

The Effect of HTAC Addition on the Efficiency of PEO in Turbulent Flow

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Abstract

Objectives: Polyethylene Oxide (PEO) is one of the most effective drag reduction additives. However, it limits and degrades under high share stress. The improvement of its Drag Reduction (DR) efficiency and degradation resistant with the addition of cationic surfactant was investigated. **Methods/Statistical Analysis:** PEO at concentrations of 10 and 20 ppm were mixed with a different concentration of Hexadecyltrimethylammonium Chloride (HTAC). Capillary viscometer and Rotating Disk Apparatus (RDA) were used to measure the viscosity and the %DR, respectively. **Findings:** The results showed an improvement in both the DR ability and degradation resistance when the complex polymer-surfactant was used, compared to the pure polymer. The maximum DR was recorded as 36% at 10ppm and 42% at 20ppm PEO and 125ppm HTAC. This improvement was due to the interaction between the micelles and the polymer. **Application/Improvements:** This improvement will promote the use of PEO/HTAC mixture in higher share stress flow application.

Keywords: Drag Reduction, Degradation, Polymer-Surfactant, Rotating Disk Apparatus

1. Introduction

Polymers have been extensively utilized in many areas of human activities such as the food industry, biomedical, as well as in the regulation and control of fluid flow^{1,2}. It is a known fact that the addition of a very small amount of polymer into an aqueous system (channel, pipe, and rotating disk) at turbulent flow state may cause a severe reduction in the fractional wall due to suppression of the formation of eddies. Effective polymeric Drag Reduction (DR) additives are usually considered to be of high molecular weight, flexible and linear. Common examples of such additives include poly ethylene oxide³, polyacrylamides⁴ as well as poly isobutylene⁵. Among these materials, the most effective polymer used as a drag-reducing agent is Poly Ethylene Oxide (PEO) which is widely used in aqueous systems such as pipe, channel and rotating disk apparatus at turbulent flows⁶.

Although the PEO is demonstrating a desirably high DR efficiency, the efficiency of PEO solutions still remains

limited with time, showing a decrease in drag - reduction under shear stress (mechanical degradation). Therefore, to enhance the stability of the macromolecule PEO polymer chain under extreme turbulent flow from mechanical degradation, some studies suggested the adoption of strategies to enhance the effectiveness of PEO molecules under mechanical degradation. One of these methods is the combination of PEO chains with different additives such as microbubble⁷, nanotube carbon⁸, and polymer-polymer complex⁹. Recently, several studies have focused on the combination of polymer and surfactant which was an attractive approach due to the support of the surfactant micelles during the interaction with polymer chain in flow systems¹⁰.

A Recent study reported by¹¹, narrated the use of different aggregation from additives such as cationic surfactants and polymers, and the results supported the notion that surfactants might alter the configuration of polymers and additives alternating from a coiled configuration to a stretched configuration. Drag reduction efficiency was reportedly enhanced when a study

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which involved the use of a combination of PEO and a cetyltrimethylammonium bromide CTAB/NaSal, cationic surfactant¹². These were evidences of a transition of the configuration of the flow from a laminar flow to a turbulent. Irrespective of these enhancements through the addition of surfactants to polymeric solutions, available literature has not actually provided enough evidence on this field of drag study, as evidenced by lack of sufficient reports on the subject area.

The characteristic of non-ionic polymers with high molecular weight PEO with or without the cationic micelles HTAC in a rotating disk apparatus was investigated. Additionally, drag reduction efficiency which was prompted by other factors as shear viscosity, and concentration was also investigated. Finally, the behaviour and effect of different ratios of additive concentrations (PEO and HTAC) on the delay and protection of molecular polymer chains from mechanical degradation were experimentally investigated.

