

New Complex for Enhancing Drag Reduction Efficiency

Emsalem Faraj Hawege and Hayder A. Bari

Abstract—Polymers have long been recognized as an effective drag reduction agent for strategic pipeline system. Unfortunately, such efficiency ends when the polymer molecule degrades in the pipeline especially when it flows through the pump. The aim of this work is to enhance the polymer's efficiency through addition of a surfactant. In particular, the present work investigated the drag reduction performance as well as degradation characteristics of anionic polymer polyacrylic acid (PAA) in the presence of a non-ionic surfactant (Tween 20). Rotating disk apparatus (RDA) and closed-loop liquid circulation (pipeline) techniques were employed in the study, and various surfactant effects, PAA concentrations and rotating speeds were tested. The results showed that the PAA drag reduction efficiency increased in the presence of Tween 20. Almost 37% drag reduction (%DR) was observed at 1200 rpm. Additionally, the influence of surfactant on enhancing the drag reduction performance of PAA was evident when the investigation was carried out in the closed-loop liquid circulation system.

Index Terms—Polyacrylic acid (PAA), tween 20, Drag reduction, RDA.

I. INTRODUCTION

Drag reduction is widely used in many industrial applications such as waste water treatment, transportation of oils, firefighting, heating and cooling rings, water transportation, biomedical and in the area of hydraulic and jet machinery [1]-[4].

Many research investigations have been carried out on the concept of skin friction of fluids and associated drag reduction techniques using polymeric additives. Dodge and Metzner [5], [6] as well as Lumley [7] highlighted the importance of wall shear stress where the polymer macromolecule stretched as a result of fluctuating strain rate. However, they also reported that these stretches did not occur in the viscous sub-layer close to the wall.

According to Lumley [7], the stretch of randomly coiled polymers in turbulent flow mode plays a huge contribution to drag reduction. Tiederman [8] and Virk [9] further reported from their experimental investigations that drag reduction (DR) is restricted at a certain asymptote value.

In another study on maximum DR asymptote, Warholic *et al.*, [10] reported that the Reynolds shear stress tends to be insignificant near the maximum DR asymptote. Thus, the

drag reduction by polymers is best explained through the viscoelastic impact of the polymer chains in the solution [11], [12].

Tesauro *et al.*, [13] suggested there is a translation of energy from the velocity fluctuations to the polymer chain. The energy is maintained when the polymer chain is in its stretched position, and when it eases back from such extended state to its equilibrium state. The disadvantage of polymeric additives, however, is that they “degrade” mechanically and thermally when exposed to shear stresses in the turbulent liquid flow [14]. When this occurs, their drag reduction efficiency significantly declined.

Some studies [15]-[18] found that the addition of surfactant into a polymer solution could be an effective technique to decrease the mechanical degradation of polymer especially in high temperature flow systems. The precise mechanism of DR by surfactant solutions is still uncertain, although certain researchers have pointed out that their viscoelastic effects could also influence turbulent DR [19].

Polymer and surfactants interact in two ways. First, the interaction is possible via negative- or positive-charged polymers with oppositely charged ionic surfactant. The electrostatic interactions play a major role in such interaction. Critical aggregation concentration (CAC) has been reported to be of lower orders of magnitudes than the critical micelle concentration (CMC) in this case. The second interaction is that between non-ionic polymer and ionic surfactant or similar-charged polymer-surfactant complex. The CAC could be near the surfactant CMC. A hydrophobic interaction between the hydrophobic portions of both polymer and surfactant could be the driving force for this type of interaction [20]-[23].

The interaction between similar-charged ionic polymer and ionic surfactant complex (similar charge) has been studied by Kim *et al.*, [23]. They found that the % DR increased after a little amount of surfactant was added to the polymer solution. The increase in the % DR which occurred was suggested to have been caused by the hydrophobic interaction between the polymer and surfactant.

In this work, the interaction and rheological properties of polymer (PAA)-nonionic surfactant (Tween 20) complex was studied using RDA and closed-loop liquid circulation techniques. The influence of different concentrations of polymer and surfactant, and effects of different rotational speeds on DR efficiency were investigated in a rotating disk apparatus. The conformation variation of PAA-Tween 20 complex was determined using transmission electron microscopy (TEM). Finally, the effect of polymer degradation on pressure drop as a function of time was investigated in a closed-loop liquid circulation (to simulate a pipeline) system.

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II. MATERIALS AND METHODS

A. Materials

Polyacrylic acid and Tween 20 with molecular weight 1,250,000 g/mol and 1228 g/mol, respectively. Both additives were purchased from Sigma Aldrich and used without further purification.

B. Method

1) Rheology test

The rheology test for this experimental work was carried out using Brookfield DV-III Ultra Programmable Rheometer. After samples preparation, the first step undertaken was to verify their viscosity and this was done using Brookfield viscometer of about 12.1cm high and 8.25 circumference testing container. It has a temperature controlled water bath at a varying temperature of about $25^{\circ}\text{C} \pm 0.05^{\circ}\text{C}$.

