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DRAG REDUCTION OF FLOW THROUGH PACKED BED MATERIAL USING NATURAL POLYMER

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ABSTRACT

Drag reduction is a technique used in controlling the turbulence produced in case of flows either through pipes or through soil strata. Drag reduction effects come into play, even with small amount of macromolecules in solutions in flows. In this study an experimental investigation of the flow of drag reducing fluids through packed bed is presented. The drag fully developed in a packed bed flow with five concentrations 0.0125%(w/v), 0.025%(w/v), 0.0375%(w/v), 0.05%(w/v) and 0.0625%(w/v) of natural polymer material namely Guar Gum is investigated experimentally. It was found in analyzing the data that as the polymer concentration increases, the magnitude of the drag reduction increases, it reaches a maximum value at optimum concentration and then begins to fall gradually with further increase in polymer concentration. In this analysis 0.02 %(w/v) to 0.04 %(w/v) has been opted as the optimum concentration for which drag reduction is found to be maximum. This optimum concentration of polymer helps in achieving the most efficient flow through soil strata or conduits. In this study three empirical models namely Ergun's empirical equation, Carmen's Model and Sawistowski Model have been used for the verification of the experimental results.The three models gave almost similar type of variation of drag with only slight variation in friction factor.

KEYWORDS: Drag Reduction, Natural Polymer(Guar Gum).

INTRODUCTION

Drag reduction can defined as a flow phenomenon by which small amount of additivescan greatly reduce the turbulent friction of a fluid. Aim of the drag reduction is to develop the fluid mechanical efficiency using active agents that known as drag reducing agent (DRA). In single and multiphase flow, drag reduction (%DR) can defined as the ratio of reduction in the frictional pressure difference when the flow rates are held constant to the frictional pressure difference without DRA, and then multiplied by 100 represented by equation,

$$\% \, DR = [(\Delta P_b - \Delta P_a) / \Delta P_b]*100 \qquad (1)$$

In this equation ΔP_b is the frictional pressure difference before adding the additives and ΔP_a is the frictional pressure difference after adding additives. A brief review of models is mentioned as under [4].

Carman Model (1938)

Carman in 1938 correlated data for flow through randomly packed beds of solid particles by a single curve, whose general equation was

$$f = 5Re^{-1} + 0.4Re^{-0.1}$$

(2)

where Re is the modified Reynolds number and can be expressed in the following equation:

$$Re = \frac{\rho u}{S(1-e)\mu}$$

(3)

And *s* is the specific surface area of the particles and is the surface area of particle divided by its volume[1].

The Ergun equation (1952)

This is a superposition of Blake-Kozeny and the Burke-Plummer equations have been widely used for predicting pressure drop for the flow of Newtonian fluids through packed beds. The equation is strictly valid for packed column of infinitely large diameter relative to the size of packing material, since the surface of the column is excluded from the evaluation of the total wetted surface of the packed bed [2].

Formulation of Ergun Equation

In order to understand the Ergun equation (Ergun, 1952), one must first know a little about the formulation. Ergun defined a Reynolds number $\boldsymbol{Re}$ that depends on thesuperficial velocity vs. (the volumetric flow rate divided by the column cross-section area) the equivalent diameter of the particle $\boldsymbol{D_p}$, the dimensionless void fraction $\boldsymbol{\epsilon}$ and ρ, the density of the fluid .

$$Re = \frac{\rho \mathrm{v_s Dp,}}{\mu(1-\epsilon)}$$

(4)

Ergun also defined that the friction factor, fp depends on vs, the pressure drop, Δp and the length of the packed bed L:

$$f_p = \frac{\Delta\mathrm{p.Dp}\,.\epsilon^2}{L\rho v_s^2(1-\epsilon)}$$

(5)

There are two independent equations that deal with flow behavior that have different Reynolds numbers. When $\boldsymbol{Re_p}$< 10, the Blake –Kozeny equation suggests that the friction factor depends mainly on the Reynolds number:

$$f_f = 75\frac{(1-\epsilon)^2\mu}{\epsilon^3\rho v_s^2\mathrm{Dp}}$$

(6)

When $\boldsymbol{Re}$> 1000, or in turbulent flows, the viscous force of the fluid is insignificant. This means the Burke-Plummer equation describes the friction factor as independent of the Reynolds number:

$$f_f = \frac{7(1-\epsilon)}{8\epsilon^3}$$

(7)

