter central rod at equal spacing of 38.6 mm c/c and at an inclination of with the horizontal alternatively in the opposite directions to minimize the accumulation of bed materials over the disks.

FIG. 1



Experimental Setup1

FIG. 2



Experimental Setup2

The experimental setup with details of disc promoter (Figure 1) consists of a 50.8 mm inner perspex column as fluidizer with two pressure tapings and a differential U-tube manometer containing carbon tetrachloride as manometric liquid. Air, used as the fluid, has been passed through a constant pressure reservoir and silica gel tower. Two rotameters, one for the lower range and the other for the higher range have been used to measure the velocity of the air. Seven number of disc promoters with varying blockage volume along with other system variables have been used in the experiment.

For a particular run, the bed has been charged with material of particular size and height and the bed pressure drop with varying flow velocity of the air have been noted. The same have been repeated for different bed materials of varying particle size, initial bed height and blockage volume of the promoters. The scope of the experiment has been given in Table1.

CHAPTER 3

NOMENCLATURE

Nomenclature

A_0 open area in promoted bed, m^2

A_c cross sectional area of the pipe, m^2

D_c column diameter, m

D_k equivalent diameter of promoted bed, $4A_0/P$, m

d_p particle size, m

L height of packed bed, m

P total perimeter, m

V superficial velocity, m./s

ρ_f fluid density kg/m^3

ϵ bed voidage

μ fluid viscosity, Pa.s

Ø sphericity

CHAPTER 4

Theoretical analysis

Theoretical analysis

Hagen-Poiseuille's equation of pressure drop for laminar flow through circular pipe is given by equation 1:

$$\Delta p = \frac{32\mu VL}{D^2} \qquad (1)$$

V=mean velocity of flow through actual c/s area(open area) of the pipe

For circular pipe,D=diameter of pipe=equivalent diameter=$4A_0/P$ (2)

For flow through porous medium, V and D can be modified by introducing the following two parameters which characterize porus medium:

(i) a_w =wetted area per unit volume of the porus medium,

(ii) Є= void fraction

For porus medium actual flow area $(A_0)=A_c * Є$ (3)

Total wetted area(for bed length L)= $a_w * A_c*L=P*L$ (4)

Equivalent diqameter for porus medium =$4* A_c* Є/P$

Or,$D=4* A_c* Є/(a_w * A_c)=4\,Є/ a_w$ (5)

Now velocity of flow through the pores =V/ Є (6)

Substituting for D from equation (5) and velocity of flow from equation (6) in equation(1), and rearranging, we get

$\Delta p=2\,\mu VL\, a_w^2/ Є^3$ (7)

Again, introducing a_v =surface area per particle volume
=particle surface area/volume occupied by particle

For a spherical particle:

$a_v=6/d_p \Rightarrow d_p=6/a_v$ (8)

now a_w can be expressed in terms of a_v and Є as under:

$a_w= a_v(1-Є)$ (9)

and putting the value of a_v from equation (8) in equation (9) ,we have

$a_w=6/d_p(1-Є)$ (10)

finally putting the value of a_w in equation (7) , we get

$\Delta p=2\,\mu VL\,[6/d_p(1-Є)]^2/Є^3$

$\Delta p=72\mu VL(1-Є)^2/(Є^3 d_p^2)$ (11)

and for non spherical particle, equivalent particle diameter can be taken equal to $Ød_p$ and hence equation 1 can be written as:

$\Delta p=72\mu VL(1-Є)^2/(Є^2 Ø^2 d_p^2)$ (12)

found to be much higher than those given by above equation. This may attributed to the length of the pores which in real is much more than that of the bed length .The flow through the porous medium is through zigzag passage resulting increased length of flow. And hence equation (12) can in general be expressed as under:

$$\Delta p = K\,\mu V L(1-\epsilon)^2/(\epsilon^2\,\text{Ø}^2 d_p^2) \quad (13)$$

The value of constants K has been obtained for unpromoted bed.

