

Creep–Recovery Experimental Investigation of Crude Oil–Polymer Emulsions

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ABSTRACT: Viscoelastic behavior of crude oil–Alcoflood polymer emulsions in terms of creep and recovery is extensively investigated using RheoStress RS100. Three different types of Alcoflood polymers in the concentration range of $100\text{--}10^4$ ppm are covered. North sea crude oil with a concentration range of 10–75% by volume is employed for emulsion preparation. All viscoelastic tests of crude oil–polymer emulsions are carried out under 0.1 Pa of shear stress to make sure that the investigated behavior lies within the linear viscoelastic range. The viscoelastic behavior of crude oil–polymer emulsion is strongly influenced by crude

oil concentration, Alcoflood concentration, and Alcoflood type. The viscoelastic behavior of crude oil–Alcoflood polymer emulsions can be simulated using the Maxwell model or the Burger model depending upon the polymer concentration. The Maxwell model can be used over the polymer concentration range of 0–5000 ppm, whereas the Burger model covers the higher polymer concentration range. © 2004 Wiley Periodicals, Inc. *J Appl Polym Sci* 92: 226–237, 2004

Key words: creep; recovery; crude oil; Alcoflood polymer; emulsion; Maxwell model; Burger model.

INTRODUCTION

Alcoflood polymer plays an important role in the production of crude oil during the enhanced oil recovery stage. Enhanced oil recovery is usually utilized in the oil production industry after the traditional methods have been completed. Around 30–50% of the original crude oil can only be produced from a well through conventional techniques.

During the polymer flooding process, an aqueous solution of Alcoflood polymer is injected into a well formation. The Alcoflood polymer solution enhances the mobility ratio and sweep efficiency; therefore, it increases recovery and oil production rates. The injection process of the Alcoflood polymer solution into the crude oil well usually leads to the emulsion formation of a crude oil–aqueous polymer solution. The oil in water emulsions consists of immiscible oil phase dispersed within the continuous phase of the aqueous solution. Emulsions can be found in other important industries such as paper, pharmaceutical, and food industries.

Creep–recovery study is very useful for revealing the viscoelastic behavior of crude oil–polymer emulsions. A sample should be examined for its deformation response to a constant applied stress over time. Materials that show viscoelastic response have long-

chain molecules. These molecules loop with each other to form complicated structures at a minimum energy state. During the deformation stage, these molecules stretch and increasing the bond vector angles and their energy state will rise. If the applied stress is released, molecules try to regain their original structure and energy state.

For pure elastic response, the magnitude of deformation is linearly proportional to the applied shear stress. The deformation response is maintained as long as the stress is applied. When the stress is released, the deformation response will disappear simultaneously. However, viscoelastic behavior to an applied shear stress will be a time-dependent response. Initially, the molecules will suffer deformation within the mechanical limits of the network. Then continuous deformation will lead to network dismantling and the liquid starts to flow. When the applied stress is released, the strain deformation is divided into a permanently maintained viscous part and a recovery elastic part. Understanding the viscoelastic behavior of crude oil–Alcoflood polymer emulsion is very useful for crude oil production, mixing, storage, and pipeline transportation processes.

Previous work on the rheological investigation of oil emulsions showed that numerous studies have been carried out on emulsions in which the continuous phase is Newtonian.^{1–5} Large numbers of experimental measurements on the rheology of dispersed solid particles in liquid emulsion have been published.^{6–10} Few studies are found on the rheological investiga-

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tions of oil emulsion in which the continuous phase is non-Newtonian polymeric solution.¹¹⁻¹³

The purpose of this work is to study the viscoelastic behavior in terms of creep-recovery investigation for crude oil-Alcoflood polymer emulsions. This study covered a wide range of concentrations of crude oil and Alcoflood polymer. Three types of Alcoflood polymers are employed.

EXPERIMENTAL

Crude oil-polymer emulsion is prepared by gradual mixing of crude oil into polymer aqueous solution. Triton X-100 (1% by volume) was added to the aqueous polymer solution as an emulsifying agent for crude oil. The polymer was completely dissolved in the aqueous phase over time without external agitation to prevent any negative impact of mixing on the polymer network.

