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Thixotropic Assessment of Some Enhanced Oil Recovery used Polymers

Mamdouh T. Ghannam[a], Mohamed Y.E. Selim[b], Abdulrazag Y. Zekri[a] and Nabil Esmail[c]
[a]Department of Chemical and Petroleum Engineering, Faculty of Engineering, United Arab Emirates University, P.O. 15551, Al-Ain, United Arab Emirates
[b]Department of Mechanical Engineering, Faculty of Engineering, United Arab Emirates University, P.O. 15551, Al-Ain, United Arab Emirates
[c]Department of Mechanical Engineering, Concordia University, 1455 de Maisonneuve Boulevard W., Montreal, Quebec, Canada M3G 1M8

Abstract*:- Experimental study of thixotropic behavior for Xanthan and Alcoflood polymers solutions and their emulsions with crude oil were studied by using RheoStress RS100. The thixotropic behavior was studied over a wide range of polymer concentrations, two concentrations of crude oil, and two different types of polymers. The Alcoflood aqueous solutions show thixotropic behavior over the examined range of concentrations. The experimental measurements of the area under the upward-curve and the downward-curve improves slightly with Alcoflood concentration up to 10^3 ppm and strongly beyond that concentration. The availability of crude oil within the Alcoflood aqueous solutions increases the rheogram profiles and therefore affects the hysteresis area. The addition of crude oil into the Alcoflood solutions reverses their behaviors to anti-thixotropic in comparison with solution behaviors. The other aqueous solutions of Xanthan gum display thixotropic behavior over the examined range of concentrations. The addition of the crude oil into the Xanthan solutions causes a significant rise of the thixotropic rheograms. The variations between the ramp-up and ramp-down curves steadily decreases with the addition of crude oil, and therefore the thixotropic area declines with more addition of the crude oil droplets phase. Both aqueous solutions of Alcoflood and Xanthan exhibiting thixotropic profiles in which the ascending curves are positioned above the descending curves. For lower concentrations aqueous solutions, both solutions display almost similar thixotropic rheogram curves. However, for high concentration of 1000 ppm, the aqueous solution of AF1235 exhibits higher thixotropic rheogram behavior than Sigma gum.

Keywords: Xanthan, Alcoflood, Crude oil, Emulsion, Thixotropic.

1. INTRODUCTION

Polymers are used widely in the enhanced oil recovery to alter the flow specifications and conditions of the aqueous solution to boost movement ratio, removal effectiveness, and rise oil quantity rates (Sherman, 1970). Enhanced oil recovery (EOR) is a recommended method to harvest almost half of the presence crude oil, which cannot be removed by the traditional methods. The injection of polymer liquid mixture to an oil well generates what we term oil-polymer emulsion, i.e., the existence of crude oil droplets distributed inside the aqueous continuous liquid phase. Polyacrylamide (PAA) and polysaccharides biopolymer are the two types of polymers that are being widely utilized in the polymer flooding phase (Kjøniksen et al., 2008; Samanta et al., 2010). The rheological characteristics of these emulsions are essential in the production of crude oil by polymer solution.

The PAA polymer is generally employed in recent applications such as coagulation, fluctuation damping agent and in the EOR (Durst et al., 1981; Flew and Sellin, 1993). The PAA can be prepared through the polymerization of the acrylamide material. The Xanthan gum is a polysaccharide material and can be involved in numerous industrial processes such as nutrition, drugs, and EOR (Kang and Pettitt, 1993; Speers and Tung, 1986).

Many experimental studies on the rheological behaviors of the PAA aqueous solutions have been reported in the literature. Some example of these are Ghoniem et al. (1981) & Chang and Darby (1983) studied the mechanical degradation of PAA aqueous solution. Li and McCarthy (1995) examined the pipelines movement activities, Dupuis et al. (1994) investigated the flow characteristics of PAA and glycerol mixture and they reported time dependence viscosity profile. Ait-Kadi et al. (1987) considered the existence of saline on the rheological properties of the PAA solution. Shin and Cho (1993) examined the influence of temperature on the PAA aqueous solution.

Xanthan gum used widely as a biopolymer in the oil recovery processes (Ryles, 1988). Xanthan gum aqueous solutions display pseudoplastic characteristics with superior suspending capabilities. Thus, Xanthan solutions utilized commonly in many applications such as make-ups, nutrition, medicines and EOR (Sutherland, 1996). Many investigations on the Xanthan solutions have been listed such as Whistler and BeMiller (1997) reported sturdy pseudoplasticity behavior for the Xanthan solutions owing to the creation of molecular collections with the shape of rigid rod. Milas and Rinaudo (1979) found the Xanthan gum would form helical assembly in the well-arranged case and thicken the liquid mixture making it one of the firmest biopolymers (Coviello et al., 1986).

Many investigations are available on the emulsions flow characteristics studies for Newtonian continuous phase (Sherman, 1970; Plegue et al., 1986; Pal and Rhodes, 1989). Limited numbers of flow behavior studies have been found on oil emulsion of non-Newtonian continuous liquid (Han and King, 1980; Pal, 1992; Ghannam, 2003). Sosa-Herrera et al. (2008) inspected the flow characteristics of 30% sunflower oil emulsion and gum mixtures at room temperature. In the absence of gum, the oil emulsions behaved in a Newtonian manner. Conversely, a non-Newtonian behavior was reported when a little of gum was added to the oil mixture.

Originally the term of thixotropy was used to display the rescindable variations of gel-sol activities due to the mechanical effect at the same temperature, i.e. solid-liquid transition. Presently, the thixotropy demonstrates the continuous reduction of high viscous gel flow resistance condition and the following recapture of the low viscous sol flow resistance at stationary condition (Mewis, 1979). Thixotropy phenomenon is commonly reported for micro-arrangement solutions and it indicates the degree of the alterations take places from one micro-arrangement situation to a new situation and back to original. These alterations due to the structure disturbance-reform cycles under the influence of stress-non stress conditions, which leads to fluid viscosity variations over a certain time from one position to a new one.

