International Journal of Polymer Science and Engineering
Vol. 1: Issue 1
www.journalspub.com

Drag Reduction Annular Flow with Polyacrylamide Additive

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Abstract

Drag reduction studies have been showed in annular flow with polyacrylamide additive. The percentage drag reduction in annular pipe flow ranges between 85–98% as the diameter increased from 0.02 to 0.033 m. The percentage drag decrease of 89 to 98% is detected as the polyacrylamide concentration is varied from 50 to 200 ppm. The correlation for drag reduction and Reynolds number is presented here under $DR = 2.06Re^{-0.037}$.

Keywords: *Drag reduction, annular flow, polyacrylamide additive*

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INTRODUCTION

The presence of small amount of polymers in solvent outcomes in the reduction of skin friction, in turbulent flow. The phenomenon is known as drag reduction and was first observed by two independent workers Tom[1] and Mysels[2] in 1949. Since then several investigations were carried out in this field. Drag reduction reported is as high as 80% and for the polymer concentration of up to 50 ppm. Drag reduction applications are in many industrial operations like water circulation cooling towers, fire hoses, desalination, sprinkler irrigation, crude oil pumping, and hydraulic transport. All these studies conclude that addition of small amounts of drag reducing agents could save substantial power. Myska *et al.*[3] proposed that drag reduction additives can be classified in to three categories, high and low molecular weight polymers, cation and anionic, zwitterionic surfactants. Among these, the high molecular weight polymers were found effective in drag reduction. Surfactant additives suffer from mechanical shocks and thermal degradation as reported by Yu *et al.*[4]. Virk *et al.*[5] reported that the drag reduction occur at a well-defined wall shear stress. He further observed that there is no delay of transition from laminar to turbulent. Drag reduction is a function of concentration, flow rate and molecular weight of solution. Lumley[6] proposed that the hydrodynamic frequencies are higher than relaxation rate of a coil. The visco-elastic effect is prominent. The drag reduction was offered due to the increase of viscous sub layer. Hinch[7] suggested that the elongation of polymer molecules results in increase in viscosity. Gennes[8] investigated that exchange of kinetic and elastic energy in the core of turbulent flow. He concluded polymer effect at small scale is not described by viscosity but by an elastic modulus. Flexible polymers in dilute solution enhance viscosity in slow flows. But in rapidly varying shear fields they behave elastically. Den Toonder *et al.*[9] 1997 elucidated that the viscous isotropic version introduced by extent of polymers play a key role in drag reduction. Drag reduction effect of CMC at concentrations lower than 1000 ppm investigated by Serife Zeybek[10].

The literature on drag reduction reveals that the addition of small amount of high polymer offer great savings in pumping power. Several studies were found for flow through circular conduits and pipe lines. But the works on drag reduction in annular pipe flow are meager. To harness benefit of drag reduction for flow through annular conduits is proposed using polyacrylamide at several concentrations as drag reducing agent and also with varying annular dimensions. Present study is directed to investigate the effect of (1) Annular pipe size (2) The percentage of polyacrylamide and (3) The flow rate. The present study was also directed to develop a model for the estimation of frictional losses. The range of variables covered in the present studies is presented in Table 1.

Table 1: *Range of Variables.*

Variable	Maximum	Minimum
Friction factor, f	16.30701	0.006719
Reynolds number, Re	14422.5	364.2857
Velocity, m/s	0.28845	0.022
Additive, ppm	200	50
Pipe diameter, m	0.03	0.02

RESEARCH MATERIALS

Material used in the study is polyacrylamide as drag reducing agent and distilled water as solvent. Properties of the material are presented here under.

