

Measurement of Drag Reduction in Polymer Added Turbulent Flow

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ABSTRAT : In this study, we used polyethylene oxides as a drag reducing additive. In order to study the effect of concentration and molecular weight of the polymer on the drag reduction, 4 molecular weights (2×10^5 , 4×10^5 , 9×10^5 , 4×10^6) and 4 concentrations (1, 5, 10, 20 wppm) of PEO were selected for the experiments. Also, the hydraulic conditions were varied from Reynolds number 30,000-60,000. The results are showed that the drag reduction effect rate was more than about 20% for all molecular weights and constructions of PEO within the range investigated in this study, and the maximum drag reduction rate was 50% for 4×10^6 of molecular weight and 20wppm of concentration. Finally, we obtained the results that the drag reduction effect tends to be higher as molecular weight and Reynolds number increase.

Keywords: Drag reduction, Degradation, Additive, PEO, Polymer

NOMENCLATURE

C : Concentration of additive(wppm)
 D : Inner diameter of pipe(mm)
 DR : Percent drag reduction(%)
 f : Friction factor
 L : Length of test section(m)
 Le : Entrance length (m)
 ΔP : Pressure loss due to friction in unit length of pipe(kPa)
 Re : Reynolds number
 U : Overall heat transfer coefficient($W/m^2 \text{ } ^\circ C$)
 v : Flow velocity(m/s)

Greek symbols

τ_w : Wall shear stress(kg/m^2)
 ρ : Density(kg/m^3)
 ϕ : Ice fraction by weigh

Subscripts

w/o : Without additive
 w : With additive

1. INTRODUCTION

The nuclear district heating as a feasible plan has been studied for a long time to pursue the various application and the effective utilization of nuclear energy. For the economical materialization of the district heating system, it should be found the method to reduce the pumping power.

There have been many researches on the drag reduction because it is very useful in many industrial fields. If effective drag reduction methods can be found, the methods will be used to reduce pumping power in the transportation of crude oil and district heating fluids and in the hydrotransport of coal. It can be also used to increase the flow rate of fire fighting water, the speed of vessels, the drain rate of sewage system, and the discharge rate in flooding situation.

Toms [1] reported that under certain conditions of turbulent flow the drag of a dilute solution of polyethyl methacrylate in monochlorobenzene was drastically reduced. This phenomenon implies that polymer solution flowing in a pipe require a lower pressure gradient to maintain the same flow rate. Virk et al. [6] showed that the friction factors of certain kinds of the polymer solution are much lower than those of the Newtonian fluids. This is due to the viscoelastic properties of the polymer solution. In the turbulent flow region, therefore, the friction factors of viscoelastic fluids are much smaller than those of Newtonian or pure viscous fluids. Kenis [5] showed that solutions were passed through a 0.117×41.0 cm fine bore tube. After one pass through the tube, greatest friction reduction at low polymer concentrations was polyethylene oxide. As a result of mechanical degradation, after 40 passes of 40 ppm solutions, polyacrylamide was more effective than polyethylene oxide. Choi et al. [11] reported that polyacrylamide was suitable for district heating system applications, because polyethylene oxide completely lost its effectiveness at temperature of $87.8^\circ C$ and the degradation rate of polyethylene oxide was much higher than that of polyacrylamide. Also Choi and Kasza [10] performed the long-term degradation behavior of 200 wppm polyacrylamide solution experimentally in a closed recirculatory flow loop at temperature $7.2^\circ C$ and $87.8^\circ C$. They concluded that the degradation behavior was found to be strongly dependent on temperature. Durst et al. [3] reported thermal degradation could be avoided with stabilizing additives, which removed free oxygen and free metal ions in the aqueous solution. Kim at al. [2] showed that ionic polymer surfactant was more effective than the nonionic polymer surfactant complex system for district heating system. It was assumed that formation of ionic polymer (PAA) – surfactant complex results from ionic binding of surfactant onto polymer

chain and on the other hand, formation of nonionic polymer (PEO) – surfactant complex results from hydrophobic bonding of surfactant molecules to polymer chain. Pollert et al [4] performed plate fin type heat exchanger experiments and measured a 50% heat transfer coefficient reduction for a cationic surfactant solution. Park et al. [7] reported turbulence characteristics of CTAC and Habon-G as surfactant solutions in channel flow. Kim et al. [14] and Yoon et al. [15] reported the drag reduction rates and degradation effects in synthetic polymer solution with surfactant additives