The Ergun equation (Ergun, 1952), which covers the entire range of flow rate, canthen be obtained by assuming that the viscous losses and the kinetic losses are additive,[3] therefore the result is:

$$f_f = 75\frac{(1-\epsilon)^2\mu}{\epsilon^3\rho v_s\mathrm{Dp}} + \frac{7(1-\epsilon)}{8\epsilon^3}$$

(8)

After experiments with different packing material and different flow rate, Ergun determined the general form of the equation:

$$f_p = \frac{150}{Re_s} + 1.75$$

(9)

Or in terms of pressure change - Δp:

$$\Delta\mathrm{p} = \frac{150 v_s L(1-\epsilon)^2\mu}{\epsilon^2\mathrm{Dp}^2} + \frac{1.75 L\rho v_s^2(1-\epsilon)}{\mathrm{Dp}\epsilon^3}$$

(10)

Where $k_1 = 150$ and $k_2 = 1.75$ are constants established via experimentation.

This arrangement of the Ergun equation makes clear its close relationship to the simpler Kozeny-Carman equation which describes laminar flow of fluids across packed beds

Sawistowski Model (1957)

Sawistowski in 1957 has compared the results obtained for flow of fluids through beds of hollow packing and has noted that equation (2) gives lower values of friction factor for hollow packing[1,2]. Thus, Sawistowski modified equation (2) as:

$$f = 5Re^{-1} + Re^{-0.1}$$

(11)

EXPERIMENTAL SETUP AND PROCEDURE

Permeameter

The constant head vertical flow type permeameter was used for hydraulic tests in this work. The main permeameter section consisted of a 10.16 cm internal diameter GI tube with a total length of 1.06 meter and a test length of 46.5 cm. Four pressures tapping making an angle of 90o to each other were provided along the circumference of permeameter at the starting and ending points of the test length. This arrangement of tapping points was adopted to ensure the mean pressure at the section under consideration. The inlet to the permeameter was regulated with the help of an outlet sluice valve of 25.42mm diameter. I.S. 2.0 mm mesh screen was used in the filter for resisting the porous media. For filling and removing of the material, the permeameter was detached from its supports each time.

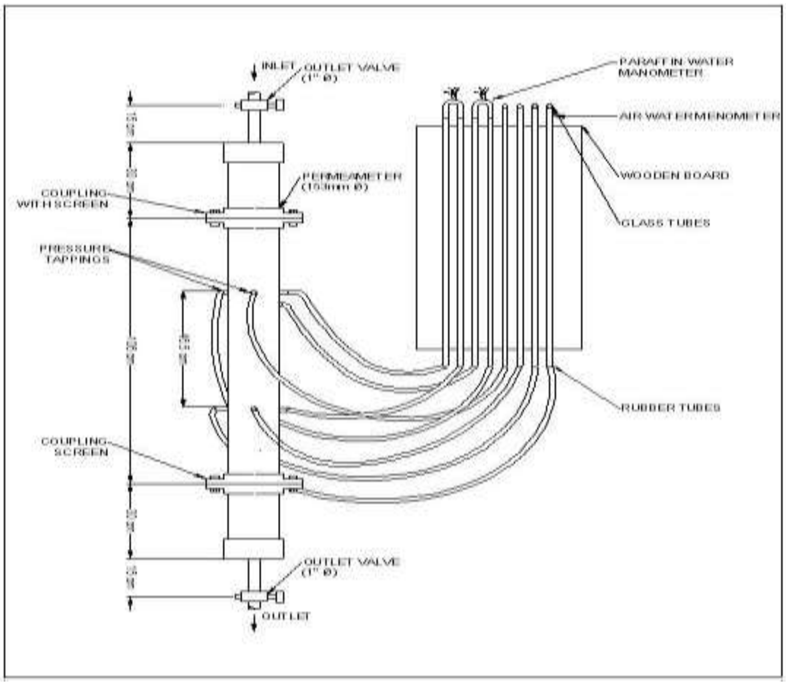


Figure 2.1: Constant head permeameter

Discharge measurement

The discharge was measured by volumetric method. The water was collected in a bucket for a certain period, which was recorded with a stopwatch and collected water was then measured with the help of a 2000 cc capacity glass jar. Volume of water collected at a particular duration will give the discharge.