Polyacrylamide

Polyacrylamide used in the present study is obtained from the National chemical laboratories, Vadodara. Polyacrylamide is a brittle, white, odorless polymer. Furthermore, polyacrylamide is relatively immune to bacterial attack. It is water soluble at all concentrations, temperatures and pH values. Polyacrylamide molecules are both very flexible and long with a relatively small diameter thereby making them susceptibility to shear degradation or mechanical breakage. It is easy to dissolve when the temperature is over 120°C. The density of the polyacrylamide is 1.30 g/cm^3. With the solution viscosity of the polymer molecular weight increased significantly. The average molecular weight of commercial polyacrylamide ranges approximately from 2×10^3 to high 15×10^6. Polyacrylamides with molecular weights greater than 2×10^7 are not unlikely. However, these large molecules greatly influence the products activity as a flocculent and rheology control agent.

At relatively low shear rates, aqueous solutions of polyacrylamide are pseudo plastic. However, at high shear rates rupturing the polymer chains can degrade the molecular weight. The stability of the polymer can be improved by the addition of sodium thiocyanate, thiourea, sodium nitrite or nonsolvents. Adding of ferrous salts along with a ferric chelating agent can accelerate the degradation of aqueous solutions of polyacrylamide.

RESEARCH METHODOLOGY

A photograph and schematic diagram of experimental set up are shown in Figure 1, respectively. It essentially consisted of a storage tank (TS), centrifugal pump (P), rotameter (R), entrance calming section (E_1), test section (T) and exit calming section (E_2).

The storage tank was of 100 liter capacity and it was made of copper. The tank was provided with a drain valve (V_1) at the bottom for periodical cleaning of the tank and with an outlet line to admit the solution to the suction side of the pump. The outlet line was provided with a valve (V_2) to isolate the pump from the storage tank whenever necessary. The discharge line from the pump splits into two. One served as a bypass line and controlled by valve (V_3). The other connects the pump to the entrance calming section (E_1) through rotameter. The rotameter is connected to a valve (V_4) for adjusting the flow at the desired value. The rotameter has a range of 0 to 166×10^{-5} m^3/s. The entrance calming section made of circular copper pipe is 0.05 m ID and a length of 2 m (40D). It is provided with a flange at the top and is closed at the bottom with a gland nut (G_1). The up-stream side of the entrance calming section is filled with capillary tubes to damp the flow fluctuations and to facilitate steady flow of the solution through the test section.

The test section was made of a graduated Perspex tube of 0.44 m length. Two pressure taps (P_1, P_2) were provided at both the ends of the test section so as to connect it to the manometer. Carbon tetrachloride served as manometric fluid. Exit calming section is also of the same diameter copper tube of 0.05 m, and it is provided with a flange on the upstream side for assembling the test section. The entrance calming section, test section and the exit calming sections were joined together by means of flanges (F) and gland nuts (G_1,G_2). The gland nuts (G_1, G2) provided at both the ends of the column served to hold the central pipe coaxially in circular column.

Annular conduits were made by arranging the pipes concentrically. Inner pipes were of ½ inch, ¾ inch and 1 inch diameter.