Again equation 13 can be used for the case of unpromoted gas-solid system. This can be further modified for the case of bed with disc promoter as under:

$$\Delta p_1 = K_1\,\mu V L(1-\epsilon)^2/(\epsilon^2\,\text{Ø}^2 d_p^2) \quad (14)$$

Δp_1=bed pressure drop in case of bed with disc promoter

K_1=constant which depends on parameter promoter in addition to the particle and bed properties.

Now, equation 14 minus equation 13 gives

$$\Delta p_1 - \Delta p = (K_1 - K)\,[\mu\, V L(1-\epsilon)^2/(\epsilon^2\,\text{Ø}^2 d_p^2)] \quad (15)$$

Or, $K_1 - K = (\Delta p_1 - \Delta p)/\,[\mu\, V L(1-\epsilon)^2/(\epsilon^2\,\text{Ø}^2 d_p^2)] = f((D_k/D_c),(t/D_c))$ (16)

$$K_1 = K + C((D_k/D_c)^{n1}, (t/D_c)^{n2}) \quad (17)$$

Substituting for K_1 in equation 14, we get an equation for packed bed pressure drop in promoted bed as:

$$\Delta p_1 = [K + C((D_k/D_c)^{n1}, (t/D_c)^{n2})][\,\mu\, V L(1-\epsilon)^2/(\epsilon^2\,\text{Ø}^2 d_p^2)] \quad (18)$$

Putting the values of constant K for unpromoted bed.'C' and exponent 'n1' and 'n2' for promoted bed as obtained from the

$(\Delta p_1 - \Delta p)/\,[\,\mu\, V L(1-\epsilon)^2/(\epsilon^2\,\text{Ø}^2 d_p^2)]$ versus promoter parameter plot

And for bed with disc promoter

$$\Delta p_1=[182.76 + C((D_k/D_c)^{n1}, (t/ D_c)^{n2})] [\mu VL(1-\epsilon)^2/(\epsilon^2 \O^2 d_p^{\,2})] \qquad (19)$$

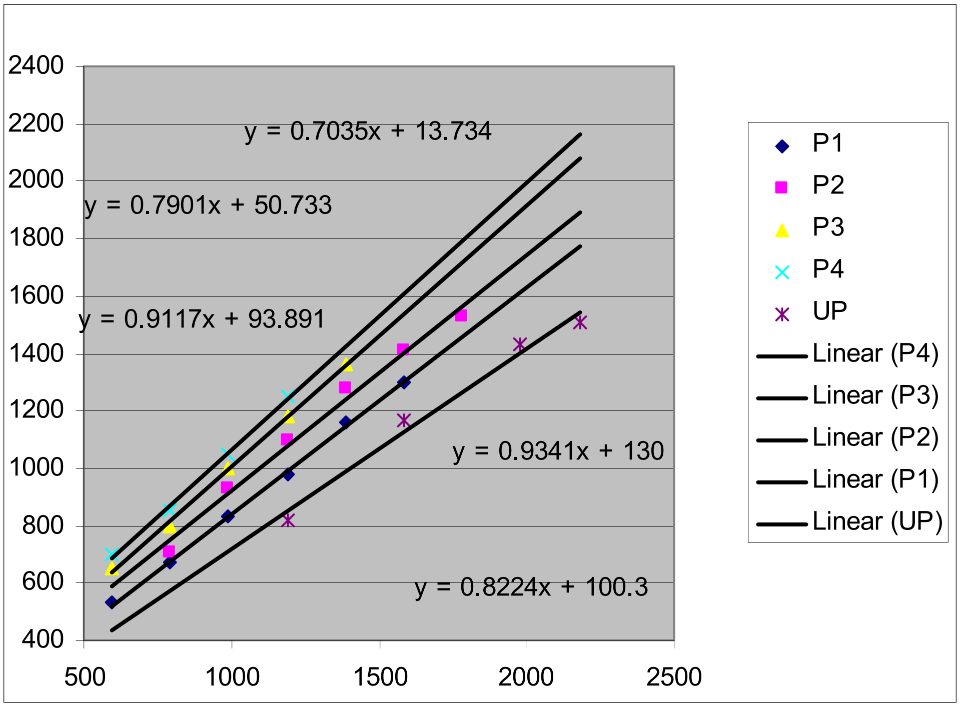
CHAPTER 5

DEVELOPMENT OF CORRELATIONS

TABLE 1

Calculation of
Pressure drop on introduction of discs(diameter constant) on given mass flow rate