One of the suggested scheme to address the thixotropic conduct from the rheogram profile is the hysteresis cycle (Cheng and Evans, 1965). The hysteresis cycle embraces of the area enclosed among the arising shear rate profile (i.e. the ascending-curve) and the plunging shear rate profile (i.e. the downward-curve). This bounded region is termed the thixotropic area. The opposite conduct can be found also and it is identified by anti-thixotropic manners where shearing elevates the short-term buildup instead of disruption impact of the dispersed elements (Barnes, 1997). For the anti-thixotropic behavior, the downward profile will be located overhead the up-ward profile presenting adverse thixotropic area (Kawashima et al., 1991).

This study emphasizes on the thixotropic behavior comparison for the two commonly used commercial polymers and their emulsions with crude oil using controlled-rate rheometer. These polymers are polyacrylamide (i.e. Alcoflood polymer) and polysaccharides biopolymer (i.e. Xanthan gums). This investigation examined different concentrations of crude oil, Alcoflood, and Xanthan gums.

2. MATERIALS AND EXPERIMENTS

2.1. Materials

Xanthan gum of Sigma was employed for this study from Sigma-Aldrich Canada Ltd (Oakville, Ontario L6H 6J8, Canada) with product # G1253 with name of Sigma. Sigma is a white to tan colored powder and employed in non-food uses such as a thickener and rheology control agents. The aqueous solutions of this material was obtained by moderate circulation of the added powder in 0.25 liter of warm distilled water to achieve the necessary concentration. Since the Xanthan solution is biodegradable and to prevent the bacterial growth, 1.0 gm formaldehyde was added and the aqueous solutions were stored at 4 ^{o}C until use.

Alcoflood polymer of AF1235 from Ciba Specialty Chemicals (Bradford, West Yorks, England) was used in this study. The water-soluble Alcoflood material of AF1235 was delivered in a white granular powder form. Alcoflood material is a high molecular weight polyacrylamide copolymers. AF1235 is suggested for low-medium permeability reservoirs with bulk density of 800 kg / m^3 and intrinsic viscosity equals 12. The AF1235 aqueous solutions was obtained by adding a certain weight of AF1235 to 0.25 liter of warm distilled water. Sufficient time was allowed to reach the status of complete dissolution without exterior agitation to prevent any mechanical effect on the polymer network.

A North Sea crude oil supplied by Shell Canada Limited was used in all experimental investigation. The crude oil viscosity equals 7.16 mPas at 40 ^{o}C, and density is 880.6 kg/m^3 at 15 ^{o}C. Triton X100 from Sigma-Aldrich Canada Ltd. with a specific gravity of 1.07 was utilized as an emulsified agent. An emulsified material was needed to obtain the crude oil-polymer emulsions. In general, an emulsified material is generally added into oil–aqueous phase system to decrease the interfacial tension of the oil-aqueous solution and to stabilize the presence of the oil droplets phase within the aqueous continuous phase (Sherman, 1983).

2.2. Experiments

The main focus of the current work is to examine the thixotropic activities of different aqueous Xanthan and Alcoflood materials solutions and the emulsions of these solutions with crude oil by Rheostress RS100 rheometer. Experimental results of thixotropic were completed through organized shear rate approach. The RS100 was automated to perform the investigational test comprised of 3-sets test. At the begging of each test, the rheometer was gradually increase from 0.15 to 700 s^{-1} shear rate to establish the ascending curve by recording the stresses and the shear rates. For the next set, the RS100 was operated at 700 s^{-1} for the whole damage of the sample. The last set, the reheometer was assigned shear rate from 700 to 0.15 s^{-1} to form the descending turn. Each set was last two minutes only. For the consistency purposes, a particular test were tried 3 times of the equal concentration. The approval acceptance of this reiteration process was approximately ± 2%.

This study tested 0-10^4 ppm of polymer addition, 25 & 75 by volume % crude oil addition, and two polymers. Crude oil-polymer mixture emulsions were arranged using crude oil, polymer liquid solution, and blending medium called emulsifying agent. Triton X-100 was added as mixing agent to form stable emulsion. Polymer aqueous solution was formed by dissolving certain polymer into a distilled water. Then a slow addition of oil to the prepared polymer liquid solution with 1% by volume of Triton X-100. The existence of an emulsifier medium into the crude oil-polymer emulsion is essential to accomplish a longer stable emulsion and to inhibit the merger mechanism of the oil droplets medium.

The thixotropic investigation of Xanthan and Alcoflood solutions and their oil emulsions were accomplished utilizing RheoStress RS100 under controlled shear rate-mode. An aquatic tank associated to the RS100 to keep the operated temperature of the RS100 machine at 22 ^{o}C temperature. The shear rate-shear stress results were acquired employing cone & plate device with 4^{o} of cone angle, 35 mm of cone diameter, and 0.137 mm gap.

3. RESULTS AND DISCUSSION

Some of the injection liquids and emulsions of crude oil in the EOR are exposed to different steps of loading, pushing, and pipeline passages. Consequently it is useful to examine the thixotropic behavior of these aqueous solutions and their emulsions of some EOR polymers such as Alcoflood and Xanthan gums. Due to the imposed stimulus in terms of the applied shear rate, the thixotropic material display time-function profile results from the physical arrangement changes on the molecular scale. The viscosity, η, of the examined sample reflects the molecular structure conditions in terms of structure status condition α and the enforced shear rate $\dot{\gamma}$. This relationship can be presented by Equation 1. The rate of the structure & arrangement alterations, Equation 2, due to rupture at high shear influence and rebuilding up at low shear impact. Thus, Equations 1 & 2 can be used to demonstrate the thixotropic behavior. For the time-dependent response, the upward- and downward-cycles form an area A of units Pa/s. The thixotropic measurement of energy / volume indicates the amount of energy per unit volume of material to breakdown the associated arrangement.