2. Materials and Methods

2.1 Materials

The non-ionic high molecular weight polymer referred to as Polyethylene oxide powder PEO 8×10^6 g/mol in this study was supplied by Shanghai Company, China. The cationic surfactant hexadecyltrimethylammonium Chloride (HTAC) in crystalline powder with a molecular weight of 319.52 g/mol was supplied by Shanghai Company, China as well. The counter-ions used in this study (sodium salicylate (NaSal) salt) for the stability of the monomers and micelles were 99.5% pure and supplied by Shanghai Company, China. Filtered water was used as the solvent during the study.

2.2 Methods

A Cannon-Fenske viscometer tube (size 50) was used for measuring the viscosity at low shear rate. Rotating disc methods are simpler alternatives for testing the efficiency of drag reduction and mechanical stability of the investigated liquids by applying shearing force and measuring the torque. The drag reduction percentage (% DR) was estimated using Equation (1).

$$\%DR = \left(\frac{T_d - T_s}{T_d} \right) * 100 \quad (1)$$

Where T_d =torque in the distilled water and T_s = torque in the dilute solution. In RDA system, the flow reaches to

turbulent state when the Reynold numbers (N_{Re}) exceeded the $3 * 10^5$ ($\omega > 640$ rpm). Here, N_{Re} was determined by using Equation (2).

$$N_{Re} = \frac{\rho r^2 \omega}{\mu} \quad (2)$$

Where ω = disk rotational speed ($(2 * \pi * rpm)/60$), r = radius of the disk, μ = fluid viscosity, and ρ = fluid density.

3. Results and Discussion

3.1 Viscosity

The shear viscosity of the polymer-surfactant mixed system as a function of HTAC concentration is depicted in Figure 1. The viscosity of the system with PEO at a concentration of 10 ppm decreased initially after the addition of a little amount of HTAC/NaSal to a concentration of 85 ppm. This reduction was due to the negative effects of the weak interaction between the surfactant micelles and the polymer chain. This can be explained as a result of partial electrostatic repulsion between the micelles itself. However, at concentrations higher than 85 ppm of HTAC, the viscosity was observed to rapidly increase. This increase resulted in the expansion of the polymer structure which dramatically increased the viscosity of the system with a concomitant increase in the concentration of the surfactant Figure 1. Though there is further addition of surfactant micelles, the viscosity of the system was relatively constant with just a slight increase beyond a surfactant concentration of 300 ppm. At this point, the polymer has reached the saturation point and the micelles were free in the solution. Similar behaviour was observed at PEO concentration of 20 ppm. However, at 20 ppm of

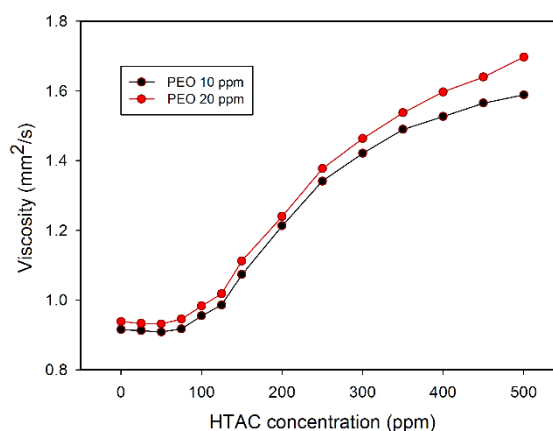


Figure 1. Viscosity for different PEO/HTAC combinations vs. HTAC concentration.

PEO the effect of the interaction on the viscosity value was observed to occur earlier than that of 10 ppm PEO. This can be explained as the change in the total number of polymers has increased the ability of polymer to attract the surfactant event at lower concentration of HTAC.