Gf(kg/m^2-hr)	P1	P2	P3	P_4	UP
594.1284	529.2398				
792.1712	669				
990.214	830				
1188.257	980				
1386.3	1160				
1584.342	1300				
792.1712		710			
990.214		930			
1188.257		1100			
1386.3		1277.42			
1584.342		1410			
1782.385		1526.669			
1980.428					
594.1284			650		
792.1712			794.4888		
990.214			998.7448		
1188.257			1180		
1386.3			1360		
594.1284				700	
792.1712				850	
990.214				1050	
1188.257				1250	
1188.257					820
1584.342					1170
1980.428					1430
2178.471					1511.089



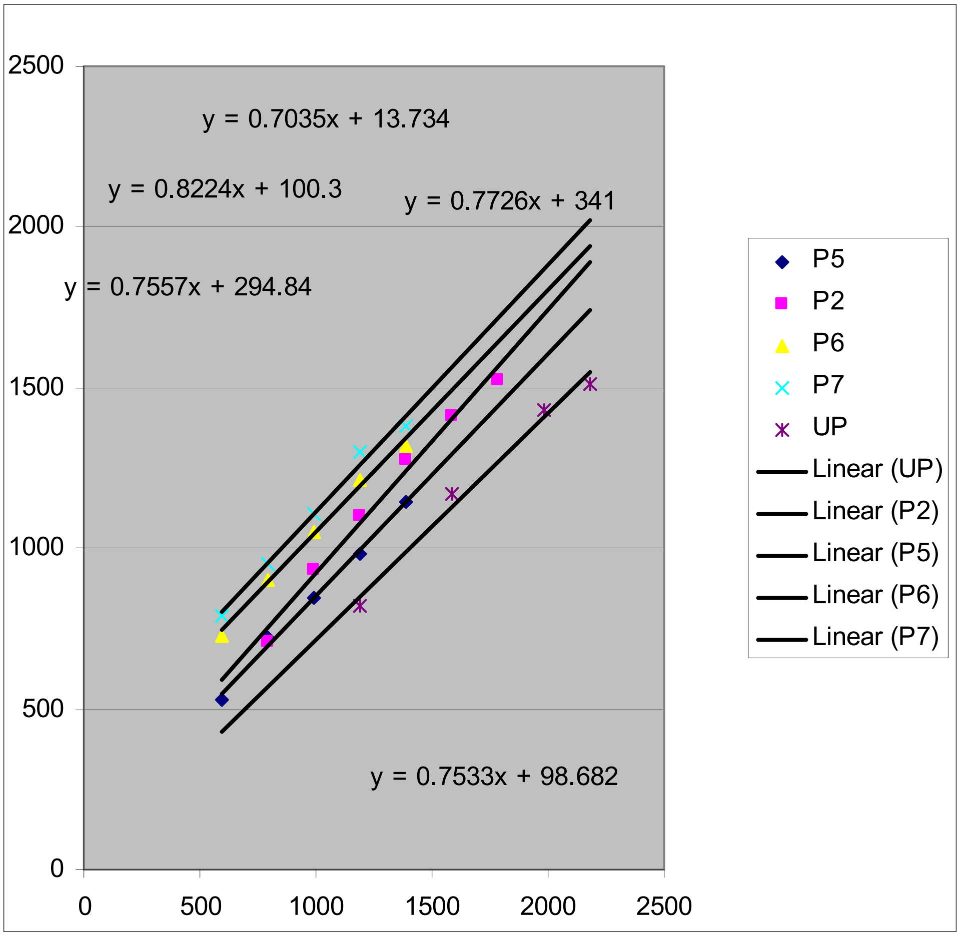
Pressure drop using disc promoter when D_k is constant vs mass flow rate

FIG. 3

TABLE 2

Pressure drop on introduction of discs(thickness constant) on given mass flow rate