The samples were investigated at various rotations per minutes (rpms) where the spindle was operated between 20 to 200 rpm. The coaxial cylinder rotational viscometer could operate at different shear stresses depending on the cylindrical spindle. The sample was poured at the annular space in between the spindle and the tube. The required rpm was altered from 20-200 rpms. The values of the shear rates and shear stresses were recorded accordingly. Same procedure was applied to all remaining concentrations.

In summary, the viscosity of each sample was determined before subsequent tests were carried out using the rotational disk apparatus (RDA). Any sample which concentration did not meet the required viscosity was discarded.

2) Rotating disk apparatus

The rotational disk apparatus is capable to perform rheology tests on samples of various physical properties (either solvent alone or mixed with the DRAs). In this case, the DRAs to be used have not been tested before. In addition, the RDA is also used to investigate the influence of torque on the samples at various rotational speeds.

The RDA equipment is made up of a 88mm high and 165mm wide stainless steel container with a removable lid of about 60mm thickness. The rotating disk has about 148 mm circumference and 3 mm thickness. The cylinder has a storage capacity of about 1.2 L of liquid sample. The disk rotational speed is computer controlled at a maximum rotational speed up to 3000 rpm and the torque value/s could be read on a computer display system. The computer display system is manufactured by Xin Jie Electronic Co. Ltd with other features such as servo motor model of DS2-20P7-AS servo driver and capacity of 0.75 kW.

The major application of the RDA was to verify the mechanical resistance of the samples before they were tested in the pipeline (closed-loop liquid circulation). It was also used to identify the samples which produced the desired viscosity. In this case, the rheology was tested for same materials of different quantities, volumes and concentrations. Same method was used for sample preparations, in 1.2 L of water. The test was carried out using water as a control, followed by the various DRA additives. Pure deionized water and the DRA additives were investigated using the RDA to determine the torque at different rpms (usually 50-3000

rpms).

Graphical representation of the RDA is illustrated in Fig. 1 below:

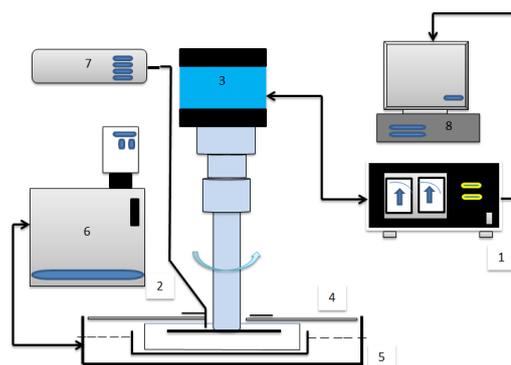


Fig. 1. Graphical image of a rotating disk apparatus for drag reduction measurement: 1) speed controller, 2) thermocouple, 3) motor, 4) solution container, 5) water bath, 6) water-circulating system, 7) thermometer, and 8) PC.

3) Closed-loop liquid circulation system (pipeline)

A closed-loop liquid circulation system was employed to observe the pressure drop versus time. Same method was used for sample preparations, in 1.2 L of water. The samples and the reference were examined in the closed-loop liquid circulation system to observe and compare the pressure drop versus time for both water and samples.

III. RESULT AND DISCUSSION

A. Rotating Disk Apparatus

Fig. 2. illustrates the effect of rotational speed on the torque of different concentrations of PAA in comparison with the torque of pure water (as reference). It could be seen that the torque decreased slightly with increasing PAA concentration compared to the torque of pure water. The torque of pure water at 2700 rpm was 29 N.M, while the torque of PAA at 50 and 1000 ppm was 26 N.M at the same rpm. This indicates that increasing the PAA concentration does not affect its drag reduction efficiency.

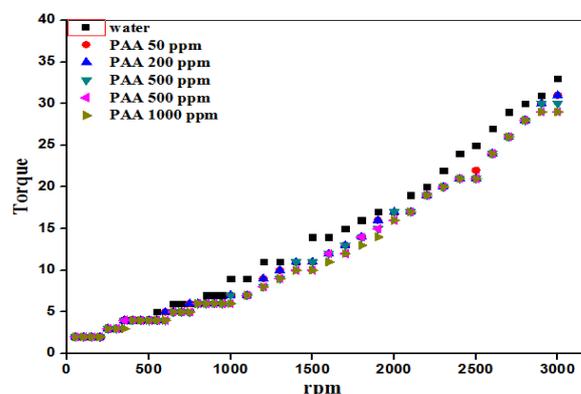


Fig. 2. Effect of rotational speed on the torque of different concentrations of PAA in water.

Fig. 3. shows the relationship between the torque and the rotational speed for different concentrations of Tween 20. It is obvious that the torque decreased a little when the

concentration of Tween 20 was increased.