Manometer

To cover the desired range of flow, two types of manometer were used:

- ***(i)*** ***Air-water manometer:*** Simple piezometers were used to measure the head losses of about 5.0 cm to 100.0 cm of water.
- ***(ii)*** ***Paraffin water manometer:*** Inverted U-tube paraffin water differential manometers were used to measure low head losses. The manometers were supported on a wooden board with a graduated scale in cm, giving a correct reading of manometer up to one mm.

Pycnometer
I.S. pycnometer is used in the specific gravity test.

Weighing balance
Electronic weighing balance were used for measuring the contents during specific gravity test and Angularity number test while spring balance was used while loading the various porous materials in the permeameter.

Thermometer
I.S. Mercury Thermometer measuring temp from 0°C to 80°C was used for measuring the temperature of water.

Source of supply
The permeameter receives its water supply from an overhead tank at a height of 2.65 m above the permeameter outlet. The tank receives its supply from a recirculating tank so that a constant head is maintained in the overhead tank.

Oven
Oven was used to dry out the soil samples collected from different boreholes before doing the sieve analysis.

EXPERIMENTAL PROCEDURE

The various tests conducted during the course of this study can be divided into two categories.

1. Gradation.
2. Viscosity calculation of polymeric material
3. Hydraulic test

Sieve analysis tests
The various samples used in the present investigation are collected from borehole samples of different regions of Jalandhar area. The sediments were sieved through the following available sieves numbered 2.36mm , 1.18 mm , 850µ ,600 µ, 500µ, 425µ ,300µ ,250µ , 212µ, 180 µ,125 µ, 90 µ ,75 µ, 45 µ and sediments retained on each sieve were stocked separately . Proper sieving of about 10 minutes were allowed to shake the material in each case so that uniform size material is allowed to pass through one sieve and retained in another sieve. This material was weighted from each sieve and the percentage finer was calculated, thereafter a plot between grain size and percentage finer on semi log graph paper was drawn which is shown in figure 3.1

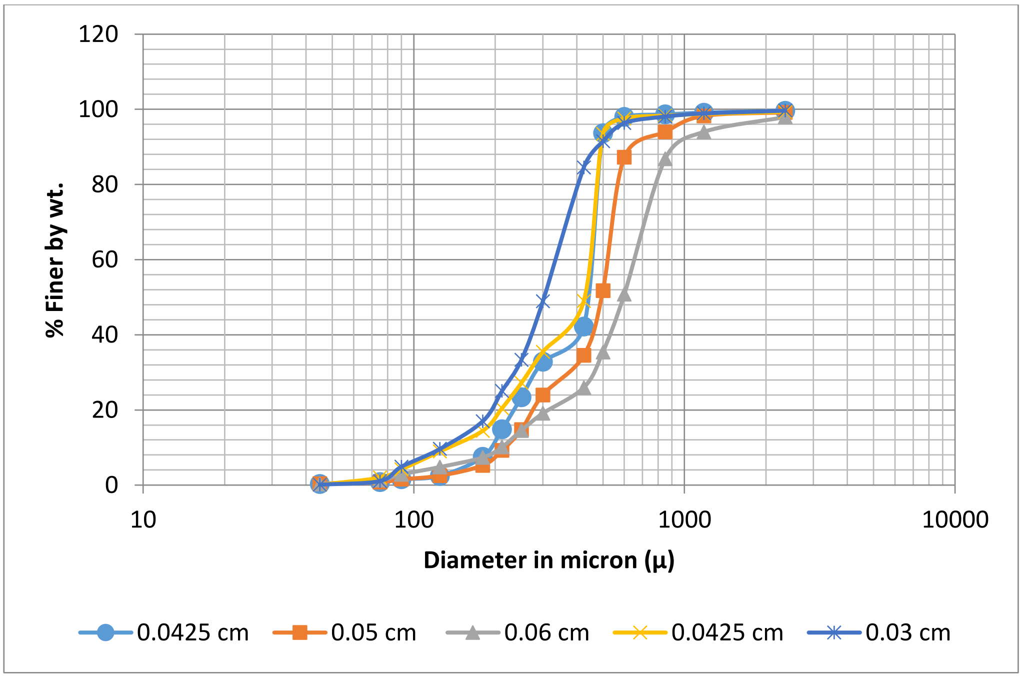


Figure 3.1: Grain size distribution graphs of sand sample

Viscosity tests

Experimental setup:

A redwood viscometer consists of inner vertical cylinder in which liquid to be tested is poured and outer cylinder which contains water to maintain the liquid at room temperature. The cylinder is 46.625mm in diameter and 88.90mm deep. A narrow bore, orifice 1.70mm diameter and 12mm length is drilled in agate seat which is cemented in the base of the inner cylinder. The flask is kept below to collect the liquid.