Alcoflood polymers

In this study, three types of Alcoflood polymers are investigated. These polymers are AF1235, AF1275, and AF1285 from Ciba Specialty Chemicals (Bradford, West Yorks, England). AF1235 is employed for low- to medium-permeability reservoirs, whereas the other two types are utilized for high-permeability reservoirs. Alcoflood polymers are high-molecular-weight polyacrylamide copolymers with a bulk density of 800 kg/m³. The intrinsic viscosity reported for AF1235, AF1275, and AF1285 is 12, 20, and 24, respectively.¹⁴

Crude oil

North Sea crude oil was employed in all of the creep-recovery investigation tests. The density and viscosity

of crude oil were 880.6 kg/m³ and 7.16 mPa.s at 40°C, respectively, whereas an acid value of 1.2(10)⁻³ kg KOH/kg was reported.

Triton X-100

Surfactants are usually added into aqueous solution as an emulsifying agent for crude oil. An emulsifying agent plays an important role in lowering the interfacial tension of crude oil-aqueous solution and stabilizing the presence of oil droplets within the aqueous phase.¹⁵ Triton X-100 from Sigma-Aldrich Canada, Ltd., was employed as surfactant with a specific gravity of 1.07 and flash point of 113°C.

RheoStress

Creep-recovery tests of crude oil-polymer emulsions are completely carried out at 22°C using RheoStress RS100 from Haake. The whole package of RS100 under control stress mode can be used for operation, measurements, and data analysis of viscoelastic behavior investigation. A cone-plate sensor with cone diameter of 35 mm, cone angle 4 °, and a 0.137-mm gap at the cone tip was used.

RESULTS AND DISCUSSION

Previous study of the flow behavior of crude oil-Alcoflood polymer emulsion shows that the degree of aggregation of the crude oil droplets increases in the presence of polymer.¹³ The flow characteristic of crude oil-Alcoflood polymer emulsions shows shear thinning behavior. The emulsion viscosity increases significantly with polymer concentration and decreases with shear rate. For shear rate <10 s⁻¹, the emulsion

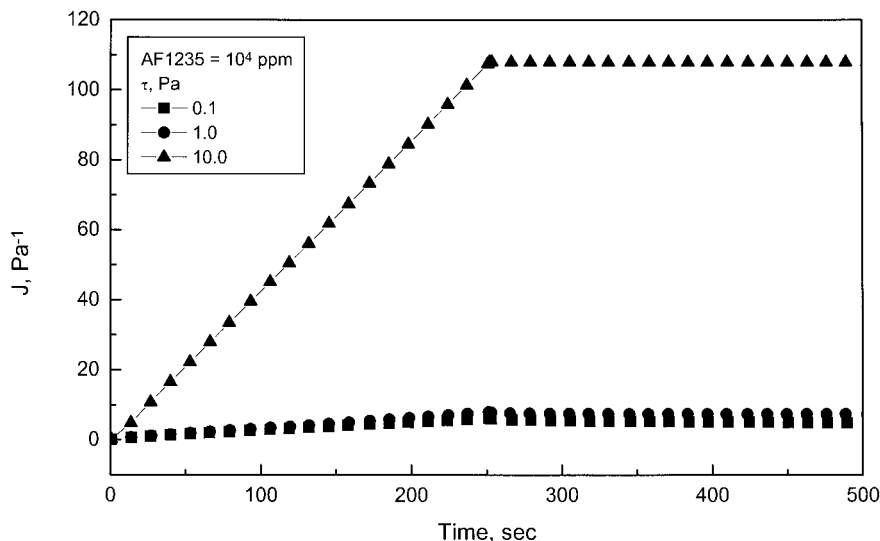


Figure 1 Linear viscoelastic range of AF1235 aqueous solution.