Gf	P5	P2	P6	P7	UP
594.1284	530				
792.1712	720				
990.214	846.98				
1188.257	980.3				
1386.3	1145.78				
792.1712		710			
990.214		930			
1188.257		1100			
1386.3		1277.42			
1584.342		1410			
1782.385		1526.669			
1980.428					
594.1284			730		
792.1712			900		
990.214			1050		
1188.257			1215.109		
1386.3			1320.78		
594.1284				790	
792.1712				950	
990.214				1110	
1188.257				1300	
1386.3				1380	
1188.257					820
1584.342					1170
1980.428					1430
2178.471					1511.089



Pressure drop using disc promoter when t is constant vs mass flow rate

FIG. 4

TABLE 3

Pressure drop due to the promoter

Disc promoter	D_c, mm	D_k,mm	(D_k/D_c)	t(thickness),mm	(t/D_c)	Pressure drop at constant thickness	Pressure drop at constant diameter
P1	50.8	28.0	0.55	3.18	0.062		998.853
P2	50.8	28.0	0.55	6.36	0.125		1087.18
P3	50.8	28.0	0.55	9.54	0.187		1187.931
P4	50.8	28.0	0.55	12.72	0.250		1120.92
P5	50.8	20.26	0.398	6.36	0.125	1002.642	
P6	50.8	34.125	0.671	6.36	0.125	1201.68	
P7	50.8	39.125	0.770	6.36	0.125	1268.12	

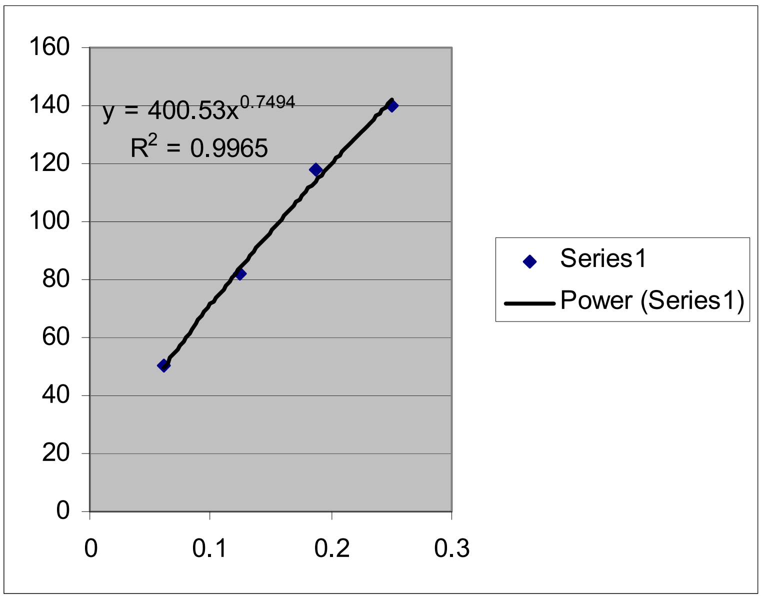
material	dp in m	Sphericity(Ø)	Viodage(Є)	height(bed)(L)	Viscocity(μ)	x
Dolomite	0.000725	0.579245	0.5294	0.12	0.0000181	2.801

$$x = [\ \mu\ VL(1-Є)^2/(Є^2\ Ø^2 d_p^{\ 2})]$$

TABLE 4

Calculation of change in pressure drop(dia. of discs consta nt)