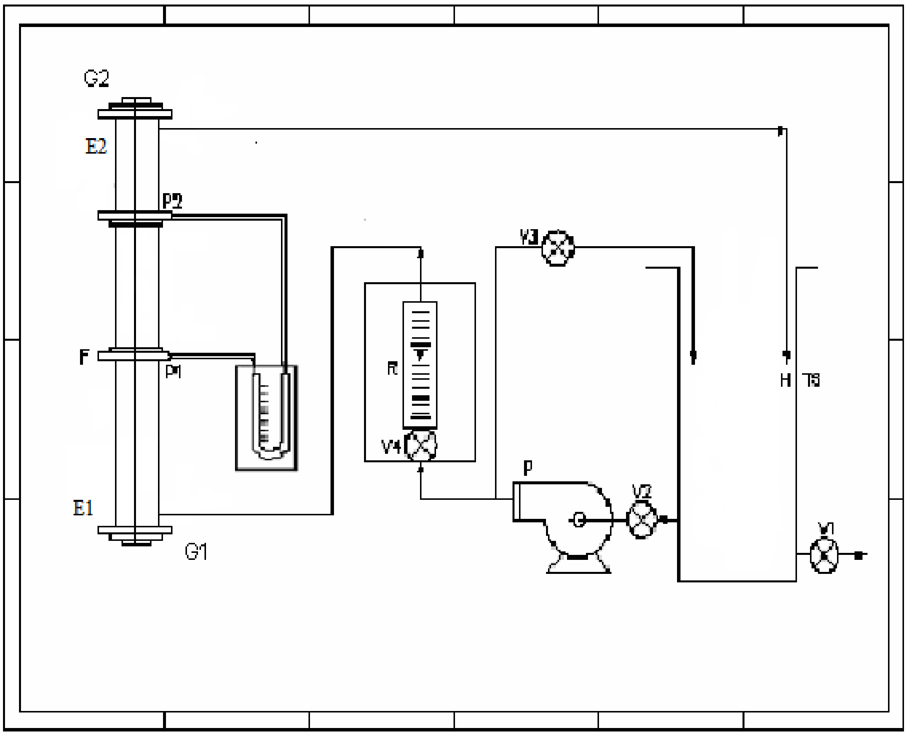

Fig. 1: *Schematic Diagram of Experimental Setup.*

EXPERIMENTAL PROCEDURE

The schematic diagram of experimental equipment is shown in Figure 1. The experimental work was carried out in a vertical test section whose length 0.44 m and of diameter 0.05 m of closed loop. Distilled water supplied through a controlled valve into the test section from a tank containing distilled water of 80 liters. The test section is preceded by entrance calming section which was found to be adequate for the development of pressure profile. The pressure drop was measured by U-Tube manometer, which contains Carbon tetra chloride (CCl_4) of specific gravity of 1.59. This experiment was conducted for the various flow rates of the water and within range of rotameter. The rotameter was calibrated prior to the commencement of the experimental work.

The annular pipe was fixed concentrically by means of gland nuts arranged at both the ends of the column. Care was taken to ensure concentric alignment while fixing the annular pipe. About 80 liters of water was taken in the tank and was pumped through the test section. After the flow rate was stabilized the difference in the manometer reading and the temperature were noted.

The flow rate was changed and the experiment was repeated. The experiment was repeated for varying flow rates and diameters of the annular pipe.

For the studies on drag reduction polyacrylamide was added to water and the above experiment was repeated covering the parameters mentioned above. The same experiment was repeated for different concentrations of the polyacrylamide in water. These measured data were used to calculate the drag reduction, friction factor (f) and the velocity (V) that is used for the correlation development. The ranges of variables are covered in Table 2.

Table 2: *Range of Variables.*

S. No	Variable	Minimum	Maximum
1.	Annular pipe diameter, m	0.02	0.033
2.	Flow rate, m^3/sec	10	80
3.	Polyacrylamide concentration, ppm	25	200

RESULTS AND DISCUSSION

Addition of small amount of additive reduce drag drastically, sometimes the reduction is up to 100%. Several works have been reported on the subject. The early works reported on the drag reduction were Tom[1] and Mysels[2], Lumley[11], Landahl[12], presented effectiveness of drag reducing agent. Hoyt[13] demonstrated the effect of fibers for drag reduction. The other mechanisms that reduce drag are coarse dust particle in air, magnetic field and flexible walls. The drag reduction in turbulent flow is effective with linear polymer of high molecular weight such as polyethylene has been subject of interest for the last four decades. The other drag reducing agents are polyacrylamide, xantha gum, guar gum, sodiumcarboxy-methylcellulose (CMC), hydroxyethyl cellulose, polyisobutylene, polymethylmethacrylate, polyisobutylene etc.