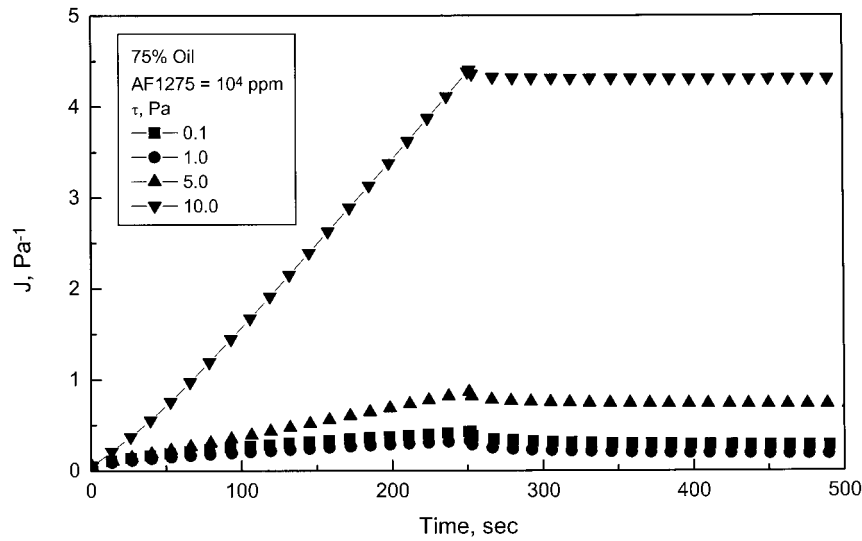


Figure 2 Effect of stress on compliance for crude oil–AF1275 emulsion.

viscosity depends upon the polymer type. AF1285 emulsion causes higher viscosity than AF1275, AF1235, and water emulsions. This conclusion can be attributed to the effect of the polymer intrinsic viscosity on the flow behavior of the crude oil–Alcoflood emulsions. The intrinsic viscosity of AF1235, AF1275, and AF1285 is 12, 20, and 24, respectively. The intrinsic viscosity of a polymer is directly proportional to the polymer average molecular weight. Therefore, the AF1285 emulsion will provide higher viscosity behavior than AF1275, AF1235, and water emulsions, in that order. For shear rate $>10 \text{ s}^{-1}$, the differences between the three tested polymers completely diminished.

Rheological investigation for materials that exhibit viscoelastic behavior show a time-dependent strain $\gamma(t)$ under applied constant stress τ_o (Pa) as

$$\gamma(t) = \tau_o J(t), \tag{1}$$

where $J(\text{Pa}^{-1})$ is the material compliance. The higher the compliance, the more easily the material can be strained at a certain applied stress. Viscoelastic response at lower values of applied stress usually leads to a linear viscoelastic behavior. Under higher values of applied stresses, nonlinear viscoelastic behavior, results of viscosity, and elasticity measurements will be dependent upon test conditions and sensor parameters. Furthermore, applied stress within the linear viscoelastic range will be nondestructive for investigating viscoelastic behavior. During this range, deformed energy can be recovered if the applied stress is released. It shows the possibility of the network to be elastically strained while the network still intact.

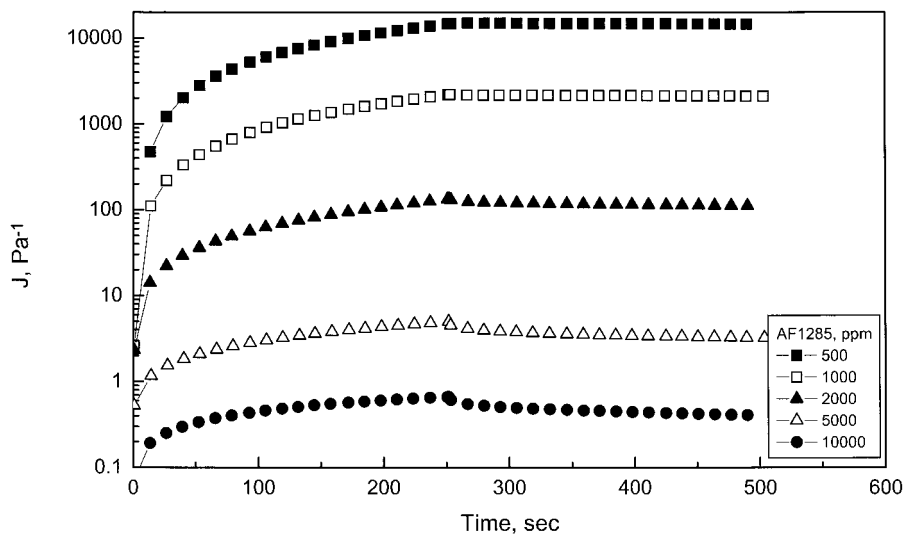


Figure 3 Compliance behavior for AF1285 aqueous solution.

