

Experimental Study of Drag Reduction by aqueous Polyacrylamide Solution

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ABSTRACT: The addition of small amounts of soluble high molecular weight polymers to wall bounded flows is known to reduce the turbulent drag. The reduction of frictional drag in turbulent flow has been an active research field in recent years. This paper researches the drag-reducing characteristics of aqueous polyacrylamide solution in a closed circulation loop. The experimental results indicate that drag-reducing effect improves with high concentration of solution at 10°C and drag-reducing effect decreases with high temperature of solution at 200wppm. This phenomenon is due to aqueous polyacrylamide solution weak ability to withstand mechanical shear and high temperature. The percentage of drag reduction of 200wppm aqueous polyacrylamide solution can be up to 65% at 10°C and 50% at 20°C. In a wide range of applications of high molecular weight polymers drag reduction is promising for reasons of economy and/or performance in the future.

Keywords: experimental study, aqueous polyacrylamide solution, drag reduction, energy-saving

NOMENCLATURE

ρ	Density[kg/m ³]		pressure holes[N/m ²]
λ	Friction factor	d	Inside diameter of the experimental pipe[m]
U	Mean velocity[m/s]	L	Length of the experimental pipe[m]
ν	Kinematic viscosity of tap water [m ² /s]	Q	Flow flux of aqueous polyacrylamide solution[m ³ /s]
L	Hagen-Poiseuille law	DR	Percentage of drag reduction
T	Prandtl-Karman law	λ_w	Friction coefficient for tap water
V	Virk's maximum drag reduction asymptote	λ_p	Friction coefficient for aqueous polyacrylamide solution
LV	Polymer laminar region		
TV	Polymer turbulent region		
Re	Reynolds number= Ud/ν		
Δp	Pressure drop for two static		

The discovery of drag reduction phenomenon in turbulent pipe flow with polymer additives was by Toms in 1948 [1].

1. INTRODUCTION

The addition of few tens of parts per million (by weight) of long-chain polymers in water flowing inside smooth pipes can produce a reduction in pressure drop up to 80% [2]. The reduction of frictional drag in turbulent flow has been an active research field in recent years [3, 4].

The additives causing drag reduction can be divided in three groups: polymers, surfactants and fibers. A detailed description of the drag reduction phenomenon is given by Gyr and Bewersdorff [5]. In this paper we will restrict ourselves to drag reduction of turbulent pipe flow by long-chain polymers.

Over the past decades numerous studies have been carried out on drag reduction by polymer additives. For a review of the early work on this subject, we refer to Lumley who outlined the different physical phenomena of drag reduction [6, 7] and to Virk who presented experimental evidence that drag reduction was limited by an asymptotic value [8]. With respect to experiments on turbulent flow with polymer additives we can mention the studies of Harder and Tiederman, Wei and Willmarth who had made observations in a channel flow [9,10]. Den Toonder et al. had carried out experiments in a pipe flow [11, 12]. All experiments mentioned above had been performed with very low polymer concentrations, leading to a small amount of drag reduction. In a wide range of applications the reduction of hydrodynamic drag is of importance for reasons of economy and/or performance. Clearly, numerous applications involving drag-reducing fluids will also be affected by the accompanying decrease in heat transfer. Interestingly, though, whereas a friction decrease is generally a beneficial

development, a reduction in heat transfer may sometimes be detrimental, especially if one aims at achieving as high a heat flux as possible for a given temperature difference. In most case, however, it is simple enough to increase the surface temperature in the heat exchange, say, to achieve again the desired heat transfer [2]. Some applications, on the contrary, would directly benefit from a reduction in heat transfer. This is the case for district cooling or heating systems.

Based on many merits of high molecular weight polymers, this paper will carry out a series of drag reduction experiments of aqueous polyacrylamide solution in a closed loop.

2. EXPERIMENTAL SET-UP AND TEST FLUID

A closed loop was used to study experimentally the drag-reducing characteristics of aqueous polyacrylamide solution. The entire experimental set-up is shown in Fig.1.