t/Dc	(Δp1-Δp)/X
0.062	50.267
0.125	81.801
0.187	117.77
0.25	140.26



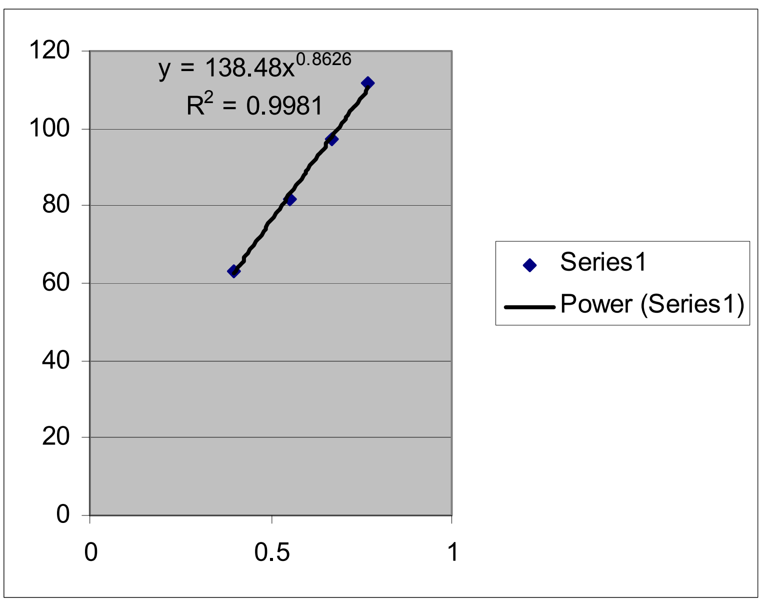
(Δp1 / [μ VL$(1-\epsilon)^2/(\epsilon^2 Ø^2 d_p^2)$]) Vs t/Dc

FIG.5

TABLE 5

Calculation of change in pressure drop(thickness constant)

Dk/Dc	(Δp1-Δp)/X
0.398	63.001
0.55	81.801
0.671	97.4
0.77	111.8



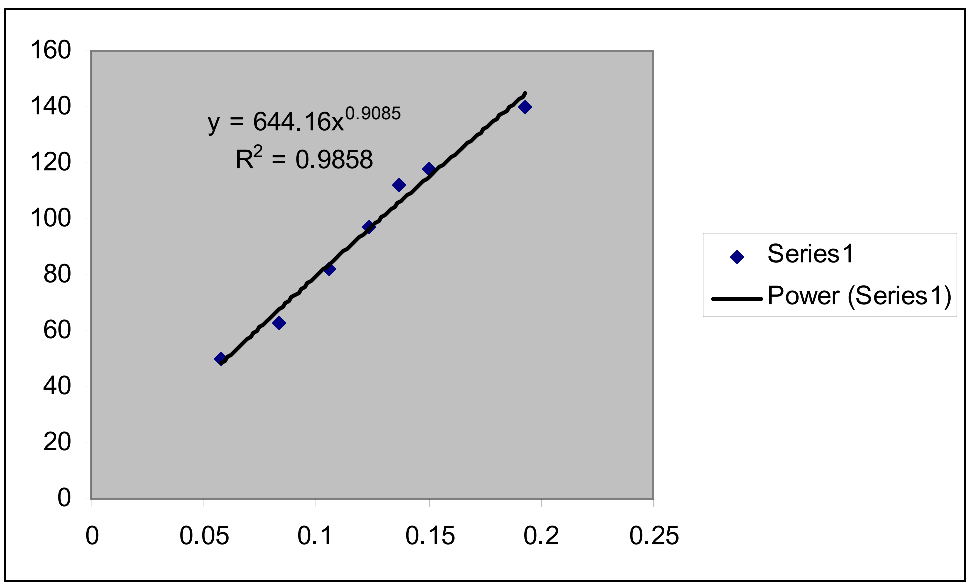
$(\Delta p1 / [\mu VL(1-\epsilon)^2/(\epsilon^2 Ø^2 d_p^2)])$ Vs D_k/D_c

FIG. 6

TABLE 6

Calculation of constant n

t/Dc	Dk/Dc	(t/Dc)^n1	(Dk/Dc)^n2	col.3*col.4	Δp1
0.062	0.55	0.090848	0.638893	0.058042	50.267
0.125	0.55	0.166339	0.638893	0.106273	81.801
0.187	0.55	0.235446	0.638893	0.150424	117.77
0.25	0.55	0.302457	0.638893	0.193237	140.26
0.125	0.398	0.166339	0.501363	0.083396	63.001
0.125	0.671	0.166339	0.741559	0.12335	97.4
0.125	0.77	0.166339	0.822122	0.136751	111.8