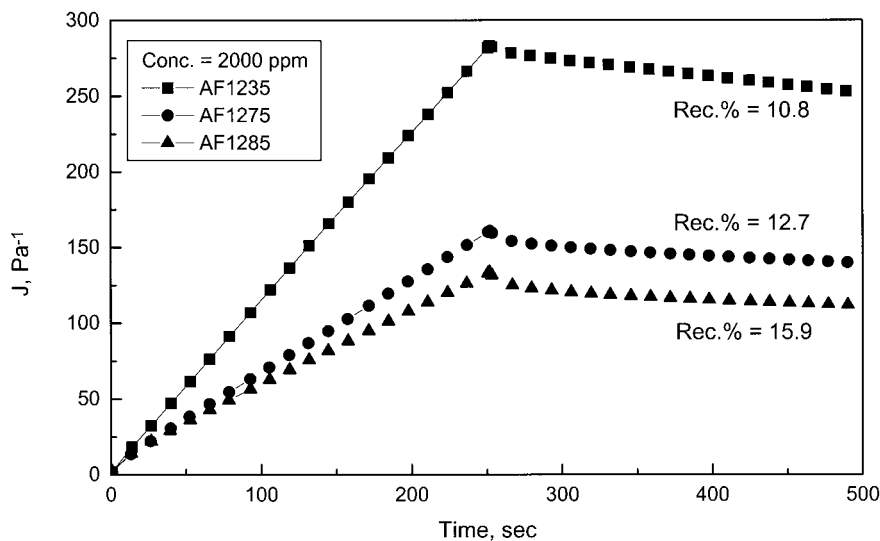


Figure 4 Compliance behavior for AF1235, AF1275, and AF1285 aqueous solutions.

Therefore, within the linear viscoelastic range, the compliance is independent of the applied stress.

Determination of linear viscoelastic range

Initially, it is useful to define the linear viscoelastic range for crude oil-Alcoflood polymer emulsions. Therefore, several values of constant shear stress are applied for 250 s to study the creep behavior. Then, the applied stress is released to study the recovery response over the next 250 s. Within the linear viscoelastic range, the compliance data at different applied stresses should coincide. On the other hand, in the nonlinear viscoelastic range, the compliance curve differs significantly from the linear viscoelastic range.

Several creep-recovery tests were examined at different values of shear stress over the range of 0.1 to 10.0 Pa for aqueous Alcoflood polymer solutions and for crude oil-Alcoflood emulsions to define the range of shear stress that provides a linear viscoelastic behavior. Figures 1 and 2 show typical examples to define the linear viscoelastic range for polymer aqueous solution and crude oil-polymer emulsion, respectively. The creep-recovery behavior of these tests shows that applied shear stress of up to 1.0 Pa will provide a linear viscoelastic response. Therefore, all further tests of creep-recovery behavior are examined at applied shear stress of 0.1 Pa to make sure that the emulsion network can be elastically deformed while not damaging the network.