Figure 3.2: Redwood Viscometer

Redwood Efflux viscometer: In redwood efflux viscometer, time in seconds for 50ml liquid to flow out through an orifice outlet is the measure of viscosity. This is expressed as “Redwood seconds”

Then kinematic viscosity can be obtained through the empirical relation:

$$\nu = At - B/t$$

(9)

For Redwood viscometer, A=0.26 and B=172 t

Viscosity for water at different polymer concentration is tabulated:

Table 3.1: Kinematic Viscosity of water at different polymer concentrations

Sr.No.	Water with polymer conc. %(w/v)	Kinematic Viscosity in Stokes(cm²/s)
1.	0.0125	0.65
2.	0.0250	4.19
3.	0.0375	5.73
4.	0.05	7.88
5.	0.0625	10.2

Reynolds number (Re)

It is a dimensionless parameter and defined as the ratio of inertial force to the viscous force i.e.

$$\mathrm{Re} = \frac{v\, d_g}{\nu} \qquad (10)$$

Where,

v = average velocity of flow through pores.

d_g = geometric mean diameter

ν = kinematic viscosity of fluid.

Friction Factor (f)

Friction factor is a direct measure of resistance to flow and is calculated from Darcy-Weisbach equation:

$$h_L = \frac{f.L.v^2}{2\, g\, d_g}$$

(11)

$$f = \frac{2.\mathrm{g.i.}d_g}{v^2} \qquad (12)$$

Where,
g = acceleration due to gravity.
I = hydraulic gradient (h/L)
d_g = geometric mean diameter
v = velocity of flow
f = friction factor

ANALYSIS OF RESULTS

Variation of friction factor and Reynolds's number

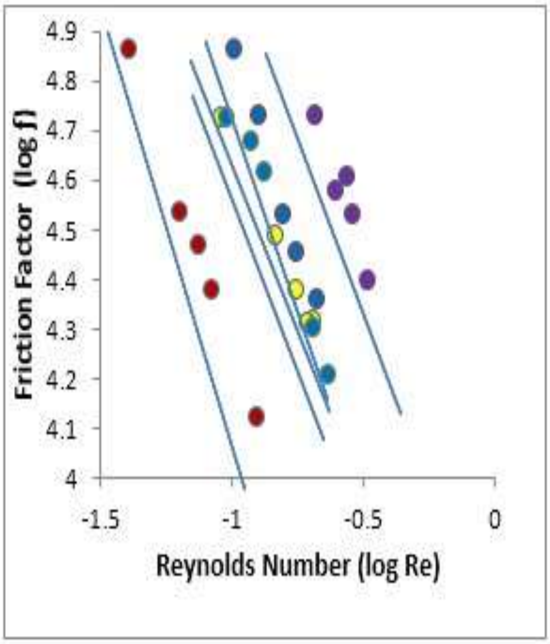
The various curves are plotted for friction factors and Reynold's number for five different sand samples and the variations are being compared with the analytical Ergun equation to validate the results of experimental analysis.The drag fully developed in a packed bed flow with five concentrations 0.0125%(w/v), 0.025%(w/v), 0.0375%(w/v), 0.05%(w/v) and 0.0625%(w/v) of natural polymer material namely Guar Gum was investigated experimentally.

Here, distilled water at room temperature 27˚C, is worked out as solvent fluid to assist the drag phenomenon. The natural polymer namely, Guar Gum is utilized as drag reducing agent at different concentrations.

In order to examine the effect of drag reducing fluid on the flow through packed bed comparison are made by analyzing the variation of the friction factor with Reynolds number for the distilled water shown in Figure 4.1. And also the variation of friction factor and Reynolds number are studied for the flow for five different concentration of polymer shown from Figure 4.2 to Figure 4.6

The experimental results are compared with three empirical models namely Ergun Equation, Carmen Model and Sawistowski Model shown in figure 4.7 to figure 4.9. These variations validate the experimental results.