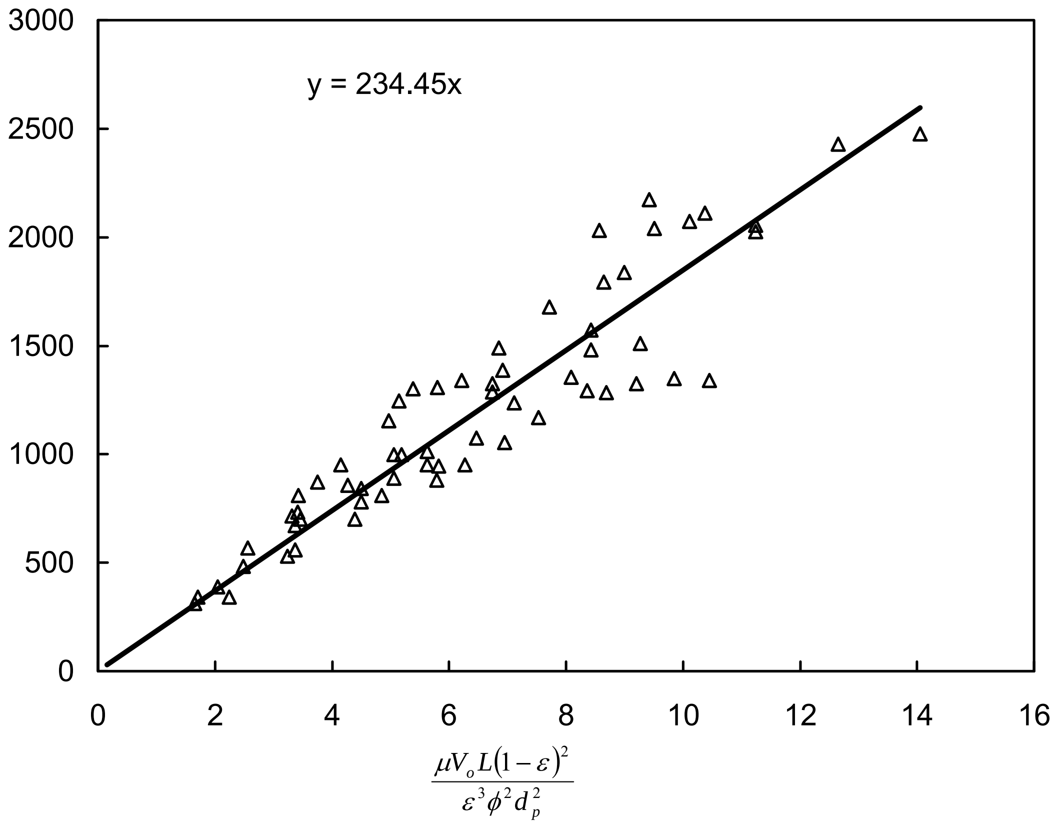
$((\Delta p1-\Delta p)/[\mu VL(1-\epsilon)^2/(\epsilon^2 \varnothing^2 d_p^2)])$ Vs $[(D_k/D_c)^{n1}, (t/D_c)^{n2})]$

FIG. 7

TABLE 7

Caluclation of percentage deviation

expt.value	col.5^0.9085	col.8*644.16	col9+235.54	calc value	dev %
908.201	0.075312	48.51276	283.7528	794.7915	12.48727
939.735	0.130468	84.04241	319.2824	894.31	4.833807
975.704	0.178893	115.2358	350.4758	981.6828	-0.61276
998.194	0.224602	144.6796	379.9196	1064.155	-6.60801
920.935	0.10468	67.4304	302.6704	847.7798	7.943579
955.334	0.149383	96.22653	331.4665	928.4378	2.815376
969.734	0.164056	105.6785	340.9185	954.9128	1.528374



Variation of packed bed pressure drop (Δp) for unpromoted bed

CHAPTER 6

RESULTS AND DISCUSSION

RESULT & DISCUSSION

. The calculated values of bed pressure drop using developed correlations have been compared with the corresponding experimental ones respectively and found to be in fair agreement. The introduction of a disc promoter in gas-solid system has been found to increase the packed bed pressure drop. This may be attributed to the fact that the presence of disc promoters in gas-solid system makes the pores more zigzag which result in increased lengths of the pores. In addition, promoter also provides resistance to the flow. The increased length of the pores increases residence time of the fluid which improves heat and mass transfer rates.