3.2 Drag Reduction

In general, increasing the amount of HTAC at any given PEO concentration can lead to an increase in the efficiency of the DR rate. Figure 2 shows the percentage DR against the Re for a PEO/HTAC mixture which contained 10 ppm of PEO and different levels (concentrations) of HTAC. During the addition of, 50 and 75 ppm of HTAC to PEO solution, the percentage DR of the complex polymer-surfactant was 23%, and 24%, respectively which was close to the percentage DR of pure polymer (22 %) at the same Re value of 1×10^6 . This indicates that there was no interaction between the polymer and the surfactant and that the little change in the percentage of DR resulted from the individual effects of the polymer and the surfactant. When the HTAC concentration was increased from 100 to 125 ppm, an increase in the percentage of the DR from 31% and 36% respectively was noted due to the increase in the viscosity of the system that leads to an increase in the length of the molecule chains (hydrodynamic radius) and generation of a new conformation structure of the polymer/surfactant mixtures, thereby resulting in the enhancement of the polymer drag reduction efficiency.

Figure 3 depicts the relationship of percentage DR with respect to Re for a newly prepared complex of HTAC-PEO solution at 20 ppm of PEO with four different HTAC concentrations. Drag reduction behaviour showed no change for a solution containing 50 and 75 ppm HTAC with 20 PPM of PEO concentrations, which was similar to the trend

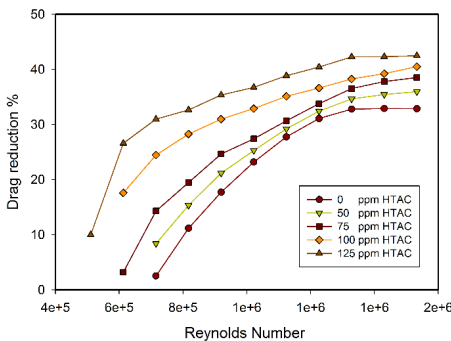


Figure 2. Effect of HTAC/NaSal concentration vs. Reynolds number on %DR for PEO/HTAC mixtures for 10 ppm of PEO solution.

obtained in 10 ppm PEO with HTAC at mixture 50 and 75 ppm except that at HTAC in 20 ppm, little change was observed in the results but not quite a significant one. For the 20 ppm PEO system, the drag reduction percentage significantly increased at HTAC concentration of 100 ppm.

After an HTAC concentration of 100 ppm, further increase to 125 ppm produced just little change in the percentage DR which equal to 42%. As the surfactant molecules tend to saturate the polymer molecules, which was mainly caused by the increase in the viscosity and the change of the structural conformation of the polymer and surfactant, an increase in the DR values was observed.

3.3 Degradation

The mechanical disintegration of polymer molecules could have a pronounced counteractive effect on the ability of the polymer to reduce drag. The process proceeded as a function of the operating time (10 min) and a rotational speed of 1800 rpm at 25°C. In general, the increase in the percentage DR was significantly affected by the increase in the concentration of HTAC. Figure 4

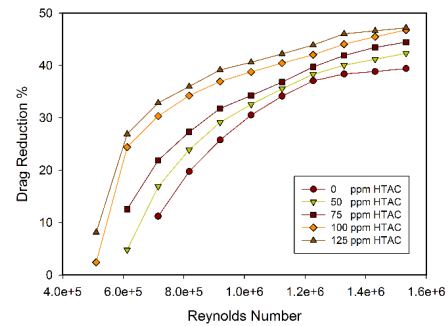


Figure 3. Effect of HTAC concentration vs. Reynolds number on %DR for PEO/HTAC mixtures for 20 ppm of PEO solution.

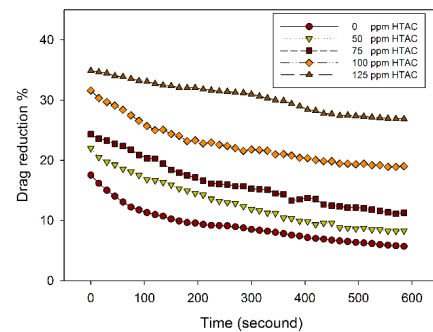


Figure 4. Effect of HTAC concentration vs. Time number on %DR for pure PEO and PEO/HTAC mixtures for 10 ppm of PEO solution.

shows the effect of the addition of HTAC/NaSal on the mechanical degradation of 10 ppm of PEO at different concentrations of HTAC.