THEORIES OF DRAG REDUCTION

Effects of Polymer Concentration

For low concentrations the drag reduction is found to be directly proportional to the concentration, for high concentrations the reduction reaches to a maximum drag reduction asymptote was said by Lumley[11]. To observe the effect of polymer concentration an experimental study was carried out in the same pipe for solutions of the same polymer with different concentrations. Friction factor versus Reynolds number plots at different polymer concentrations occur in a region confined between an upper limit Prandtl-Karman law and maximum drag reduction curve. It is seen that the drag reduction effect of polymer additive increases with increasing polymer concentration.

EFFECTS OF PIPE DIAMETER

Pipe diameter is another important parameter in drag reduction. Virk[14] reported that the onset of drag reduction shifts toward higher polymer concentrations with increasing pipe diameter. The drag reduction of a polymer solution becomes more pronounced as pipe diameter is reduced. It has been speculated that dependence of the drag reduction characteristics on pipe diameter is due to the changing length scale ratio of the polymer chains to turbulence. As diameter increases, larger eddies are observed which suppresses the drag reduction ability of the polymer.

Comparison of Polymeric and Surfactant Additives

Cationic, anionic and zwitter ionic surfactants are used as drag reducing additives in the turbulent flow and the research studies in this field has grown in recent years. The drag reduction additives are generally used in recirculation turbulent flow system.

The differences in the flow behavior of polymeric and cationic surfactants were studied by Myska and Zakin[15] in 1997. According to this study, polymer solutions degrade irreversibly under shear and lose their drag reduction behavior. Cationic surfactants degrade under high shear, but the structures are repairable and they regain their drag reduction ability when shear is reduced. Dilute polymer solutions become drag reducing when the critical shear rate is exceeded. Surfactant solutions generally show a gradual departure from the laminar flow curve and drag reducing until a critical shear rate is reached. Friction factors significantly below those predicted by the maximum drag reduction asymptote for high polymers can be reached in cationic surfactant and aluminum disoap systems.

Turbulent mean velocity profiles for cationic surfactants can be significantly steeper than the limit predicted by the elastic sub layer model for the high polymers.

Despite their higher level drag reductions than polymers, use of surfactants has been quite limited. The main drawback of surfactants is on their negative impact environment compared to polymers.

Turbulent Pipe Flow Characteristics

We consider a fully developed turbulent flow through a straight pipe with diameter D. The mean shear stress at the wall, τ_ω, for Newtonian and non-Newtonian fluids and for all regimes is given by

$$\tau_\omega = \frac{D\Delta P}{4\Delta x}$$

where, $\frac{\Delta P}{\Delta x}$ is the constant pressure gradient. The wall shear stress is usually expressed in terms of the Fanning friction factor *f* given by

$$f = \frac{\tau_\omega}{\frac{1}{2}\rho U_b^2}$$

With U_b the mean velocity in the pipe and ρ the density of the fluid. For instance, the expressions for *f* for laminar and fully turbulent pipe flow of a Newtonian fluid are, respectively

$$f = \frac{16}{\mathrm{Re}} \qquad \frac{1}{\sqrt{f}} = 4\log \mathrm{Re}\sqrt{f} - 0.4$$

$\mathrm{Re} = \frac{\rho U_b D}{\eta}$ is the Reynolds number based on the constant viscosity η of the fluid. For polymeric liquids the viscosity is in general shear-rate dependent, so that the usual definition of the Reynolds number cannot be used. In this paper we use a method proposed by Pinho and Whitelaw[16] and Draad *et al.*[17]. In this approach the Reynolds number is based on the viscosity at the pipe wall (η_ω) as obtained from

$$\eta_\omega = \frac{\tau_\omega}{\gamma_\omega}$$

where, $\eta_\omega = \eta(\gamma_\omega)$ and γ_ω is the local shear rate at the wall.

At maximum drag reduction of non-shear-thinning fluids the friction law approaches an empirical asymptote, called the maximum drag reduction asymptote or virk asymptote given by $\frac{1}{\sqrt{f}} = 19\log \mathrm{Re}\sqrt{f} - 32.4$

For shear-thinning fluids, the friction factor versus the wall Reynolds number collapses the data near Virk asymptote. This does not happen when we use the Reynolds number based on the viscosity of water. Therefore, we will use the wall

Reynolds number Re in the above equation.

