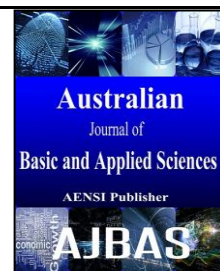




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### Polymer-Surfactant Complex for Enhancing the Mechanical and Drag Reduction Performances of a Turbulent Flow

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#### ABSTRACT

Polymer additives in drag reduction (DR) are vulnerable to the mechanical and the thermal degradation. In the present work, an interaction between nonionic polymer Hydroxypropyl cellulose and anionic surfactant sodium Oleate (HPC - S.O) complex in aqueous solution has been studied by using rheology and RDA techniques to evidence complex capability and stability in enhancing the drag reduction and mechanism degradation performance, respectively. The effect of the concentration of the polymer on the drag reduction and the effect of increasing concentration of surfactant to the polymer-surfactant complex in enhancing the drag reduction were studied. In addition, the effect of the rotational speed on the drag reduction has also been studied. A maximum of 48 % DR was observed at 500 rpm with a concentration of 1000 ppm of HPC - S.O complex.

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#### INTRODUCTION

Drag reduction (DR) has wide applications in industry such as; transportation of oil, wastewater treatment, firefighting, transport of solids in water, heating and cooling rings, hydraulic and jet machinery, and also biomedical applications Gasljevic *et al.*(2001), Harwigsson *et al.*(1996), Hellsten (2002), Zakin *et al.* (1996).

A lot of research work has been done to enhance the DR efficiency of fluids by using Polymer additives(hayder *et al.* 2005,2008,2009,2010,2011,2012,2013,2014) (PAs) after Dodge *et al.*(1959). Lumley (1996) suggested that there is a serious value of wall shear stress at which the macromolecules become stretched due to the fluctuating strain rate. Though, in the viscous sub-layer close to the wall, polymer coils are not greatly twisted and viscosity does not rise greatly above solvent viscosity. Lumley (1973) concluded that the stretching of randomly coiled polymers due to robust turbulent flow is pertinent for DR. Virk (1975) based on experimental results suggested that DR is incomplete by an asymptotic value. Warholic *et al.* (1999) lead experiments with polymer solutions and concluded that the Reynolds shear stress becomes insignificant near the maximum DR

asymptote. Polymer DR was also clarified by viscoelastic effects of the polymer chains in the solution Metzner *et al.* (1970). Tesauro *et al.* (2007) proposed that energy is transported by the velocity fluctuations to the polymer chain; which is kept in the form of stretching of the polymer chain (which in turn wastes the energy into heat), and by easing of the polymer chain from extended to an equilibrium state. But these DR additives are found to be exposed to mechanical and thermal degradation Zhang *et al.* (2005) leading to a damage in the drag reduction effectiveness at strong shear forces or a high temperature. Especially it has been well reported that polymer chains are degraded by severe mechanical force in a turbulent flow field.

Several studies Kim *et al.* (2000), Suksamranchit *et al.* (2006), Gasljevic *et al.* (2007), Suksamranchit *et al.* (2007) found that the addition of surfactant into a polymer solution could be an active technique in decreasing the mechanical degradation of polymer particularly in high temperature flow systems. The precise mechanism of DR by surfactant solutions is still indistinct; though, certain researchers have proposed that viscoelastic effects of surfactant solution could be accountable for turbulent DR Mysels (1949). Polymer and surfactants interact in two ways. First, the interaction is possible for

polymers with negative or positive charge with oppositely charged ionic surfactant. The electrostatic interactions play a deep role here. Critical aggregation concentration (CAC) has been reported to be some orders of magnitudes lower than the critical micelle concentration in this case. The interaction between non-ionic polymer and ionic surfactant or (similar charge) polymer-surfactant complex is the second conceivable interaction type, where the CAC can be near to the critical micelle concentration (CMC) of surfactant. A hydrophobic interaction between the hydrophobic portions of both polymer and surfactant is the driving force for the interaction with this type Diamant *et al.* (1999), Goddard *et al.* (1993), Hansson *et al.* (1996), Jung *et al.* (2011).