CHAPTER 7

CONCLUSION

Conclusion

From the comparison between the predicted values of fixed bed pressure drops and the corresponding experimental ones for unpromoted and promoted beds, the following conclusions were made:

(i) The predicted and the corresponding experimental values of fixed bed pressure drops are in fair agreement. (ii) The fixed bed pressure drops are dependent on the packing size, length of the bed, fluid viscosity and density and the characteristics of the promoter. (iii) The fixed bed pressure drop increases in the presence of disc promoter in the bed. This may be attributed to the fact that the presence of disc promoters in gas-solid system makes the pores more zigzag which result in increased lengths of the pores. In addition, promoter also provides resistance to the flow. The increased length of the pores increases residence time of the fluid which improves heat and mass transfer rates. (iv) The fixed bed pressure drop increases with in number of disc (blockage volume) in the bed. This increase is in the range of 10-20% in the range of the present experimentation.

CHAPTER 8

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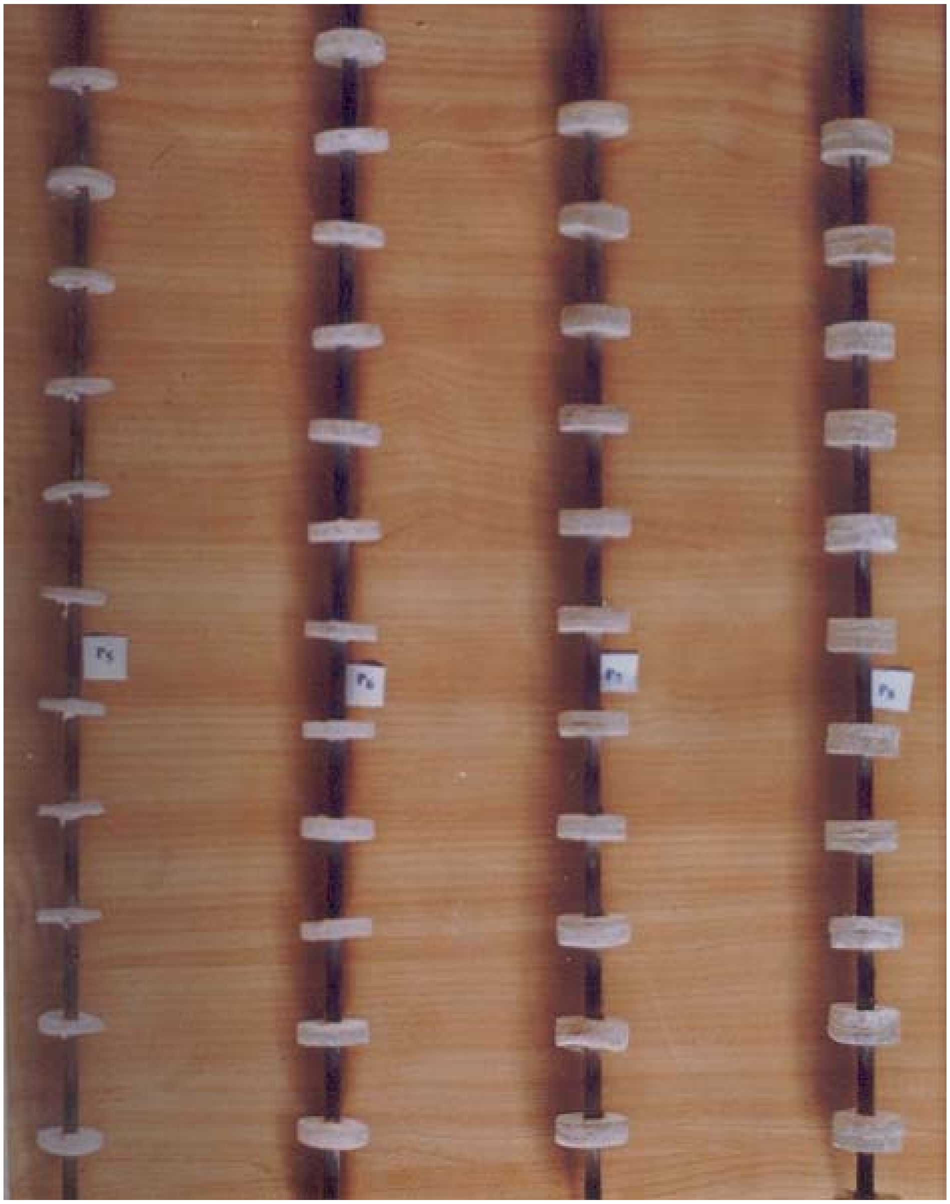
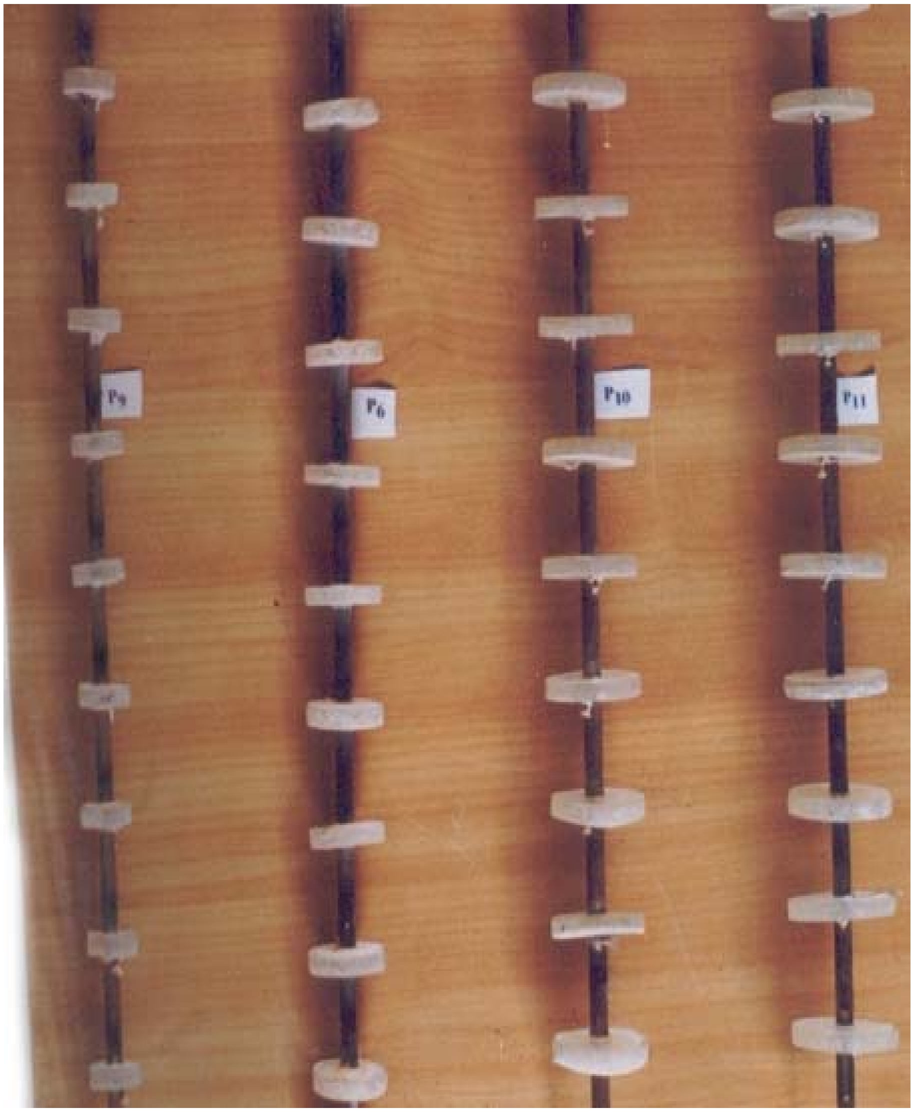
Experimental setup



Details of disk promoter (varying disk thickness)



Details of disk promoter (varying disk diameter)