$$\eta = \eta(\dot{\gamma}, \alpha) \qquad (1)$$

$$d\alpha / dt = f(\dot{\gamma}, \alpha) \qquad (2)$$

3.1. Thixotropic Behavior of Alcoflood Aqueous Solutions and Crude Oil Emulsions

Figure 1 displays the behavior of shear rate versus shear stress for different additions of Alcoflood polymer. Figure 1 shows the ascending- & descending-cycles reported for the 10^3 & 10^4 ppm concentrations of AF1235 as typical examples of the Alcoflood polymer solutions. The low and high polymer concentrations of AF1235 exhibit thixotropic activities, i.e. the upward-profiles are located overhead the downward-profiles. Furthermore, the Alcoflood polymer concentration shows a major impact on the rheograms conduct, namely the more addition of material yields higher rheograms curves behavior. To investigate the impact of AF1235 addition on the hysteresis loop, i.e., the area between the upward- & downward-curve, many experimental runs were carried out. The area under the upward-curve and downward-curve rises marginally with AF1235 up to 10^3 ppm and then increases strongly with AF1235 concentration up to 10^4 ppm. For the whole range of the AF1235 addition, the ramp-up curve is slightly above the ramp-down curve providing a thixotropic area for all tested AF1235 solutions. Modelling analysis was completed for all the examined aqueous solutions of AF1235 and the results can be presented by Equation 3 with the regression coefficient r^2 equals 0.98. The thixotropic measurement in Pa/s and X is the material addition in ppm.

$$\text{Thixotropic Area} = 272\, e^{(0.000104\, X)} \qquad (3)$$

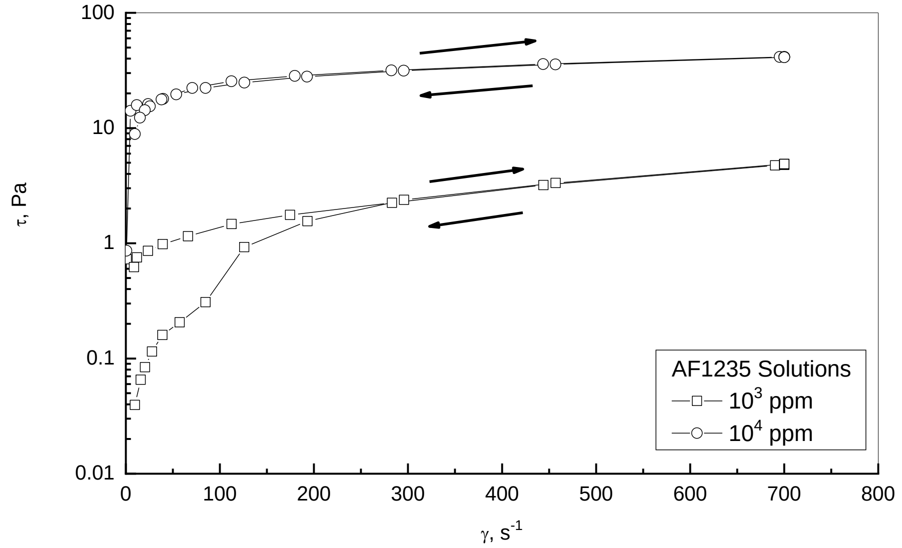


Fig. 1. Thixotropy behavior of low & high AF1235 concentrations.

To address the impact of the oil addition on the thixotropic activities, Figures 2-3 display the rheograms behaviors of low and high AF1235 concentrations in the existence of two crude oil concentrations of 25% & 75% in comparison with their polymer solutions, respectively. As can be concluded from Figures 2-3, the occurrence of oil considerably upsurges the rheogram profiles and consequently influences the hysteresis area. Figure 1, without crude oil addition, illustrates that the ramp-up cycle is positioned over the ramp-down cycle for the aqueous solutions of AF1235. Conversely, a reverse behavior is noticed for the crude oil emulsions of AF1235 as can be resulted from Figures 2-3. These Figures display a slight anti-thixotropic profile of the oil-AF1235 emulsions which is the opposite to the results of the AF1235 aqueous solutions in Figure 1. Figures 2-3 exhibit that the descending curve is located slightly above the ascending curve in which it is called the "anti-thixotropic" response due to the existence of the crude oil. This behavior was reported over a limited shear rate range. For the lower to medium concentrations of AF1235 (i.e. up to 5000 ppm), the anti-thixotropic shear rate range is 700-100 s^{-1}. While, for the greater addition of 10^4 ppm AF1235, the anti-thixotropic range is 700-300 s^{-1}.

This sort of activities can be referred to the roles of the Brownian effect and the shear-influenced consequence. The first effect due to the Brownian motion of the chaotic motion of molecules created from the destruction of the micro arrangement being affected. This kind of continuous chaotic mobility causes the molecules to transport to certain sites to be attached to the micro assembly (Barnes, 1997). Additionally, the next effect which is the shear-influenced will take place in the ramp-down set. During the descending period of decreasing shear rate cycle, the shear-influenced promotes the crude oil dews to recollect their novel form to boost the re-forming method of the examined emulsion (Kawashima et al., 1991). To emphasize these outcomes, this work examines the thixotropic area in Pa/s of the polymer solutions and oil-emulsions measured by the software associated with the RS100 machine. These measurements are reported in Table 1 as function of the concentration of each AF1235 and crude oil. From the concluded results, the more oil accumulation into the polymer solution the more gradual departure of the ramp-down curve from the lower position to the upper position w.r.t. the ramp-up cycle which enhances the degree of the emulsion re-structuring.

Table 1. AF1235 Solutions and Oil Emulsions Thixotropic Area

% Crude Oil Addition	10^3 ppm AF1235	10^4 ppm AF1235
0	302	769.5
25	1.0	- 135
75	- 244	- 1599