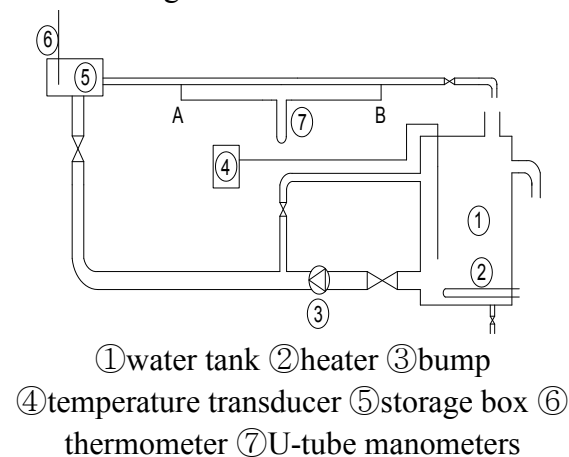


Fig.1: Experimental set-up

The main test section is a straight and smooth PVC pipe of 1.527×10^{-2} m inside diameter and 3.5 m length, both sides of which have enough steady segments. Fluid

temperature was measured at the entrance and exit of the experimental pipe. The pressure drop along the length of the pipe was measured by means of two static pressure holes for 2m spaces along the pipe and connected to a mercury U-tube manometer. Flow flux was measured by volume method. High temperature runs were carried out using two 2,000 watt heaters along with a 750 watt trimmer heater which was connected to a regular which could control temperature within $\pm 1^\circ\text{C}$ of the desired.

Polyacrylamide additive (six million molecular weight) was dissolved in tap water for 1000wppm of aqueous solution 24 hours before testing which was diluted to concentrations of 100wppm, 150wppm and 200wppm for experiments, respectively.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Before aqueous polyacrylamide solutions experiments, we researched the relation between friction factor and Reynolds number of tap water in the experimental pipe. The results show that friction factor accords with Hagen-Poiseuille law in laminar flow and Prandtl-Karman law in turbulent flow. The expressions for laminar and fully turbulent pipe flow of a Newtonian fluid are, respectively:

$$\lambda = 64/\text{Re} \quad (1)$$

$$\frac{1}{\sqrt{\lambda}} = 2.0 \lg(\text{Re} \sqrt{\lambda}) - 0.8 \quad (2)$$

At maximum drag reduction of non-shear-thinning fluids the friction law approaches an empirical asymptote, called

Virk or maximum drag reduction asymptote given by [8]:

$$\frac{1}{\sqrt{\lambda}} = 9.5 \lg(\text{Re} \sqrt{\lambda}) - 19.0 \quad (3)$$

This paper evaluates the drag-reducing characteristics of aqueous polyacrylamide solutions based on the laws above. All laws are represented by the solid lines in Fig.2.

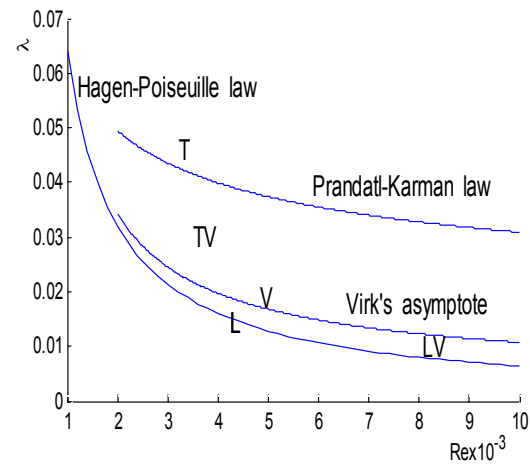


Fig.2: Typical drag reduction region

We measured pressure drop and flow flux for different concentrations of aqueous polyacrylamide solution at different temperatures. According to Reynolds formula and Darcy formula, we can obtain the relation between friction factor and Reynolds number. The corresponding expressions are:

$$\text{Re} = \frac{4Q}{\pi d \nu} \quad (4)$$

$$\lambda = \frac{\pi^2 d^5 \Delta p}{8 \rho l Q^2} \quad (5)$$

We experimented 100wppm, 150wppm and 200wppm of aqueous polyacrylamide solutions at $10 \pm 1^\circ\text{C}$, $15 \pm 1^\circ\text{C}$, $20 \pm 1^\circ\text{C}$, $25 \pm 1^\circ\text{C}$, $30 \pm 1^\circ\text{C}$, respectively.

3.1 Effect of concentration

The concentration of aqueous

polyacrylamide solution has a great impact on the drag-reducing effect. The typical experimental results as follows:

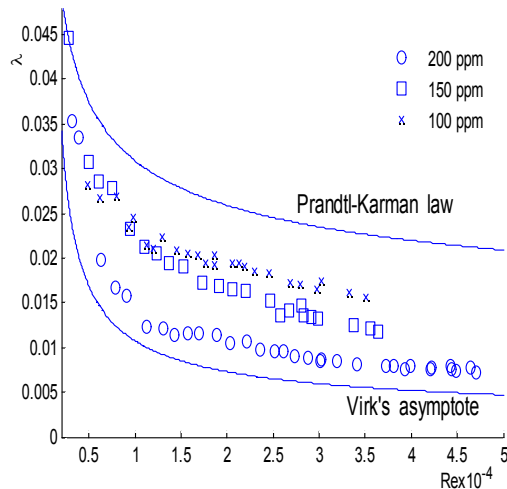


Fig.3: Friction factor vs. Reynolds number for three different concentrations at 10°C