The focus of this study was to show if there any positive interaction between non-ionic polymer Hydroxypropyl cellulose and anionic surfactant Sodium oleate as well as the effect of this interaction on drag reduction and degradation. The effect of concentration of polymer, surfactant and rotational speed on the DR efficacy has been investigated in a rotating disk apparatus. In addition to this, we have been used the transmission electron microscopy to show the conformation variation of a mixture of Hydroxypropyl cellulose and surfactant.

## MATERIALS AND METHODS

### 2.1 Materials:

The Hydroxypropyl cellulose with Molecular Weight 1000000 g/ mol was purchased from Sigma Aldrich. It was used without further purification. The Sodium Oleate with Linear Formula  $(CH_3(CH_2)_7CH=CH(CH_2)_7COON)$  and Molecular Weight 304.44 g/ mol was also purchased from Sigma Aldrich and used without further purification. Double deionized water was used to prepare samples and make dilutions, accordingly.

### 2.2. Method:

#### 2.2.1 Rheology test:

Viscosity measurements were performed by Brookfield DV-III Ultra Programmable Rheometer, provided with testing container of height 12.1cm and inner diameter of 8.25cm. Rheometer was equipped with a temperature controllable water bath, while the operating conditions were kept constant at a temperature of  $25^\circ C \pm 0.05^\circ C$ . Spindle rotation speed was altered from 20 to 200 RPM, respectively.

Samples of different concentrations (50, 200, 500, 700 and 1000) ppm were prepared with polymer, surfactant, and mixtures of polymer with surfactant in 200 ml of deionized water, respectively. The samples were left overnight to get homogenized solutions. Deionized water samples were studied as a reference, to study the change in viscosity parameters. Shear rate and shear stress were

measured at (20- 40- 60- 100- 120- 180 and 200 RPM).

#### 2.2.2 Rotating disk apparatus:

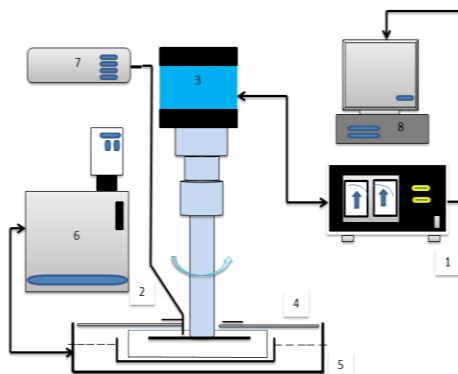
In this study, RDA was employed to simulate the *external flow*, as shown schematically in the Figure 1. It consists of stainless steel solution container dimensions (88 mm high x 165 mm diameter), which is covered with a 60 mm thick removable lid. The rotating disk is provided with dimensions of 148 mm diameter and a thickness of 3 mm. Maximum solution capacity of the cylinder is almost 1200 mL. Rotational speed of the disk is computer operative with a maximum rotational speed up to 3000 rpm. Torque value exerted by the fluid can be obtained from the computer display system. The servo motor model is Xin Jie Electronic Co. Ltd. with the servo driver DS2-20P7-AS, where the motor capacity is 0.75 kW. Samples were prepared as previously, with the same concentration parameters (50, 200, 500, 700 and 1000) ppm respectively, in the deionized water with a maximum cylinder capacity (1200 mL). Samples and the reference were examined at the rotating disk apparatus to measure torque with different rotational speed ranges from 50 to 3000 rpm. The torque results obtained were plotted against the rotational speed, to study a comparison between the samples and deionized water.