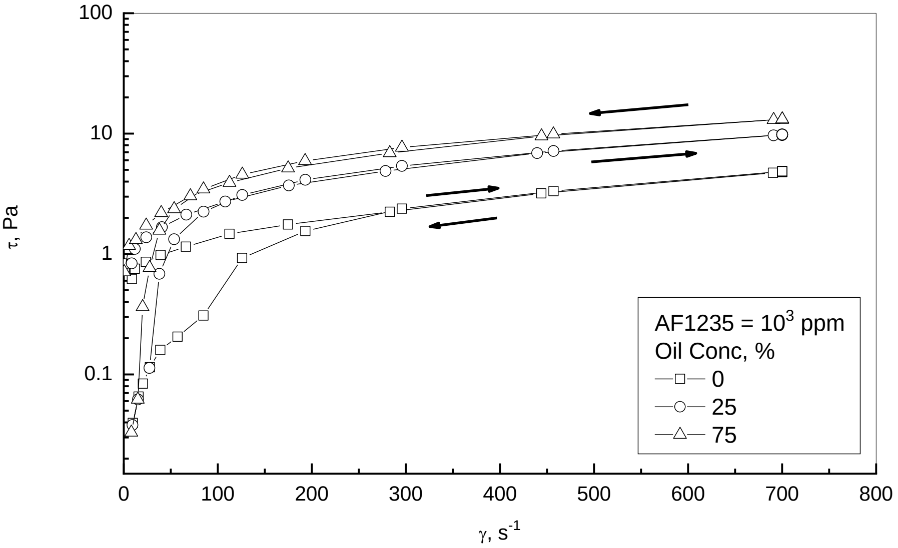


Fig. 2. Thixotropic behavior of different oil emulsions for 10^3 ppm AF1235.

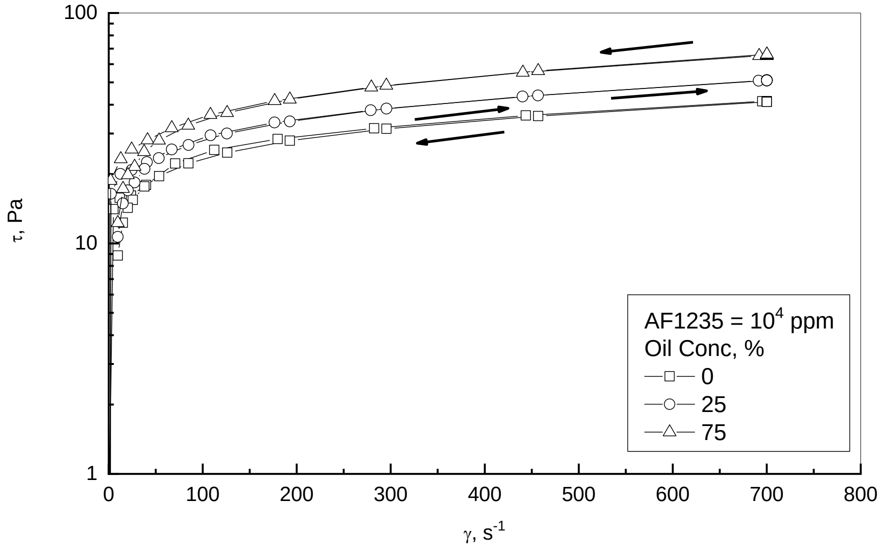


Fig. 3. Thixotropic profiles of different oil-10^4 ppm AF1235 emulsions.

3.2. Thixotropic Behavior of Xanthan Aqueous Solutions and Crude Oil Emulsions

The thixotropic behaviors for 500 and 5,000 ppm Sigma aqueous solutions are demonstrated in Figure 4 to show the thixotropic behavior of two different concentrations of Xanthan material. Figure 4 displays the rising and sliding cycles developed by the shear rate ramp cycles. It shows that the Sigma liquids develop thixotropic activities, in which the upward-cycle are located above the downward-profiles. Furthermore, the Xanthan addition shows a significant effect on the response profile in which the greater the polymer addition the greater cycles develop.

To investigate the influence of the Xanthan addition on the development of the ramp-up & ramp-down cycles, the fitting analysis was conducted following Equations 4-5.

$$A_{\text{Ramp-up}} = 1604.37\ e^{(0.0002\ X)} \quad (4)$$

$$A_{\text{Ramp-down}} = 1444.51\ e^{(0.0002\ X)} \quad (5)$$

Where $A_{\text{Ramp-up}}$ and $A_{\text{Ramp-down}}$ are the area under the ascending curve and descending curves in Pa/s, and X is the Xanthan addition in ppm, respectively. It is worthwhile to report the regression coefficient r^2 associated to these fitting analysis is 0.99.

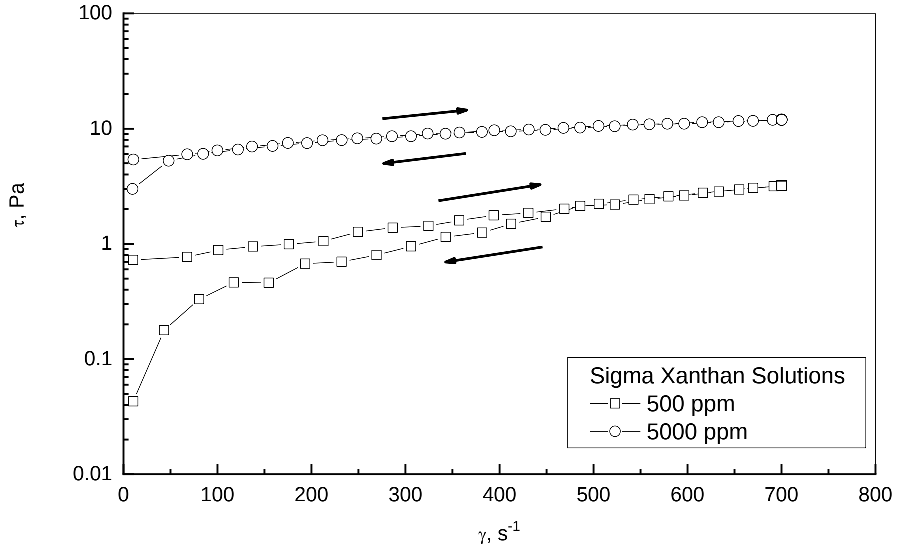


Fig. 4. Thixotropic activities of low & high Sigma concentrations.

To investigate the effect of oil addition within the emulsion, Figure 5 display the rheogram profile of 500 ppm Sigma for different oil emulsions. Figure 5 demonstrates the results of the oil amounts of 25% and 75% on the performance of the rising and sliding profiles in the presence of 500 ppm of Sigma liquid. As the results of this figure, the more addition of oil into the 500 ppm Sigma solution causes a significant rise of the flow rheograms. Figure 6 shows similar thixotropic behavior for more Xanthan gum accumulation of 5000 ppm in oil occurrence. Figure 6 illustrates the thixotropic activities for oil addition of 25% & 75%, respectively. For the high concentration of 5000 ppm of Sigma gum, the rheograms behaviors are similar to those reported in Figure 5 but with higher responses.