The drag reduction is defined as the reduction in pressure-drop due to the addition of the polymers,

$$DR\% = \frac{\Delta P_N - \Delta P_P}{\Delta P_N}.100\% = \frac{f_N - f_p}{f_N}.100\%$$

at the same wall Reynolds number.

The suffices 'N' and 'P' stand for the Newtonian (non-drag-reducing) and the polymeric (drag-reducing) fluid, respectively.

The various chemicals employed for drag reduction are presented in Table 2. Observations reveal polyacrylamide has not been used for the study of drag reduction in annular conduit. Therefore, polyacrylamide is selected in the present study as drag reducing agent. The experimental program was conducted with varying concentrations of polyacrylamide (PAA) in water solution in annular conduits using varying annular pipe diameters.

Experiments were conducted in vertical column of 5 cm diameter. The experimental setup and procedure has been presented in the proceeding sections. Drag reduction effects were measured through the pressure drop. The drag reduction is computed and presented in terms of effective friction factor. The drag may be due to shear near the wall and between the layers of fluid and also due to the form drag. All these types produce the pressure loss, the relative proportion is unclear but the cumulative effect can be measured the means of manometer as drop in pressure.

The pressure drop is measured by U-tube manometer as mentioned in chapter 4. The measured pressure difference is used for the computation of friction factor by the following equation:

$$f = \frac{\Delta P g_c D}{2LV^2\rho} = \frac{\tau_\omega}{\frac{1}{2}\rho\upsilon^2}$$

The superficial velocity is computed by the following:

$$V = \frac{q}{\pi\frac{D^2}{4}}$$

The Reynolds number calculated by the following equation:

$$\mathrm{Re} = \frac{D_e\upsilon\rho}{\mu}$$

EFFECT OF PERCENTAGE DRAG REDUCTION

Present study aims at the reduction of pumping power with drag reduction agent additive. The additive chosen is polyacrylamide (PAA). Its efficiency can be observed from drag reduction.

A graph is drawn as percentage drag reduction versus Reynolds number with annular pipe diameter as parameter and shown in Figure 2 while Figure 3 is graph demonstrating the effect of polyacrylamide (PAA) concentration on drag reduction.

These plotted graphs reveal the following information. The percentage drag reduction ranges between 85–98% as the annular pipe diameter increased from 0.02 to 0.033 m.

A marginal variation in drag reduction is observed in the case of 0.025 to 0.033 m while that reduced to 82% for annular pipe of 0.02 m. Figure 3 demonstrate the effect of PAA concentration. The figure reveals the reduction in drag is high in the range of 50–200 ppm.

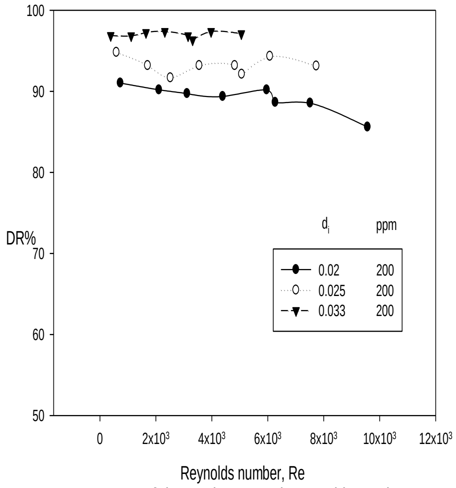

Fig .2 Variation of drag reduction with Reynolds number- Effect of annular pipe diameter.