2. THERORICAL CONSIDERATIONS

In order to obtain fully established friction factors, it is essential to measure the pressure drop between two pressure taps in the fully developed flow region. The entrance length, Le for laminar flow of Newtonian fluids is given by Kays and Crawford[12]. The maximum value of Le would be about 100 diameters for the case of laminar flow. The hydrodynamic entrance region for turbulent flows of Newtonian fluids is fairly short, and 20 diameters are usually sufficient [12]. Yoo [8] experimentally observed that above $x/d=40$, there was no change in the pressure drop measurements for Newtonian and purely viscous non-Newtonian fluid. He also measured the pressure drop along the axial direction for concentrated viscoelastic fluids and found that above $x/d=80$, all pressure drop measurements were independent of the tap intervals and locations. Tung et al. [9] confirmed this earlier finding Yoo [8] and concluded that the hydrodynamic entrance length for 2000 wppm Separan solution is approximately 100 pipe diameters, while the hydrodynamic entrance length of Newtonian and purely viscous fluid is much smaller than 100 pipe diameter. According to Cho and Hartnett [13], for non-Newtonian fluids, the pressure drop was measured at $x/d>110$ for all concentration of aqueous polyox and

Separan solution, and no difference was observed by changing tap intervals and locations beyond $x/d=110$. For this reason, the pressure drop was measured at $x/d=115$ for all solutions in the present investigation. In the pipe flow of a Newtonian or non-Newtonian, the commonly used relationship between the pressure drop and the mean velocity is expressed in terms of the Fanning friction factor. The friction factor is essentially a dimensionless pressure gradient, and it is a function of the Reynolds number for fully development flow of Newtonian fluids. For fully developed turbulent flows, the friction factor for a viscoelastic fluid may be significantly smaller than for a Newtonian fluid. In the limiting case of Virk's maximum friction reduction asymptote, the friction factor is given as Virk et al.[6]

$$f^{-1/2} = 19.0 \log_{10}(\text{Re}_a f^{1/2}) - 32.4 \quad (1)$$

Also, the von Karman relation for Newtonian fluids is used by Choi et al.[11], ie.,

$$f_N^{-1/2} = 1.74 \ln(\text{Re} f^{1/2}) - 0.40 \quad (2)$$

for $3 \times 10^3 < \text{Re} < 3 \times 10^6$

and the Blasius equation is also used for f_N

$$f_N = 0.079 \text{Re}^{-0.25} \quad (3)$$

It is also noted that a generally and widely accepted definition of percent drag reduction is as follows :

$$DR(\%) = \left(1 - \frac{\Delta P_w}{\Delta P_{w/o}} \right) \times 100 \quad (4)$$

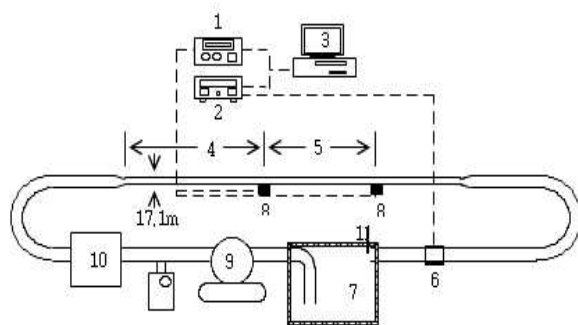
or

$$DR(\%) = \left(1 - \frac{f_w}{f_{w/o}} \right) \times 100 \quad (5)$$

3. EXPERIMENTAL

The experimental laboratory facility used in the present investigation is shown schematically in Figure 1. The pipe is made of brass with 17.1 mm in inner diameter. Water and the additives are premixed at the storage tank for the system. A screw mixer stirs water and the additives in the storage tank and a mono pump with 8m³/hr in capacity circulates the mixture, which is driven by a variable-speed electric motor.

To compensate irregularity of pumping power and to bleed any entrapped air bubbles, a surge tank is established next to the pump. There is the entrance length of 2,000 mm to ensure fully developed flow between surge tank and differential pressure transmitter. The equipment measuring the pressure at both ends of the test section of 2,000 mm in length are installed along the pipe axial direction, as shown in Figure 2, which connected to a HP 3852 data acquisition system. After passing through the test section, the flow rate is measured by a Doppler flow meter sensor. Water and the additive passing through the test section are to be returned back to the water tank in the closed loop system.