The concentration of polymer shows a considerable effect on friction factor. The curves show how friction factor for the lowest polymer concentration i.e. 0.0125% (w/v) and for the highest polymer concentration i.e. 0.0625% (w/v) show change in frictional factor. The friction factor gives only a slight change as the concentration is increased but value of Reynolds number is reduced.al analysis is clearly depicted by the empirical model shown in figure 4.7 to figure 4.9 which validates the experimental results.



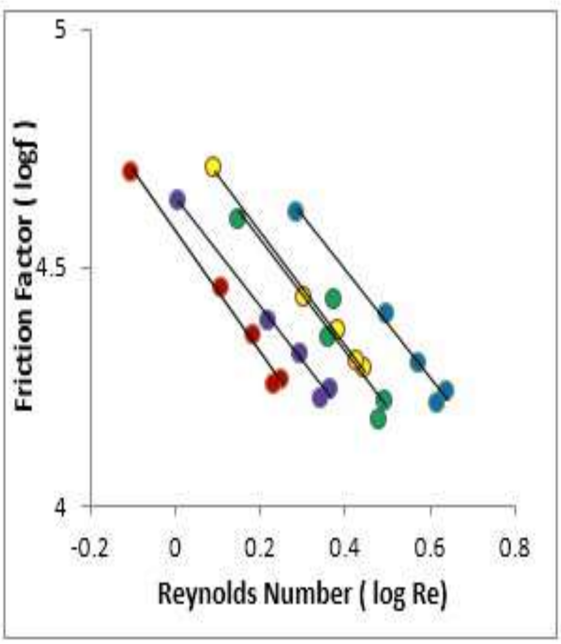


Figure 4.1: Curve of friction factor versus Reynolds Number for different samples with distilled water
Figure 4.2: Friction factor versus Reynolds Number for sample 1 at different concentrations

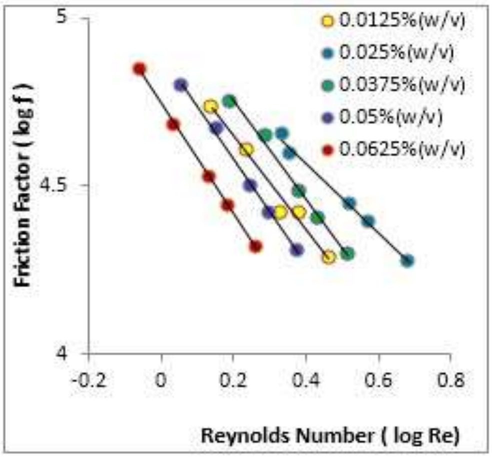


Figure 4.3: Friction factor versus Reynolds Number for sample 2 at different concentrations

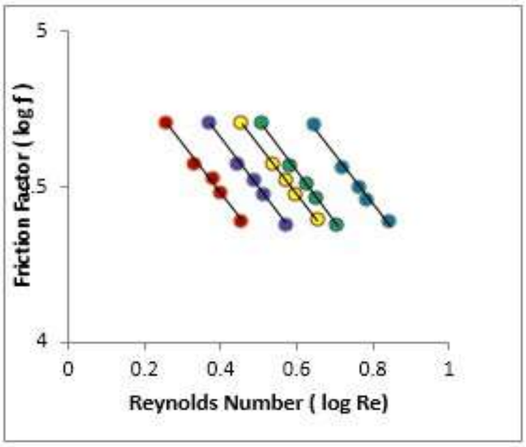


Figure 4.5: Friction factor versus Reynolds Number for sample 4 at different concentrations

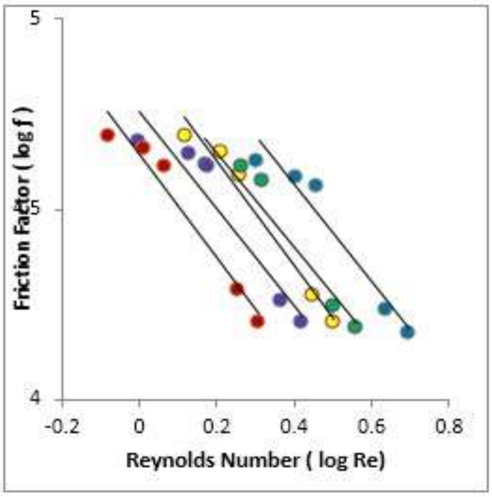


Figure 4.4: Friction factor versus Reynolds Number for sample 3 at different concentrations