## RESULT AND DISCUSSION

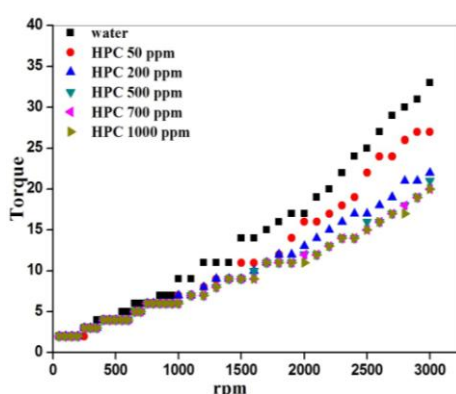
Figure 2 illustrates the effect of adding the concentration of Hydroxypropyl cellulose on the torque as a function of rotational speed compared the torque of pure water. It can be seen that the torque decrease sharply by increasing the concentration of Hydroxypropyl cellulose. The decreasing in the torque was almost one out of five at 3000 rpm and 50 ppm concentration, by raising the concentration till 200 ppm the torque decline significantly to one out of three at the same rpm. Although the concentration of polymer was increased up to 1000 ppm, but the changing in the torque was almost same after 500 ppm. Consequently, the drag reduction efficiency increased rapidly by increasing the concentration of Hydroxypropyl cellulose.

Figure.3. shows a relationship between the torque and the speed (rpm) at different concentrations of Sodium oleate. It's obvious that the decreasing in the torque of Tween 20 was almost 10 % for all concentrations of surfactant at 3000 rpm. That means the torque of Tween was not affected by increasing the concentration of surfactant from 50 to 1000 ppm.

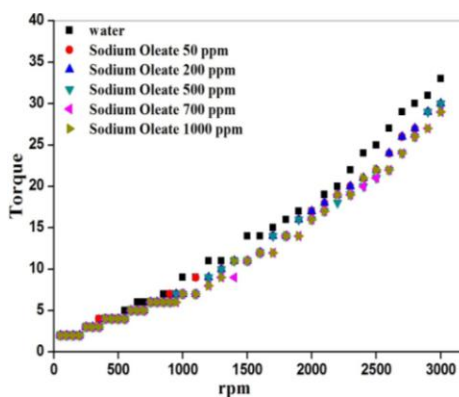
Figure 4. shows the effect of using mixture from Hydroxypropyl cellulose-Sodium oleate on the torque as a function in rotational speed. It can be seen that the effect of using same concentration of Polymer-Surfactant mixture or using a Polymer on the torque was not a big difference.



**Fig. 1:** Graphical image of a rotating disk apparatus for drag reduction measurement: (1) speed controller, (2) thermocouple, (3) motor, (4) solution container, (5) water bath, (6) water-circulating system, (7) thermometer, and (8) PC.



**Fig. 2:** Effect of concentration on torque as a function of rotational speed of Hydroxypropyl cellulose in water solution.

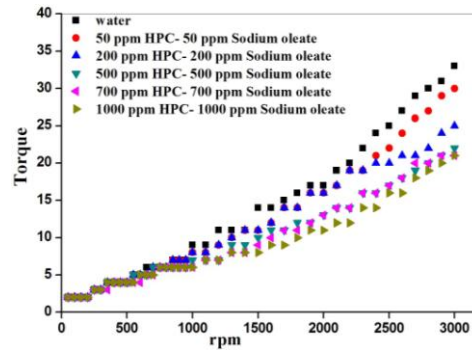


**Fig. 3:** Effect of concentration on torque as a function of rotational speed of Sodium oleate in water solution.

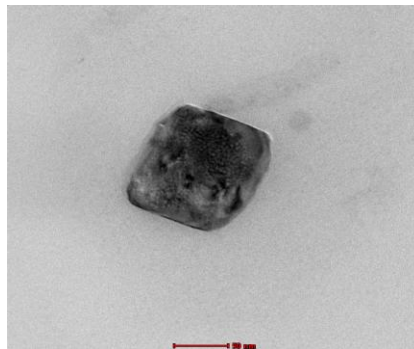
Figure 6 explains the % DR as a function of rotational speed for different concentrations of Hydroxypropyl cellulose. The % DR was observed to be increased rapidly with increasing concentration of Hydroxypropyl cellulose from 50 to 1000 ppm. The percentage of drag reduction was 22 % at 50 ppm and 1700 rpm, while by increasing the concentration to 1000 ppm the % DR has risen rapidly to almost 40% of the same rpm values.