1. Differential pressure transducer
2. Doppler flow meter
3. PC
4. Entrance length
5. Test section
6. Doppler flow meter sensor
7. Water tank
8. Pressure sensor
9. Moineau pump
10. Surge tank
11. Thermo meter

Figure1: Schematic diagram of the drag reduction test loop.

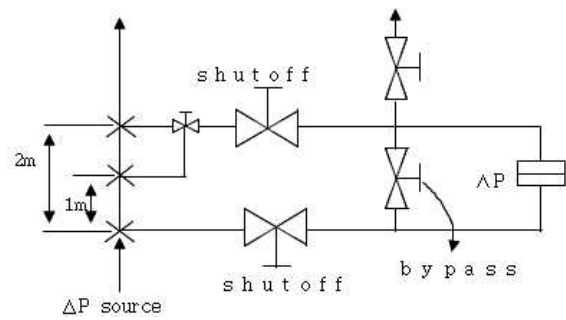


Figure 2: The circuit for differential pressure measurement.

In this study, for the application to nuclear district heating system, experiments on the drag reduction by polymer addition was performed with PEO (polyethylene oxide), which are known to be environmentally inoffensive. The experiments were performed with 4 molecular weights (2×10^5 , 4×10^5 , 9×10^5 , 4×10^6) and 4 concentrations (1, 5, 10, 20 wppm) of PEO. Also, the hydraulic conditions were varied from Reynolds number 30,000-60,000.

4. RESULTS AND DISCUSSION

Figure 3 shows the friction factor in this range, $30,000 < Re < 60,000$. If Re_d is known, friction factor is evaluated from the formula given by Haaland [10] as

$$\frac{1}{f^{1/2}} \approx -1.8 \log \left[\frac{6.9}{Re_d} + \left(\frac{\varepsilon/d}{3.7} \right)^{1.11} \right] \quad (6)$$

As shown in the figure, It is found that surface roughness is 0.00085mm in this system. So, Haaland equation in pure water system can be expressed as follows

$$f = -0.004699 \log(Re) + 0.07174 \quad (7)$$

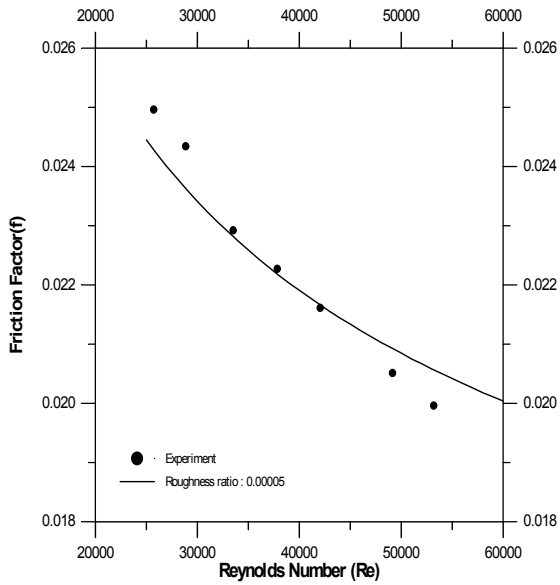


Figure 3: Friction factors for pure water.

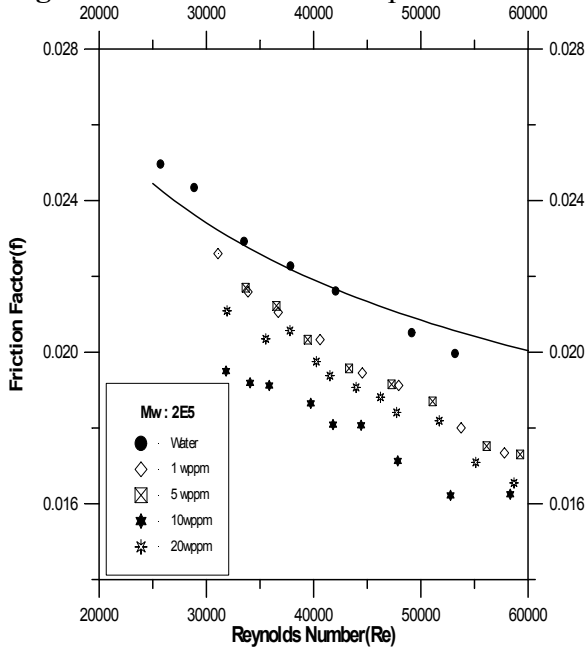


Figure 4: 4 Friction factor with PEO (Mw: 2×10^5).