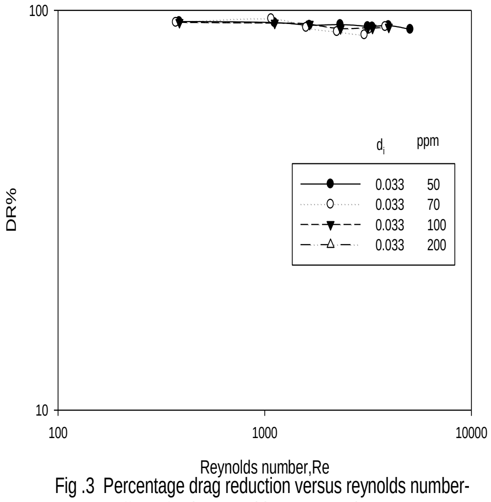

Fig .3 Percentage drag reduction versus reynolds number- Effect of polyacryamide concentration.

EFFECT OF ANNULAR PIPE DIAMETER

The concentrically placed annular pipe affects friction factor significantly. The plots in Figures 4 and 5 are drawn for f versus Re with annular pipe diameter as parameter without and with the addition of polyacrylamide (PAA) to water, respectively.

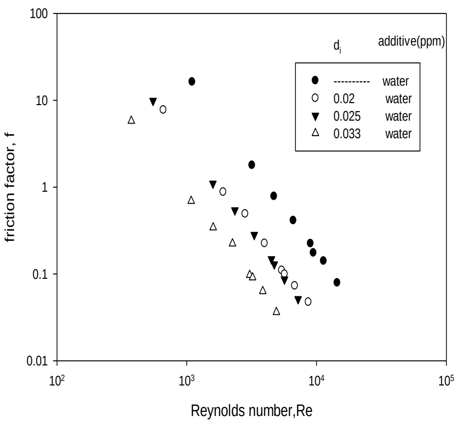

Fig 4 f vs Re for water-Effect of annular pipe diameter

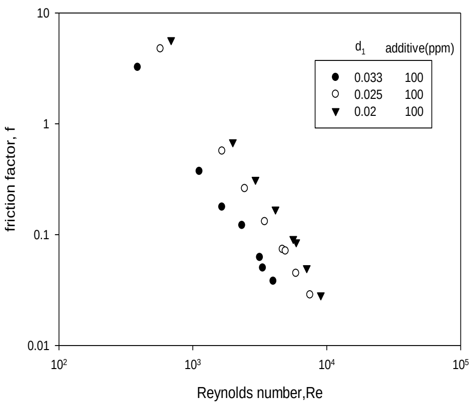

Fig 5 f vs Re with PAA additive to water- Effect of annular pipe diameter

The figure reveals the following information, friction factor (f) values are decreasing with Reynolds number with exponent on Re as 2. Conduit with and without annular pipe exhibiting same exponent on Re indicating the same regime.

Figures 4 and 5 are based on annular velocity and equivalent diameter. The plots in Figure 5 the conduit with 0.02 and 0.025 m annular pipe diameter are coinciding while the conduit with 0.033 m annular pipe diameter deviates. Figure 5 is graph drawn as f versus Re with PAA concentration of 100 ppm and with annular pipe diameter as parameter. The reveals friction factor (f) values are decreasing with Reynolds number (Re) and the exponent remains at a value of -2. For any Re, f values are decreasing with PAA.

The drag reduction is significant at higher pipe diameter namely 0.033 m; it is due to higher annular velocity and increased turbulence.

EFFECT OF POLYMER CONCENTRATION

Figure 6 is graph drawn as f versus Re with PAA concentration as parameter, f values are decreasing with Reynolds number and the exponent remains at -2. Significant variation has not been found for PAA concentration as it varied from 50–100 ppm but is significant above 100 ppm.