In the case of pure PEO 10 ppm solution, the initial drag reduction was 17%, but for PEO/HTAC complex, the DR percentage was (23%, 24%, 30% and 35%) for (50, 75, 100 and 125 ppm HTAC) efficiency, respectively. Figure 4 also showed that the drag efficiency decreased (8%, 12% 19% and 29 % respectively) after 10 min, showing a significant decrease for the surfactant with concentration of 50 and 75 ppm when compared to that of a higher concentration of HTAC over the same period of time. In the case of higher concentrations, the viscosity was higher and results in better resistance to degradation. This was due to the number of HTAC micelles which were incorporated to the skeleton of polymer chains that increased their resistance towards degradation. This means that the new structure can stabilize the polymer and delay the degradation of PEO. But for the fact that molecules in the coiled configuration are more prone to degradation than those that are flexible it could be reasonable to suggest that flexible polymers are less degradable in the presence of other materials.

Figure 5 shows the influence of the addition of surfactants on mechanical degradation (DR) for varying concentrations of 20 ppm PEO in conjunction with different concentrations of HTAC. In general, the addition of HTAC improved the resistance against mechanical degradation. In the case of 50 ppm HTAC solution, the drag reduction decreased from 28% to 17% which was observed after 10 min. For the 100 ppm HTAC, a decrease of approximately 27% was observed after 10 min which was a great improvement on the resistibility of the system to degradation, when compare to that of pure 20 ppm PEO

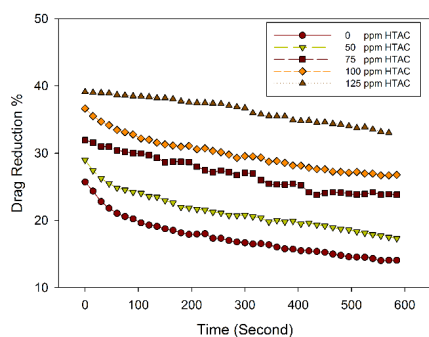


Figure 5. Effect of HTAC concentration vs. Time number on %DR for pure PEO and PEO/HTAC mixtures for 20 ppm of PEO solution.

which showed approximately 38% reduction in DR ability in the early stages of degradation (after 10 min.). For the 125 ppm HTAC, the DR ability was decreased by approximately 20% after 10 min. The number of micelles in the solution also increased with a further addition of HTAC. As HTAC/NaSal can improve the properties of PEO solution (such as hydrodynamic radius) against mechanical degradation compared to that of the pure PEO solution, the PEO complex could be considered a better energy and environmentally sustainable approach for drag reduction.

4. Conclusion

In this work, the investigation of the drag reduction efficacy and degradation stability of PEO with or without cationic micelles HTAC in the rotating disk apparatus was investigated. The rheological results demonstrated increases in the viscosity of all the complexes which indicated that interaction had taken place between the surfactant micelles and polymer chain. As HTAC/NaSal can improve the properties of PEO solution (such as hydrodynamic radius) for enhanced resistance against mechanical degradation compared to that of the pure PEO solution, the PEO complex can be considered a better energy and environmentally sustainable approach for drag reduction. The addition of cationic surfactant HTAC into the aqueous solution of non-ionic polymer PEO to enhance the drag reduction efficiency was achieved through the improvement of the polymer chain stability resistance against shear degradation. Although the surfactant-polymer complex reduced the drag percentage, the increase in the concentration of the surfactants in the polymer solution led to an increase in the viscosity of the system, which results in a negligible effect on the drag reduction efficacy.

5. Acknowledgement

This work was supported by University of Malaysia Pahang (UMP) and The Ministry of Higher Education and Scientific Research Iraq through the provision of study grant and scholarship, respectively.

6. References

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