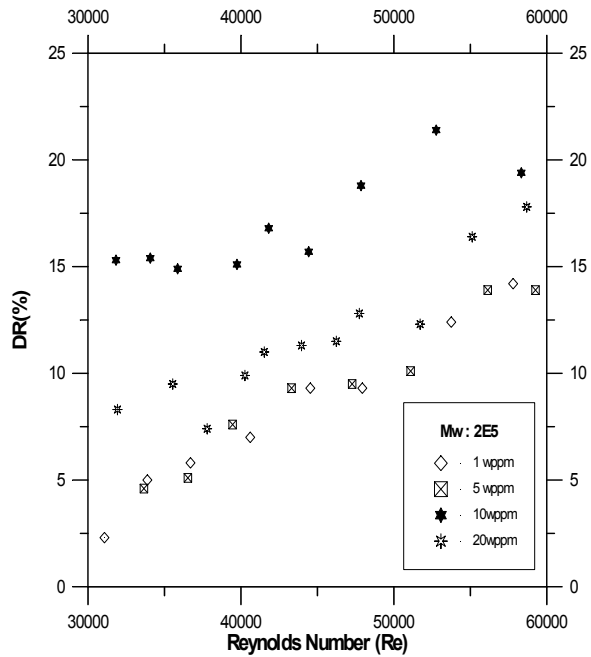


Figure 5: Drag reduction with PEO (Mw: 2×10^5).

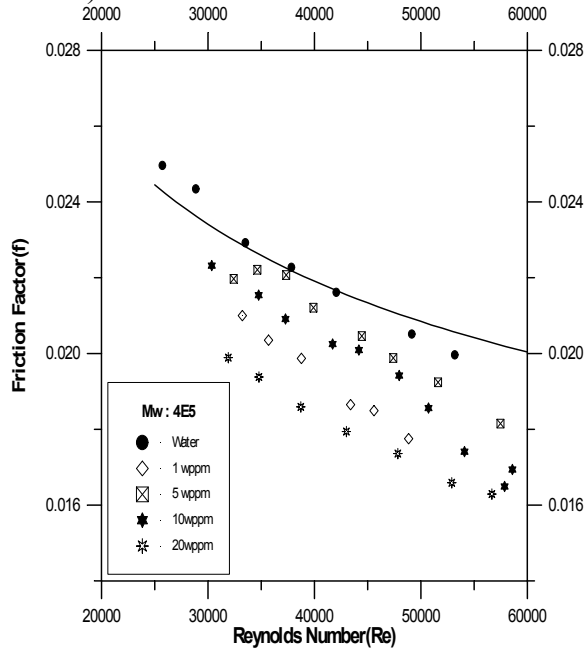


Figure 6: Friction factor with PEO (Mw: 4×10^5).

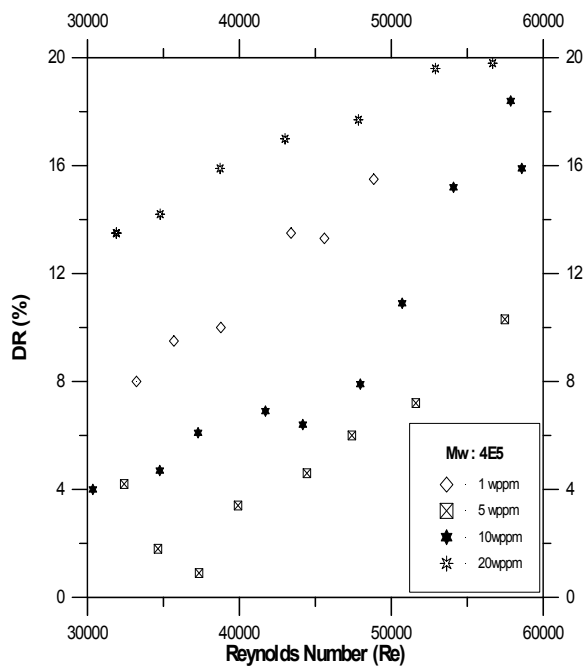


Figure 7: Drag reduction with PEO (Mw: 4×10^5).