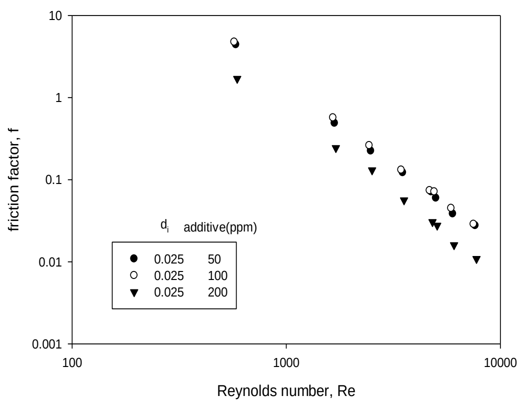

Fig 6 f vs Re-Effect of PAA concentration

EFFECT OF ANNULAR PIPE DIAMETER

A cross plot is drawn in Figure 7 as friction factor versus annular pipe diameter for the case of pure water and for water with PAA additive. Friction factor values decrease with increase in annular pipe diameter and it is very significant as it varies from 0.025 to 0.033 m diameter.

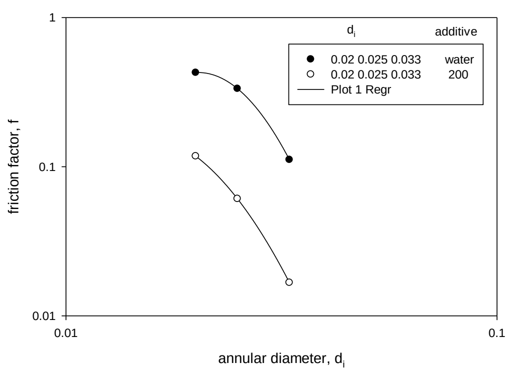

Fig 7 friction factor vs annular pipe diameter

EFFECT OF CONCENTRATION

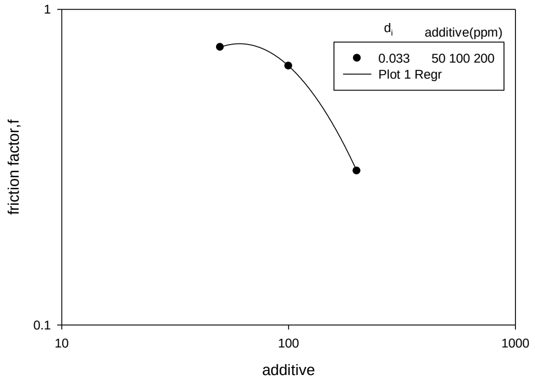

Fig 8 friction factor vs PAA concentration

Figure 8 depicts the effect of additive concentration. As the additive increases friction factor f values decreases. The decrease is marginal from 50 to 100 ppm and is significant above 100 ppm. In the present study 100 ppm is minimum concentration and there onwards reduction in friction factor is significant.

CORRELATION FOR PERCENTAGE DRAG REDUCTION

A graph is drawn as percentage drag reduction versus Re and shown in the Figure 9. On linear regression the following correlation is resulted with regression coefficient mention along with it. The equation is useful for predicting drag reduction at any Reynolds number, Re.

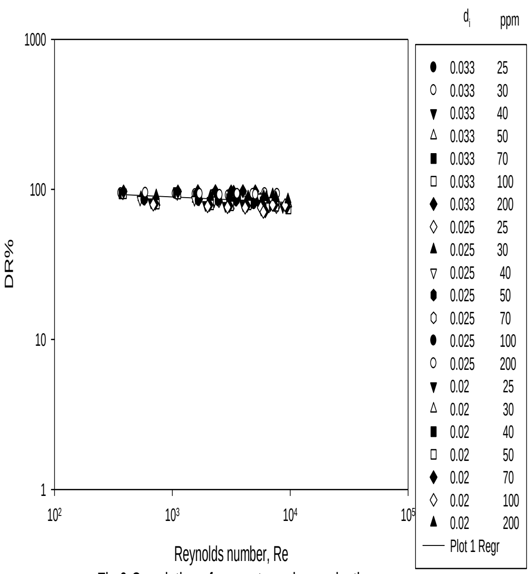

Fig 9 Correlation of percentage drag reduction

CONCLUSION

The percentage drag decrease in annular pipe flow sorts between 85–98% as the diameter enlarged from 0.02 to 0.033 m. The percentage drag decrease of 89 to 98% is identified as the polyacrylamide concentration is altered from 50 to 200 ppm. The correlation for drag decrease and Reynolds number is shown here as under: $DR=2.06Re^{-0.037}$