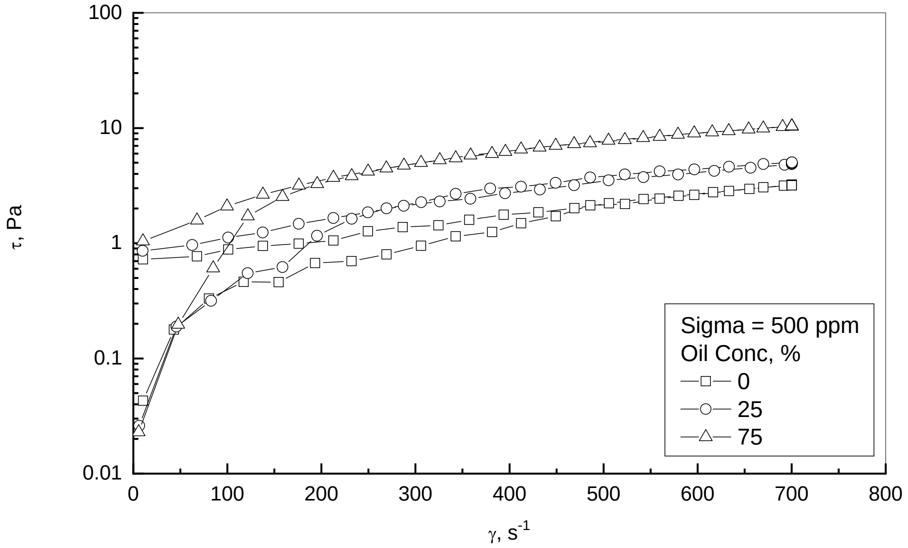


Fig. 5. Thixotropic activities of different oil-500 ppm Sigma emulsions.

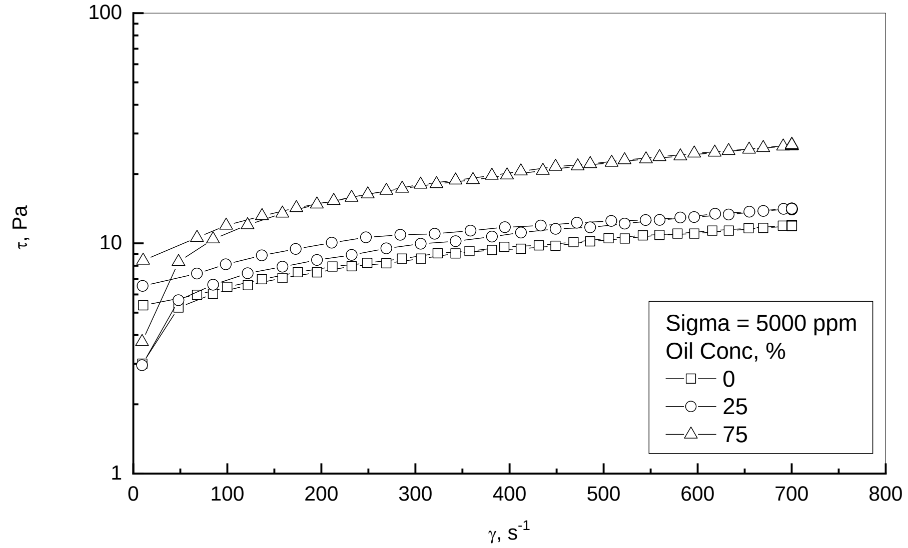


Fig. 6. Thixotropic activities of different oil-5000 ppm Sigma emulsions.

To explain the influence of oil existence on the thixotropic results in terms of $A_{ramp-up}$ and $A_{ramp-down}$, Figure 7 shows the reliance of the $A_{ramp-up}$ and $A_{ramp-down}$ cycles on the oil addition for the 500 and 5000 ppm Sigma concentrations. Figure 7 shows, firstly, that the ascending curves for the aqueous solutions are slightly above the descending curves. Secondly, the variances among the ramp-up & ramp-down phases gradually diminish with accumulation of more oil, and subsequently the thixotropic results marginally declines in the presence of oil status. Within the duration of the descending period, the more accumulation of oil phase enhances the recapture mechanism of the initial assembly status of the oil liquid mixture due to the effects of both of Brownian and the shear-influenced of the oil droplets.

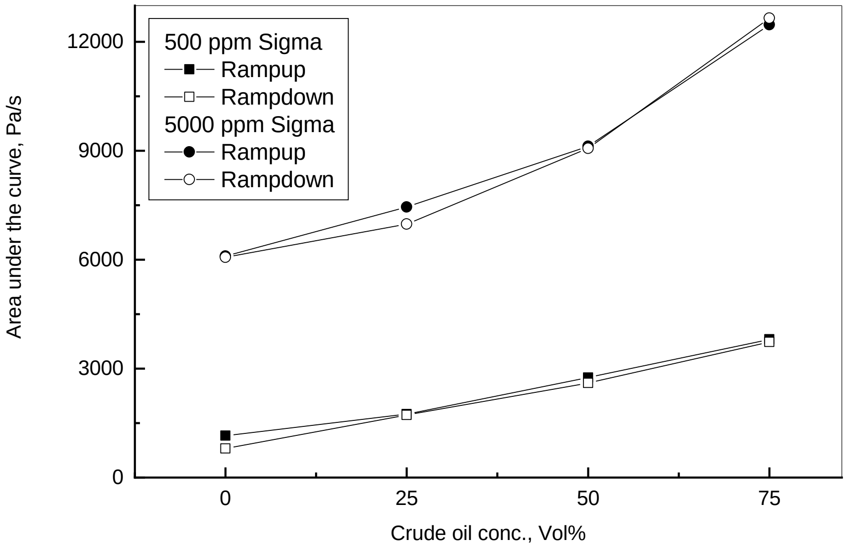
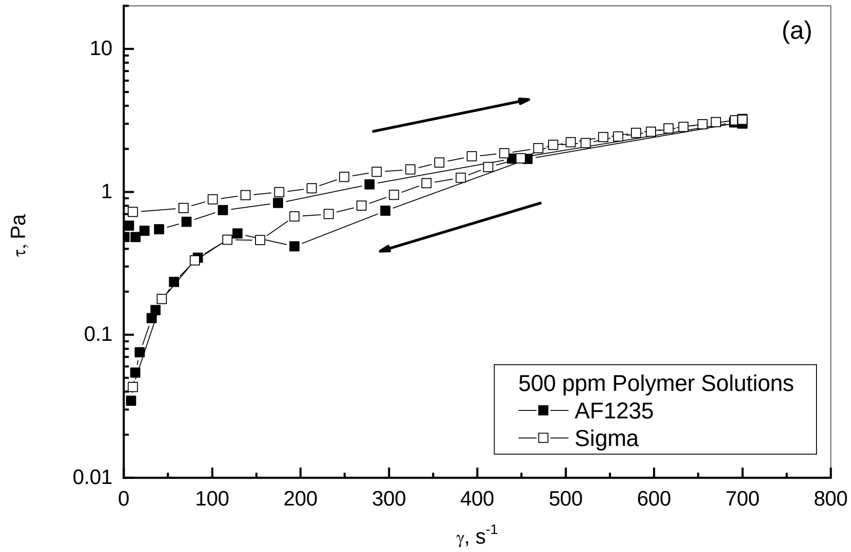