The relationship between rotational speed and % DR of Sodium oleate at different concentration

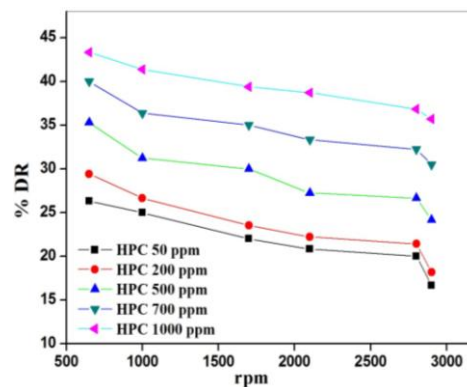
explains at Figure 7. It obvious that the drag reduction has been decreased rapidly by increasing the rotational speed. The percentage of drag reduction of Sodium oleate was almost 23 % at 500 ppm and 1200 rpm, while it decreased rapidly to just over 6 % at same concentration and rpm. In contrast, the drag reduction has been increased by increasing the concentration of the surfactant. But this increasing in drag reduction was a little compared using HPC.



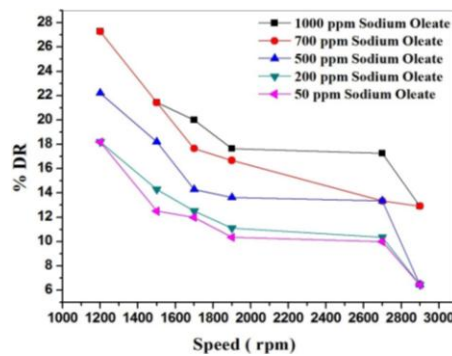
**Fig. 4:** Effect of concentration on the torque as a function of rotational speed of Hydroxypropyl cellulose-Sodium oleate mixture in water solution.



**Fig. 5:** TEM image of Hydroxypropyl cellulose-Sodium oleate mixture at 500 ppm.



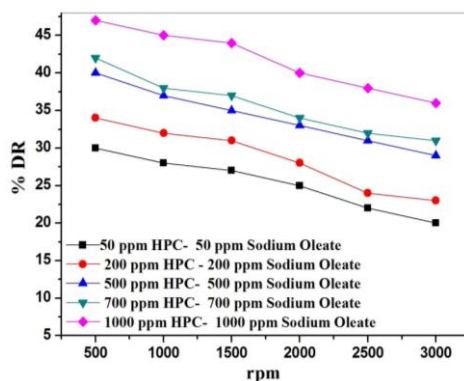
**Fig. 6:** Effect of drag reduction (%DR) as a function of rotational speed at different concentration of Hydroxypropyl cellulose.



**Fig. 7:** Effect of drag reduction (%DR) as a function of rotational speed at different concentrations of Sodium Oleate.

Figure 8. illustrates the effect of using equal concentrations of polymer-surfactant mixtures on the drag reduction efficiency as a function on rotational speed. It can be seen that the % DR of mixtures polymer-surfactant has been increased compared the % DR of HPC or % DR of Sodium oleate. The

percentage of drag reduction of HPC and Sodium oleate at 500 ppm and 1500 rpm was just over 30 % and almost 19 % respectively, while the percentage of mixture HPC-Sodium oleate has been increased to over 36 %.



**Fig. 8:** Effect of drag reduction (%DR) as a function of rotational speed at different concentration of Hydroxypropyl cellulose and Tween 20 mixtures.

#### 4. Conclusion:

In conclusion, the effect of surfactant, rotating speed and concentration on the drag reduction efficiency of non-ionic polymer Hydroxypropyl cellulose-Sodium oleate mixture have been investigated by using a rotating disk apparatus. The DR efficacy induced by the cellulose-Sodium oleate mixture is found to be obvious higher than that of pure Hydroxypropyl cellulose. The percentage of drag reduction was 32 % for Hydroxypropyl at 500 ppm and 1000 rpm, while the percentage has been risen by adding 500 ppm of surfactant to the polymer to almost 39 %.

#### ACKNOWLEDGEMENT

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