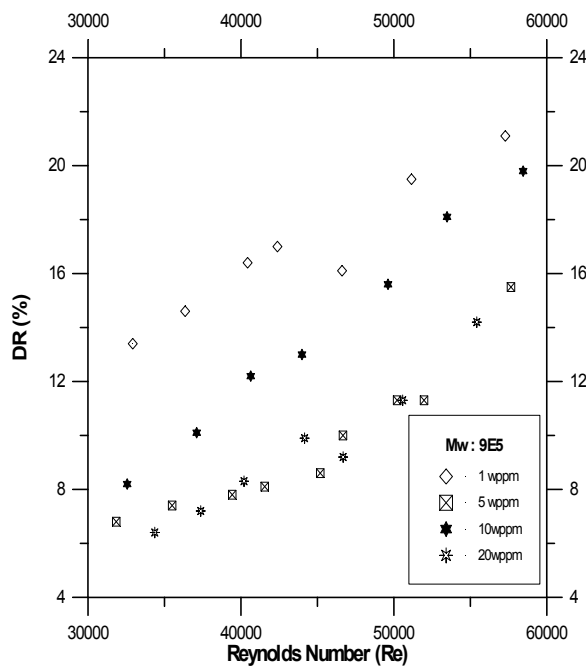


Figure 9: Drag reduction with PEO (Mw: 9×10^5).

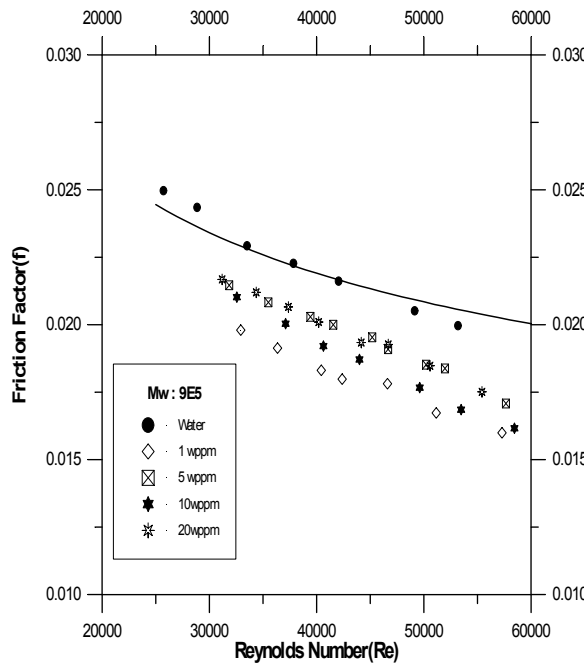


Figure 8: Friction factor with PEO (Mw: 9×10^5).

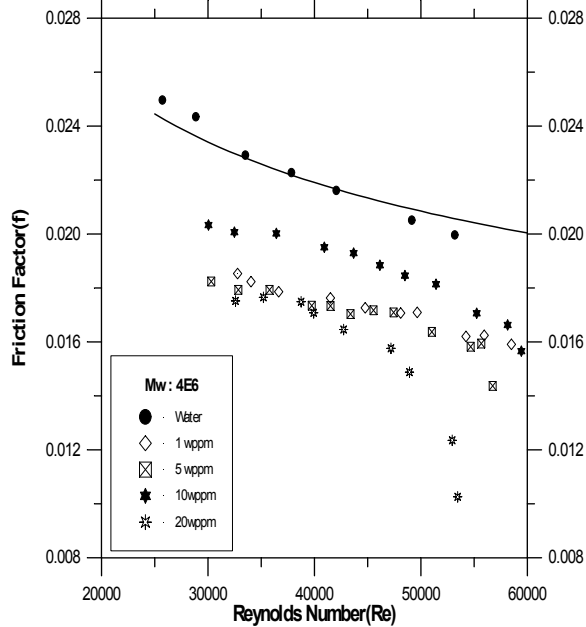


Figure 10: Friction factor with PEO (Mw: 4×10^6).