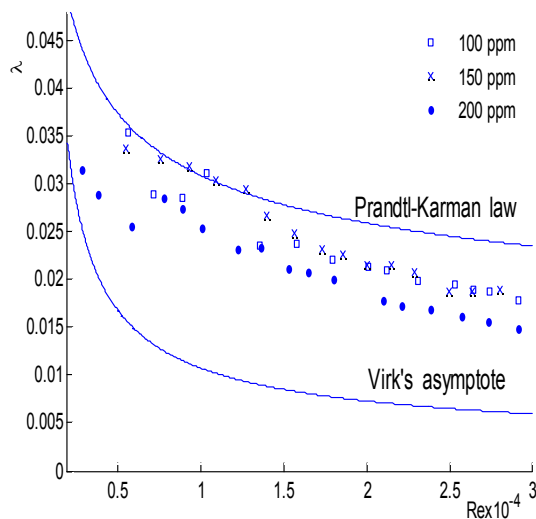


Fig.4: Friction factor vs. Reynolds number for three different concentrations at 20°C

It is clear from Figs.3 and 4 that the drag-reducing effect of aqueous solutions has a great improvement with high concentration. The drag-reducing datas of 200wppm aqueous polyacrylamide solution at 10°C are close to Virk's maximum drag

reduction asymptote.

In order to evaluate distinctly the drag-reducing effect, we define the reduction of the friction factor with respect to the Newtonian fluid at an equal mean Reynolds number as the amount percentage of drag reduction due to the addition of the polymers, i.e.:

$$DR = \frac{\lambda_w - \lambda_p}{\lambda_w} \times 100\% \quad (6)$$

So we can get that the percentage of drag reduction of 200wppm aqueous polyacrylamide solution can be up to 65% at 10°C and 50% at 20°C.

3.2 Effect of temperature

The effect of temperature on drag reduction in the pipe flow of aqueous polyacrylamide solutions has been studied. The typical experimental results as follows:

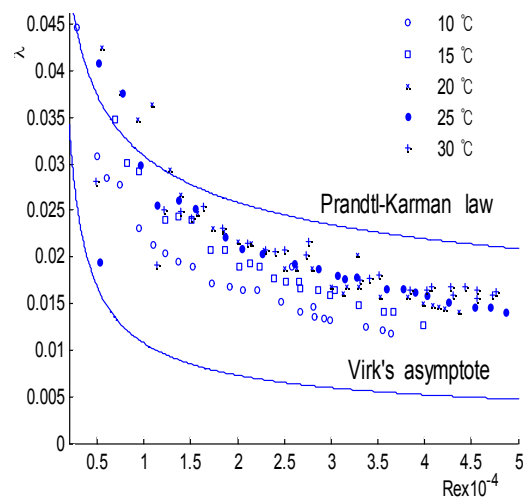


Fig.5: Friction factor vs. Reynolds number for different temperatures at 150wppm

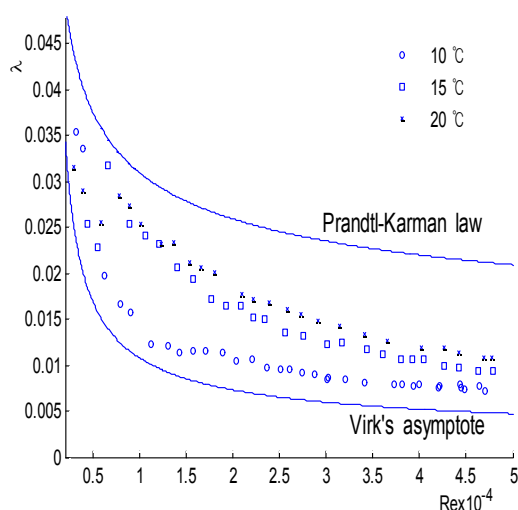


Fig.6: Friction factor vs. Reynolds number for different temperatures at 200wppm

The change of temperature has an important effect on macromolecule configuration and ability of withstanding shear. So the temperature of aqueous polyacrylamide solution has impact on drag reduce effect at a certain extent. From Figs.5 and 6, it is concluded that there are considerably greater drag reduction at the lower temperature under the same Reynolds number and concentration. This phenomenon is due to mechanical shear by pump and high temperature so as to long-chain of polyacrylamide molecules easily to break. The effect of drag reduction gradually weakens so that it is hard to form controlled and steady fluid. Choi, U.S. et al studied the long-chain degradation behavior of 200 wppm polyacrylamide solution experimentally in a closed circulation flow loop at temperatures of 7.2°C, 25°C and 87.8°C. The degradation of behavior was found to be strongly dependent on temperature. The results indicated that, the effort of degradation on pressure drop was most pronounced at 87.8°C. At this temperature, the degree of reduction decreased in one