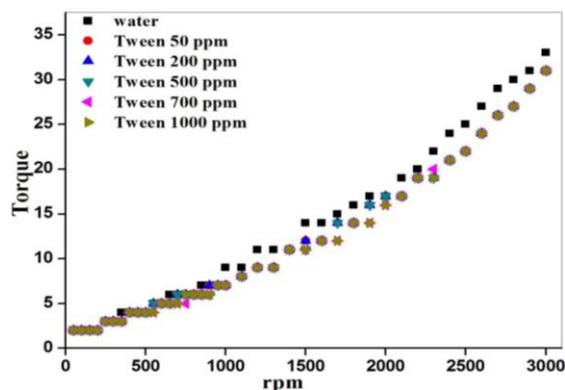


Fig. 3. The relationship between the torque and the rotational speed of different concentrations of Tween 20.

Despite the increase in either PAA or Tween 20 concentration, the torque showed very little change. However, increasing the concentration of the PAA-Tween 20 mixture showed a significant change in torque. Fig. 4 explains the function between rotational speed and torque of different concentrations of PAA-Tween 20 mixtures. At 2700 rpm, the torque of water (reference) was 29 N.M. At the same rpm, the torque of 50 and 1000 ppm of PAA-Tween 20 mixtures was 26 and 22 respectively. It was suggested that such decrease in torque occurred following the hydrophobic interaction between PAA-Tween 20 complexes [24].

On the other hand, the drag reduction of the PAA-Tween 20 mixture increased when the surfactant concentration was increased to 1000 ppm. As observed, the interaction between PAA and Tween 20 was very strong at 1000 ppm [22], [24].

We can see this interaction through the TEM image shown in Fig. 5.

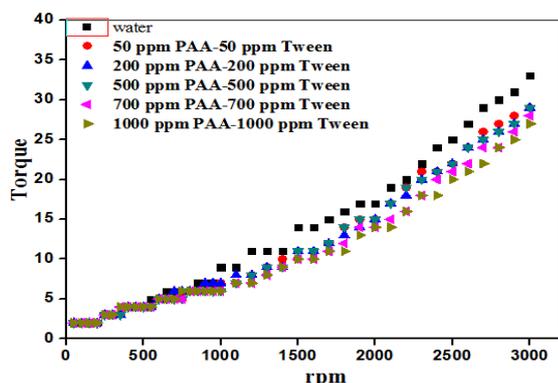


Fig. 4. The function between the rotational speed and the torque of PAA-Tween 20 mixtures, in different concentrations, in water.

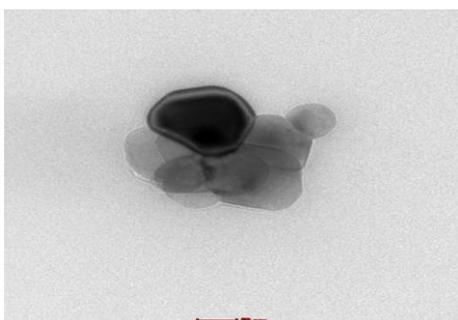


Fig. 5. TEM image of PAA -Tween mixture.

B. Closed Loop Liquid Circulation (Pipeline)

Fig. 6 illustrates the comparison between pressure drop (ΔP) values of reference (water) and different concentrations of PAA-Tween 20 mixtures as a function of time. It could be seen that the ΔP decreased when the concentration of the mixtures increased. The ΔP of reference was around 101 Pascal (Pa), while ΔP of 50 ppm PAA- 50 ppm Tween was almost 95 Pa during the first 10 sec. After that ΔP decreased slightly to 93 Pa. By increasing the mixture concentration to 1000 ppm, the ΔP decreased to 90 Pa during first 10 sec. After 15 sec, ΔP of the mixture decreased rapidly to 87 Pa. This decrease in ΔP of the mixture might have occurred following the hydrophobic interaction between PAA and Tween 20.

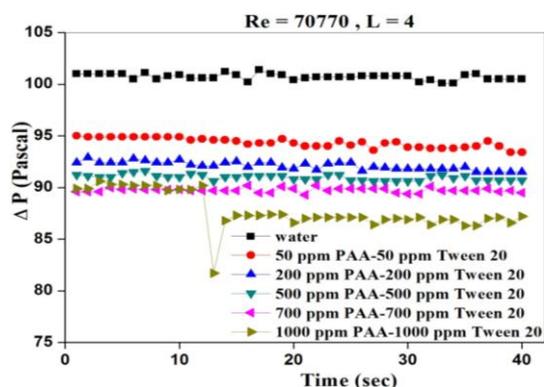


Fig. 6. Compare the values of the pressure drop of reference (tap water) and PAA - Tween 20 mixtures as a function of time.

IV. CONCLUSION

In conclusion, we managed to study various effects of different concentrations of polymer and surfactant, along with different rotational speeds on DR efficiency using RDA. The DR efficiency attributed by the PAA-Tween 20 mixture was found to be significantly higher than that of pure PAA. In addition, it could be seen that ΔP decreased dramatically when the concentration of PAA-Tween 20 complex was increased as a function of time.

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