REFERENCES

1. Toms B.A., Some Observation on the Flow of Linear Polymer Solutions through Straight Tubes at Large Reynolds Number, *Proceedings of the First International Congress of Rheology*, North Holland, Amsterdam, 1949; 2: 135–141p.
2. Mysels K.J. Flow of Thickened Fluids. *VS Patent, 2,492,173*, Dec 27, 1949.
3. Myska J., Lin Z., Stepanek P., *et al.* Influence of Salts on Dynamic Properties of Drag Reducing Surfactants, *J Non-Newtonian Fluid Mech.* 2001; 97: 251–266p.
4. Yu B., Li F., Kawaguchi Y., Numerical and Experimental Investigation of Turbulent Characteristics in a Drag Reducing Flow with Surfactant Additives, *Int J Heat Fluid Flow.* 2004; 25: 961–974p.
5. Virk P.S., Merill E.W., Mickley H.S., *et al.* The Toms Phenomenon: Turbulent Pipe Flow of Dilute Polymer Solutions, *J Fluid Mech.* 1967; 30: 305–328p.
6. Lumley J.L, Drag Reduction in Turbulent Flow by Polymer additives. *J Polymer Sci Macromol.* 1973; 7: 263–290p.
7. Hinch E.J., Mechanical Models of Dilute Polymer Solutions in Strong Flows, *Phys Fluids.* 1977; 20(10): 222–230p.
8. De Gennes P.G., Towards a Scaling Theory of Drag Reduction, *Physica.* 1986; 140A: 9–25p.
9. DenToonder, Hlusen J.M.J., Kuiken M.A., *et al. Drag Reduction by Polymer Additives in a Turbulent Pipe Flow: Numerical and Laboratory Experiments. J Fluid Mech.* 1997; 337: 193–213p.
10. Serife Zeybek, Experimental Investigation of Drag Reduction Effects of Polymer Additives on Turbulent Pipe Flow, *Dept of Chemical Engineering, Middle East Technical University*, August 2005, 1–54p.
11. Lumley J.L. Drag Reduction by Additives. *Ann Rev Fluid Mech.* 1969; 1: 367p.
12. Landahal M.T. A Drag Reduction by Polymer Addition. *Proc 13th IUTAM Congr.* (ed.E.Becher & G.R.Mikhailov). Springer, 1972.
13. Hoyt J.W. Turbulent Flow of Drag Reducing Suspensions. *Naval Undersea Centre Rep.* NUC TP 299, 1972b.
14. Virk P.S., Drag Reduction Fundamentals, *AIChE J.* 1975; 21: 625–656p.
15. Myska J., Zakin J.L. Difference in the Flow Behaviors of Polymeric and Cationic Surfactant Drag-Reducing Additives, *Ind Eng Chem Res.* 1997; 36: 5483–5487p.
16. Pinho F.T., Whitelaw J.H., Flow of Non-Newtonian Fluids in a Pipe, *J Non-Newtonian Fluid Mech.* 1990; 34: 129–144p.
17. Draad A.A., Kuiken G.D.C., Nieuwstadt F.T.M. Laminar-turbulent Transition in Pipe Flow for Newtonian and Non-Newtonian Fluids. *J Fluid Mech.* 1998; 377: 267–312p.

18. Smith R., Edwards M.F. Pressure Drop and Mass Transfer in Dilute Polymer Solutions in Turbulent Drag-Reducing Pipe Flow. Schools of Chemical Engineering, University of Bradford, Bradford BD7 1DP, U.K. *Int J Heat Mass Transfer*. 1982; 25(12): 1869–1878p.
19. Nikuradse J. *Laws of Flow in Rough Pipe*, VDI Forsch-Heft 361, 1933.