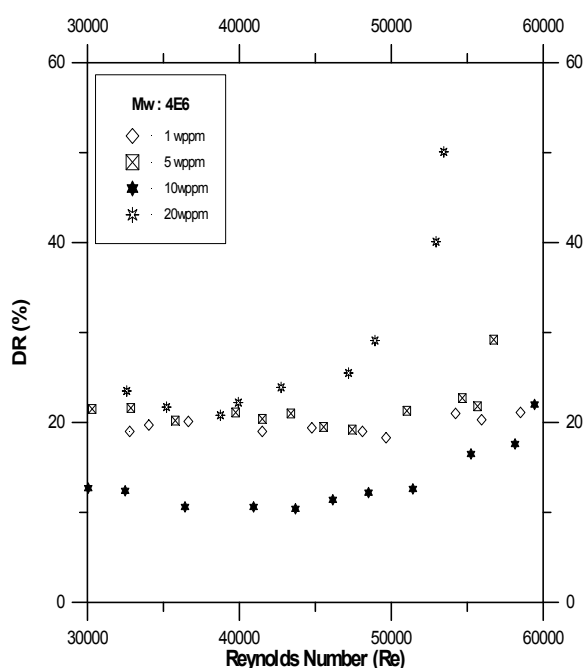


Figure 11: Drag reduction with PEO (Mw: 4×10^6).

Figures 4 – 11 show the friction factor and the drag reduction ratio on various molecular weights (2×10^5 , 4×10^5 , 9×10^5 , 4×10^6) and concentrations (1, 5, 10, 20 wppm) of PEO. As shown in the figure, the more added PEO, the more reduce the friction factor obviously. But, It is found out the concentration indicated the minimum friction factor varies with the molecular, in this investigation, the minimum friction factors of molecular weights 2×10^5 , 4×10^5 , 9×10^5 , 4×10^6 are 10, 20, 1, 20 wppm, respectively. Also, the figures show that if Reynolds number increase in this system, the drag reduction ratio is gradually increase. Especially, the drag reduction ratio is obviously increased around $Re=50,000$ at the condition of molecular weight of 4×10^6 and concentration of 20 wppm. The drag reduction effect rate is more than about 20% for all molecular weights and constructions of PEO within the range investigated in this study, and the maximum drag reduction rate is 50% for 4×10^6 of molecular weight and 20 wppm of concentration.

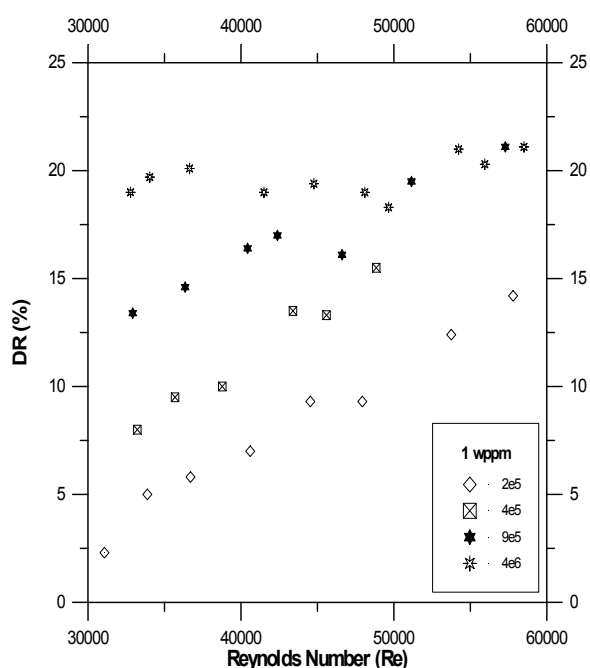


Figure 12: The effect of DR according to molecular weight (1 wppm).