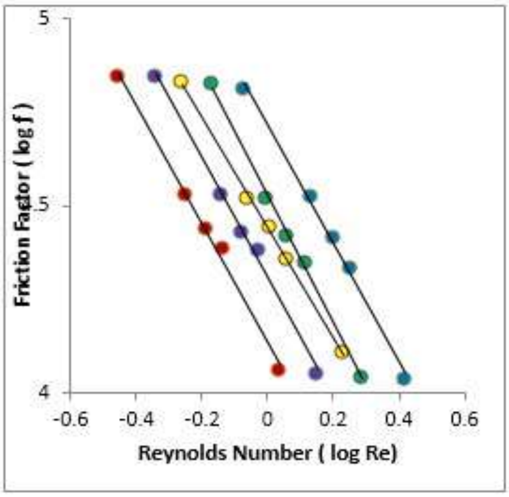


Figure 4.6: Friction factor versus Reynolds Number for sample 5 at different concentrations

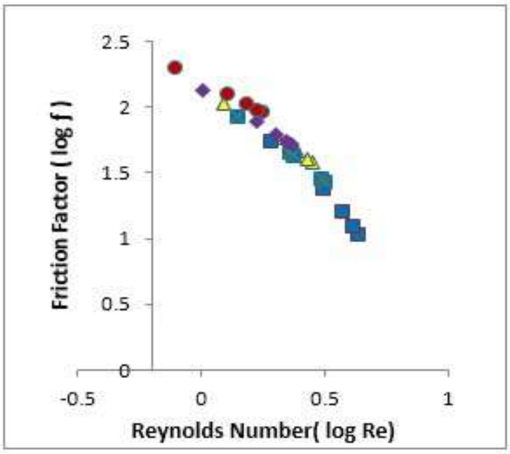


Figure 4.7: Curve of friction factor versus Reynolds Number for different samples (Ergun Equation)

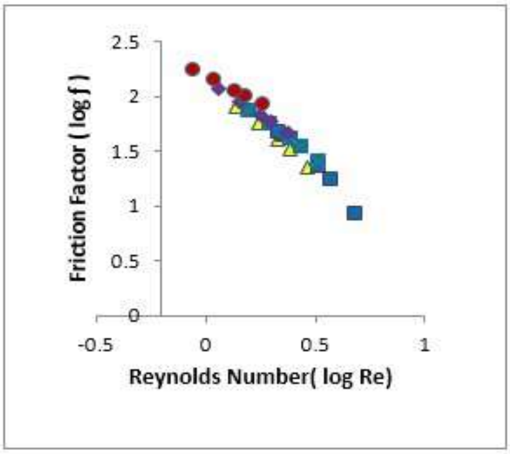


Figure 4.8: Curve of friction factor versus Reynolds Number for different samples (Carman Model)