day from approximately 56% to the asymptotic value of about 6 % with shear-degraded dilute polyacrylamide solution. However, at 7.2°C, the level of friction reduction was stabilized at more than 50% for the one-month duration of the test. This important discovery suggests that polyacrylamide is currently the promising additive for closed-loop district cooling systems [13].

4. CONCLUSION

A set of experimental tests had been presented on the drag-reducing effect in terms of friction loss. We have provided and analyzed an extensive set of experimental data for the turbulent pipe flow of aqueous polyacrylamide solutions. The following conclusions were drawn from the present study.

- (1) The drag reduction effect of aqueous solutions has a great improvement with high concentrations at 10°C. There are considerably greater drag reduction at the lower temperature under the same Reynolds number and concentration.
- (2) Aqueous polyacrylamide solutions degrade rapidly during the early stages of circulation. However, further degradation after the initial rapid degradation is very low. Finally the effect of drag reduction becomes steady.
- (3) In order to make drag reduction by polymers practical applications, we should explore much stronger ability to withstand mechanical shear and high temperature. We have obtained many characteristics of aqueous polyacrylamide solutions through large numbers of experiments so that we will experiment in practical district cooling or heating systems.

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REFERENCE

- [1] Toms, B.A. 1948. Some observations on the flow of linear polymer solutions through straight tubes at large reynolds numbers. Proceedings International congress on Rheology. Vol II. pp135-138. Amsterdam, North Holland.
- [2] Fossa, M, Tagliafico, L.A. 1995. Experimental Heat Transfer of Drag-Reducing Polymer Solutions in Enhanced Surface Heat Exchangers. Experimental Thermal and Fluid Science. Vol 10. pp221-228.
- [3] Escudier, M.P, Presti, F, Smith, S. 1999. Drag reduction in the turbulent pipe flow of polymers. J. Non-Newtonian Fluid Mech. Vol 81. pp197-213.
- [4] Ptasinski, P.K, Nieuwstadt, F.T.M, Van Den Brule, B.H.A.A, Hulsen, M.A. 2001. Experiments in Turbulent Pipe Flow with Polymer Additives at Maximum Drag Reduction, Flow. Turbulence and Combustion. Vol 66. pp159-182.
- [5] Gyr, A, Bewersdorff, H.W. 1995. Drag Reduction of Turbulent Flows by Additives. The Northlands.
- [6] Lumley, J.L. 1969. Drag Reduction by Additives. Ann. Rev. Fluid Mech. Vol 1. pp367-384.
- [7] Lumley, J.L. 1973. Drag Reduction in turbulent flow by polymer additive [J]. J.Polymer. Vol 7. pp263-290.
- [8] Virk, P.S. 1975. Drag Reduction fundamentals. AIChE J. Vol 21. No 4. pp625-656.
- [9] Harder, K.J, Tiederman, W.G. 1991. Drag Reduction and Turbulent Structure in Two-Dimensional Channel Flows. Philos. Trans. Roy. Soc. London A. Vol 336. pp19-34.
- [10] Tiederman, W.G. 1989. The Effect of Dilute Polymer Solutions on Viscous Drag and Turbulent Structure. In: Gyt, A.(Ed.), IUTAM symposium: Structure of Turbulence and Drag Reduction. pp187-200. New York.
- [11] Den Toonder, J.M.J, Hulsen, M.A, Kuiken, G.D.C, Nieuwstadt, F.T.M. 1997. Drag Reduction by Polymer Additives in a Turbulent Pipe Flow: Laboratory and numerical experiments. J.Fluid Mech. Vol 337. pp193-231.
- [12] Den Toonder, J.M.J. 1995. Drag Reduction by Polymer Additives in a Turbulent Pipe Flow: Laboratory and numerical experiments. Delft University of Technology, Delft, The Netherlands.
- [13] Sellin, R.H.J, Moses, R.T. 1989. Drag reduction in fluid flows. Ellis Horwood, Halsted Press. pp163-167