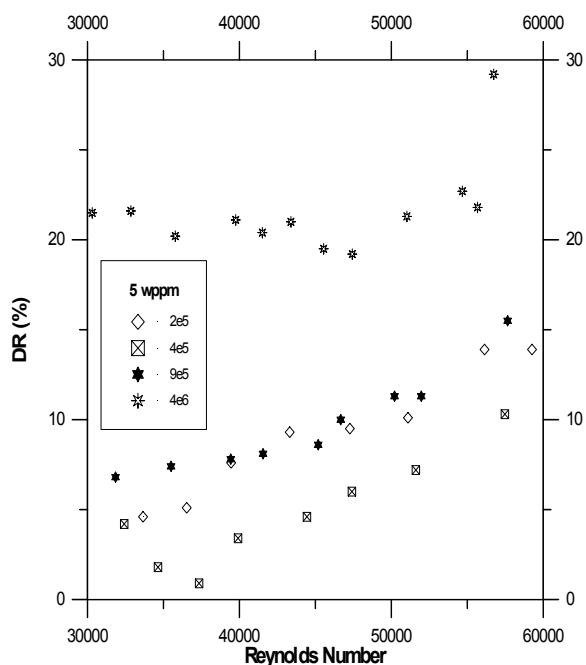


Figure 13: The effect of DR according to molecular weight (5 wppm).

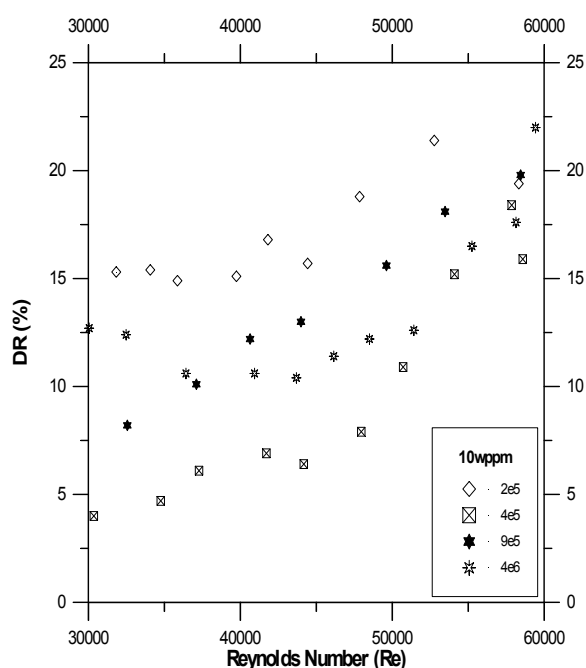


Figure 14: The effect of DR according to molecular weight (10 wppm).

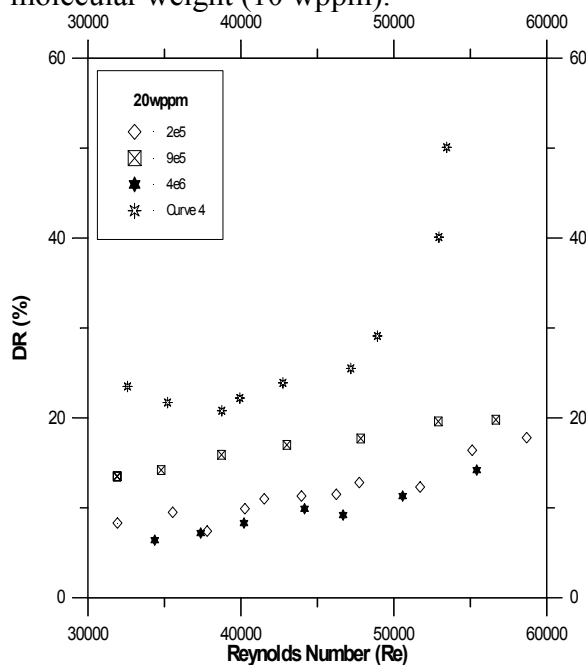


Figure 15: The effect of DR according to molecular weight (20 wppm)

Figures 12-15 show the drag reduction ratio on various molecular weights at fixed the concentration of PEO. As shown in the figures, it is found that the drag reduction ratio increase in proportion to the weigh in the molecular weight at 1 wppm, but the

molecular weight of 2×10^5 indicate the maximum drag reduction at 10 wppm

5. CONCLUSION

In order to study the effect of concentration and molecular weight of the polymer on the drag reduction, PEO was selected for the experiments. The results are showed that the drag reduction effect rate was more than about 20% for all molecular weights and constructions of PEO within the range investigated in this study, and the maximum drag reduction rate was 50% for 4E6 of molecular weight and 20wppm of concentration. Finally, we obtained the results that the drag reduction effect tends to be higher as molecular weight and Reynolds number increase.

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