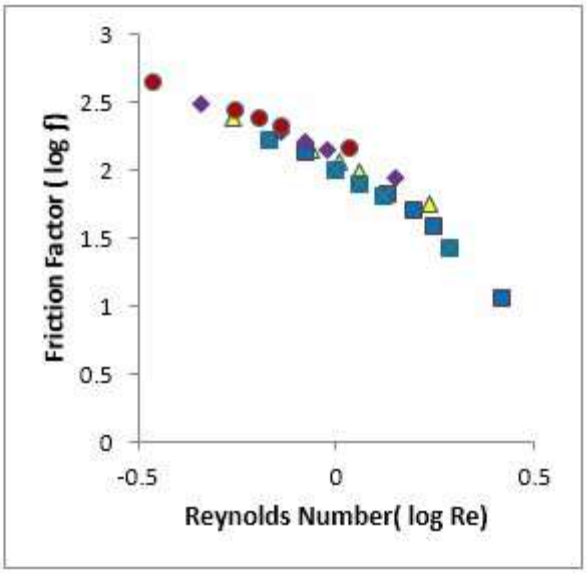


Figure 4.9: Curve of friction factor versus Reynolds

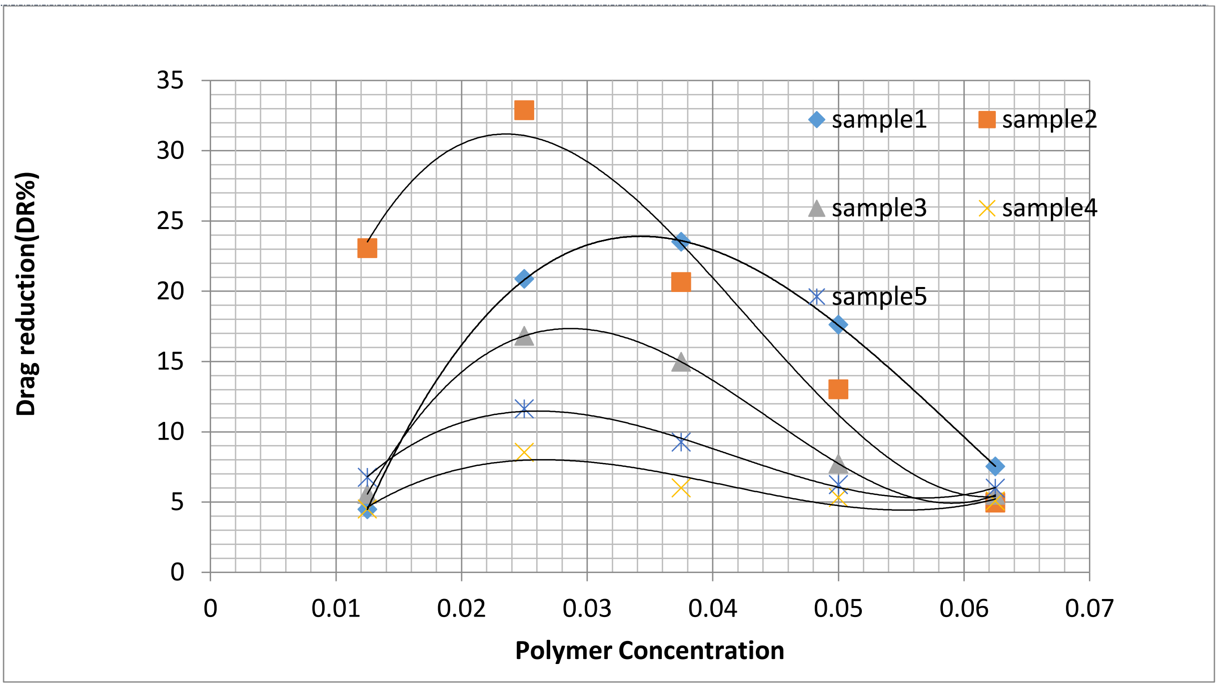
Number for different samples (Sawistowski Model)
Drag reduction efficiency can also be expressed in terms of the friction factors of the solvent and the drag reducing fluids as:

$$\mathrm{DR\%} = \left(\frac{f_{solvent} - f_{polymer}}{f_{solvent}}\right) \quad (13)$$

Where, $f_{solvent}$ is the friction factor for solvent (distilled water) and,
$f_{polymer}$ is friction factor for polymeric solution with different concentrations
The values obtained of drag reduction for samples 1 to 5 at different concentrations are given in Table 4.1

Table 4.1: Drag reduction calculation for different samples

Polymer concentration	Sample1	Sample2	Sample3	Sample4	Sample5
0.0125%(w/v)	4.47	23.06	5.58	4.5	6.76
0.025%(w/v)	20.88	32.89	16.83	8.54	11.63
0.0375%(w/v)	23.51	20.66	14.97	6	9.27
0.05%(w/v)	17.63	13.02	7.74	5.31	6.23
0.0625%(w/v)	7.53	4.95	5.5	5.08	5.99



Curve of Drag reduction versus polymer conc.

CONCLUSION

- It is seen that as the polymer concentration increases, the magnitude of the drag reduction increases, reaches a maximum value at optimum concentration and then begins to fall gradually with further increase in polymer concentration. This type of behavior can also be found in turbulent pipe flow
- In this analysis 0.02 %(w/v) to 0.04 %(w/v) has been opted as the optimum concentration for which drag reduction is found to be maximum.
- The plots of Friction factor and Reynold's number on log-log scale shows a linear variation at low Reynold's number. It has been observed that the resistance of bed decreases as Reynold's number increases.
- Ergun's empirical equation,Carmens Model and Sawistowski Model used for analyzing the drag reduction for polymeric solution and with distilled water, exhibit the same kind of behavior of friction factor variation. Thus experimental analysis also validates the analytical results.

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