Fig. 7. Oil concentration impact on the ascending & descending areas.

3.3. Thixotropic Comparison of AF1235 and Sigma Solutions and Emulsions

The detailed explanation of the thixotropic descriptions for aqueous solutions and oil emulsions of AF1235 and Sigma polymers are presented in the preceding parts. It is necessary for the present work to examine the matches and changes in the thixotropic behaviors of the examined solutions and oil-emulsions. Figures 8-a and 8-b illustrate the thixotropic behaviors of AF1235 and Sigma aqueous solutions with low and high concentrations of 500 ppm and 5000 ppm respectively as typical examples. Figure 8-a displays that the thixotropic cycles for low concentration of 500 ppm, as can be concluded, the two different aqueous solutions are almost coincide on top of each other and show similar behavior for both of AF1235 and Sigma aqueous solutions. On the other hand for the more addition of 5000 ppm, Figure 8-b shows that the ascending-descending rheograms behavior of AF1235 solution is higher than the corresponding behavior reported by the Sigma aqueous solution. Furthermore, Figure 8 displays that the ramp-up cycles are positioned overhead the ramp-down cycles for both solutions of Alcoflood (AF1235) and Xanthan (Sigma) exhibiting thixotropic profiles.



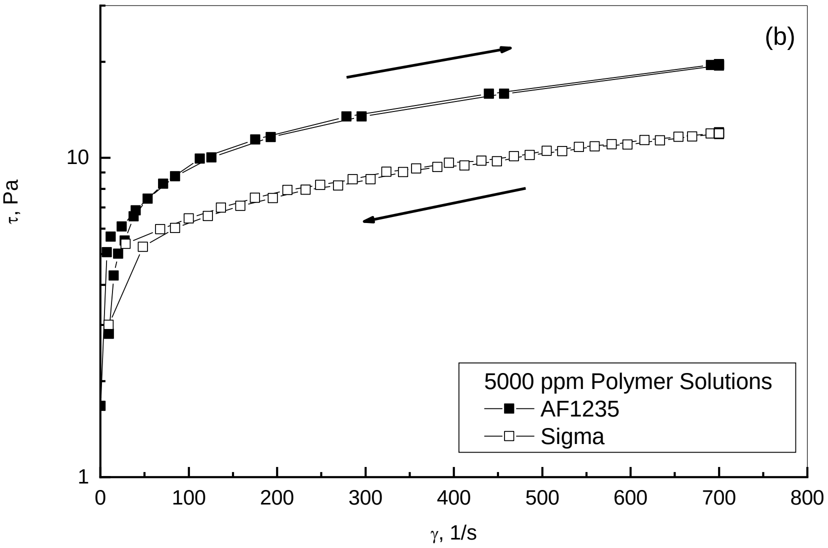


Fig. 8. Thixotropic activities of low & high polymer solutions.

To address the effect of the whole examined range of polymer addition on the thixotropic activities of both tested materials, Figure 9 illustrates the results of the area of the ramp-up cycle and the ramp-down cycle versus the polymer addition of the AF1235 and Sigma aqueous solutions. For the polymer addition of < 1000 ppm, there is no significant differences between the areas reported for both tested polymer materials as can be determined from Figure 9. For polymer addition beyond 1000 ppm, the areas reported for the Alcoflood aqueous solutions are considerably higher than those reported by the Xanthan solutions. This result is much more pronounced with polymer concentration. Furthermore, Figure 9 displays that the thixotropic area, i.e. the hysteresis loop, for the Alcoflood solutions is marginally higher than the thixotropic area exhibited for the Xanthan solutions.

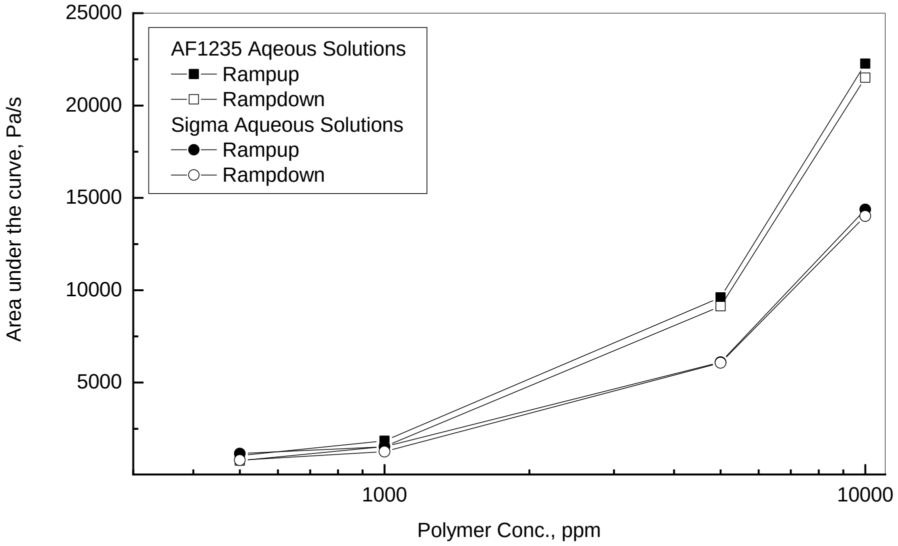


Fig. 9. Areas under the ascending & descending cycles for polymer liquids.

Figures 10-a & 10-b show the outcome of the oil presence on the thixotropic behavior of the 5000 ppm of Alcoflood and Xanthan solutions, respectively. The ramp-up and ramp-down cycles of low oil emulsion (i.e. 25% crude oil concentration) and high oil emulsion (i.e. 75% oil concentration) are reported in Figures 10-a & 10-b for the same polymer concentration of AF1235 and Sigma. For both cases of low & high oil additions, the rheogram behavior of oil-AF1235 case is considerably upper than the one reported for the oil-Sigma case for the whole assigned shear rate. Moreover, for the case of AF1235, the addition of 25% crude oil causes the descending curve moves closer to the ascending one creating either a very narrow gap between the ascending and descending or a full coincidence of the ascending & descending cycles. However, the more addition of oil (i.e. 75% crude oil-AF1235 emulsion) the descending curve moves further away from the ascending curve creating a larger loop of anti-thixotropic activities for the shear rate of 700-100 s^{-1}. Comparable remarks can be reached for the Sigma emulsions. In the situation of 25% oil-Sigma emulsion, the descending curve located lower than the ascending cycle resulting a thixotropic behavior. However, for the 75% oil-Sigma emulsion, the descending curve moves above the ascending curve leading to anti-thixotropic profile over the shear rate of 700-200 s^{-1}. Therefore, the addition of high crude oil concentration (i.e. 75%) to the polymer solutions of both polymers develops the rheogram profile to transform from thixotropic activities as in the Figure 8 to the anti-thixotropic case as in the Figure 10-b due to the results of the Brownian effect and the shear-influenced effect.

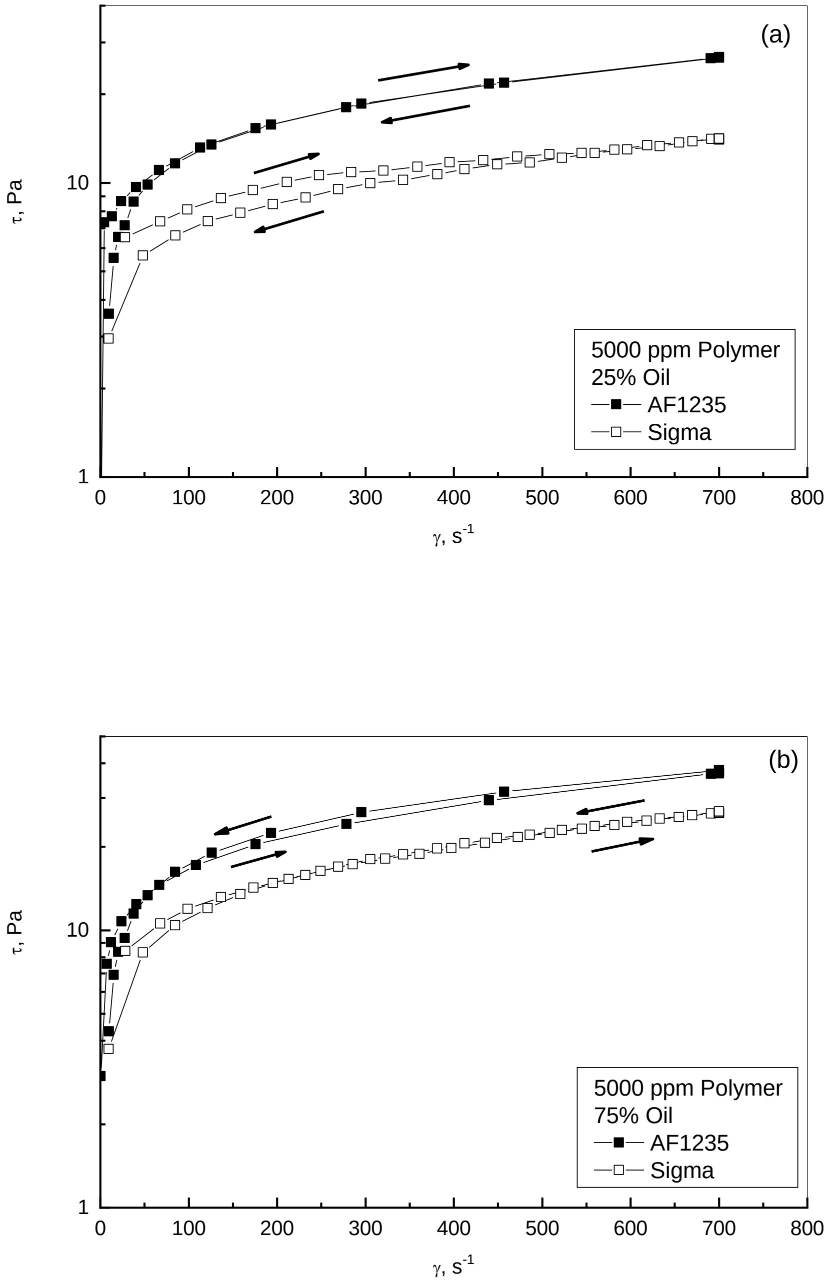


Fig. 10. Thixotropic activities of different polymer emulsions.

To investigate the influence of oil on the thixotropic activities of both tested polymer solutions over the whole examined range of polymer concentrations up to 10^4 ppm, Figure 11 illustrates the areas of the ramp-up and ramp-down against polymer concentration. Two oil additions of 25% & 75% were studied to monitor the thixotropic behavior of different polymer solutions at low and high crude oil concentrations. For the lower oil concentration of 25%, Figure 11-a shows that the ramp-up curve is noticeably above the ramp-down curve for the Xanthan emulsions exhibiting thixotropic behavior as concluded earlier. However, for the Alcoflood solutions, the discrepancies between the ramp-up & the ramp-down cycles reported for aqueous liquids in Figure 9 are significantly diminished by the addition of 25% crude oil. In order to emphasize the role of crude oil in the study of thixotropic behavior, higher crude oil concentration of 75% was investigated in both polymer solutions of Sigma and AF1235. The experimental results of the thixotropic behavior of both tested polymer solutions in the occurrence of 75% oil are revealed in Figure 11-b. As can be found, the existence of more oil addition leads to further departure of both emulsions from the thixotropic behavior of the polymer solutions toward the anti-thixotropic behaviors. These consequences can be attributed to the influence of the Brownian effect and the shear-influenced effect on the crude oil re-structure mechanism as reported in the earlier discussion.

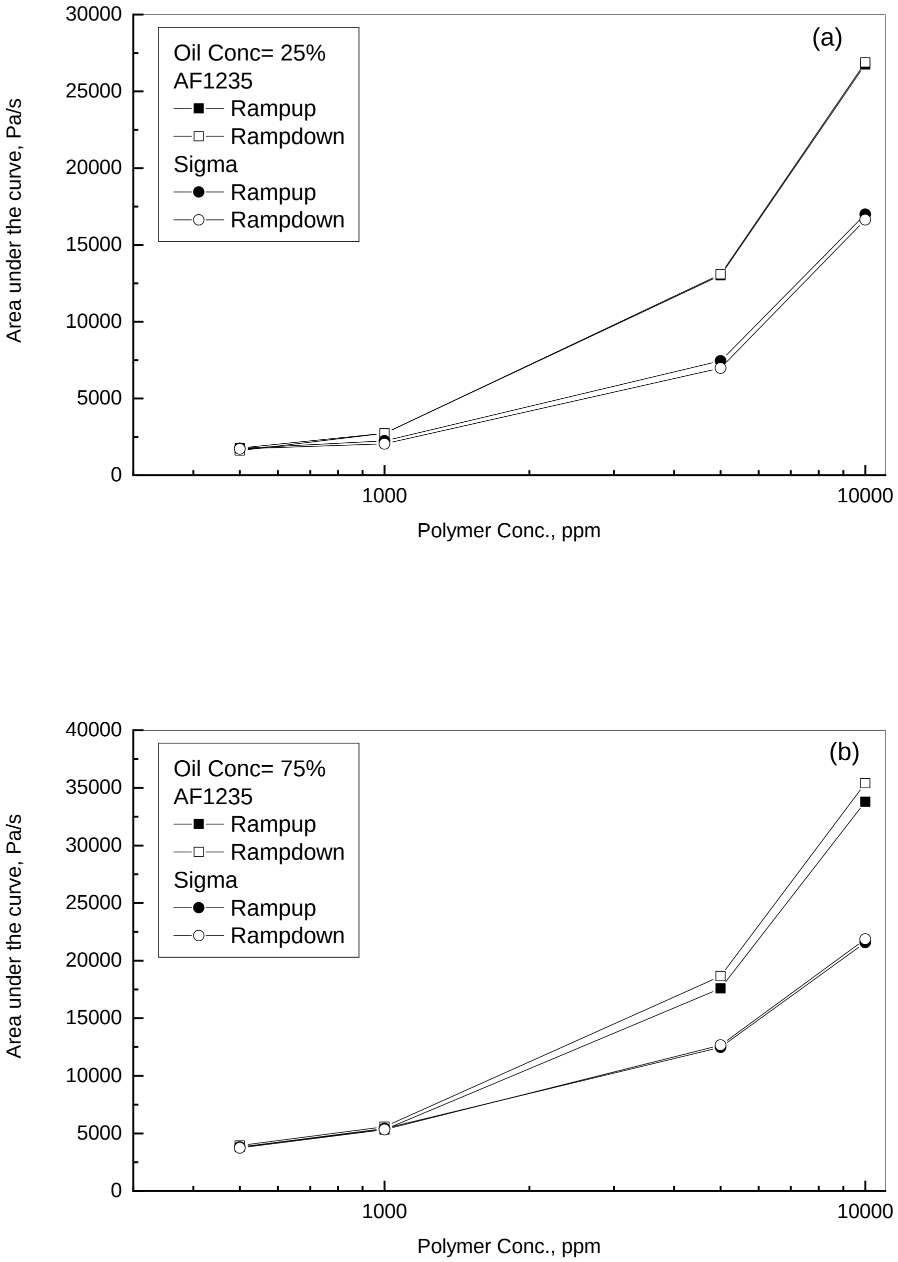


Fig. 11. Area of ascending & decending cycles for 75% oil-different polymer emulsions.

4. CONCLUSIONS

The thixotropic behavior of Xanthan and Alcoflood solutions & their emulsions with crude oil was studied. The low and high polymer concentrations of AF1235 aqueous solutions exhibit thixotropic behavior. The area under the upward- & downward-curves rises slightly with AF1235 concentration up to 10^3 ppm and then increases strongly up to 10^4 ppm. The addition of crude oil into AF1235 solutions rise their rheogram behavior and influence the hysteresis area as well. The presence of crude oil within the AF1235 aqueous solutions exhibit anti-thixotropic behavior. Sigma aqueous solutions exhibit thixotropic activities for the tested Xanthan additions. The occurrence of the oil inside the Xanthan gum of Sigma solutions leads to a significant upsurge of the flow rheograms. The differences between the up-ward curves and down-ward curves gradually decreases with the addition of crude oil, and thus the thixotropic area gradually declines with the presence of oil dispersed status. For addition of less than 1000 ppm, the two aqueous solutions of AF1235 and Sigma gum display almost similar thixotropic behavior. For concentration higher than 1000 ppm, the aqueous solution of AF1235 provides higher thixotropic rheogram curves than the other solution of Sigma gum. The hysteresis loops for the Alcoflood solutions are slightly higher than the thixotropic area exhibited by the Xanthan solutions. The accumulation of 75% oil addition within the liquid solutions of both polymers results the formation of the anti-thixotropic behavior instead of thixotropic profiles as in the case of aqueous solutions of both polymers.

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