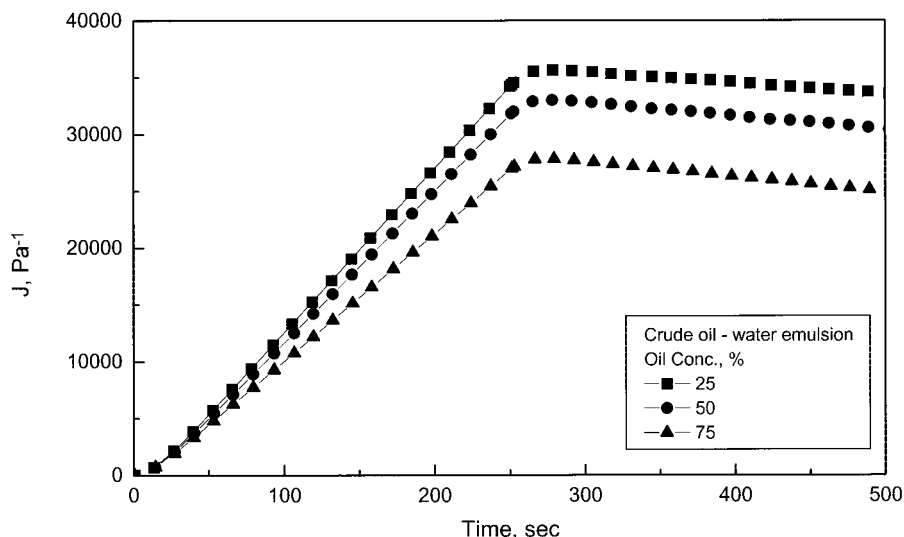


Figure 5 Crude oil-water emulsion compliance behavior.

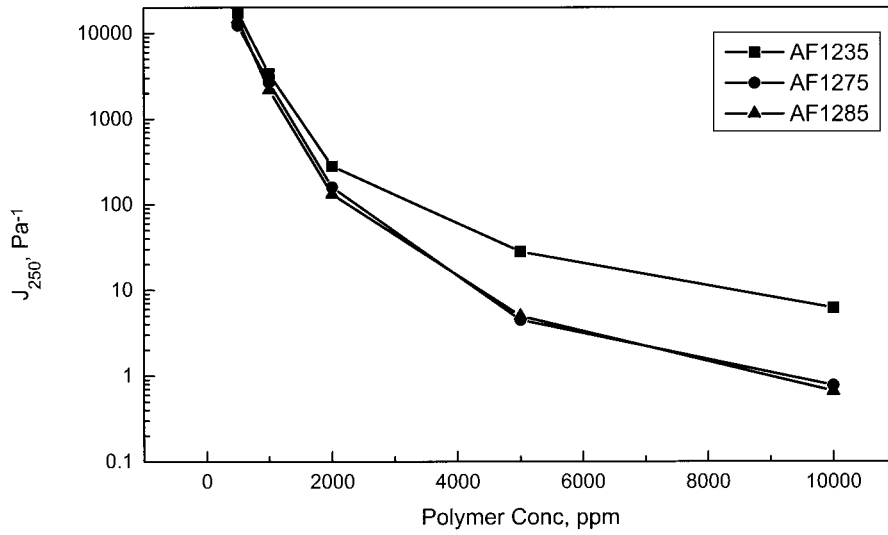


Figure 6 J_{250} versus concentration of polymer aqueous solutions.

Effect of concentration of polymer aqueous solutions

Figure 3 shows the compliance behavior versus time for different concentrations of AF1285 polymer aqueous solution over the range of 500 to 10^4 ppm as a typical example for the other employed polymers. The polymer concentration plays a significant role in the behavior and magnitude of polymer compliance. The lower the concentration of polymer added the higher the compliance will be. For example, at time of stress applied of 250 s, the compliance reaches $15,000 \text{ Pa}^{-1}$ for 500 ppm, whereas it drops to 0.6 Pa^{-1} for 10^4 ppm. All concentrations of AF1285 show viscoelastic behavior with different degrees of recovery. The degree of recovery increases with polymer concentration.

Effect of different polymer aqueous solutions

Figure 4 shows the viscoelastic behavior of 2000 ppm polymer aqueous solution for the three tested Alcoflood polymers. Under similar test conditions, AF1235 shows the highest compliance values among the three tested Alcoflood polymers. Much less compliance is reported for the other two polymers, AF1275 and AF1285, than for AF1235. The conclusion stands for other polymer concentrations. The greater the concentration of Alcoflood added, the wider the gap between the behavior of AF1235 on one side and the behavior of AF1275 and AF1285 on the other side. For example, at a concentration of 10^4 ppm, the creep-recovery behavior of AF1275 and AF1285 almost coincides and

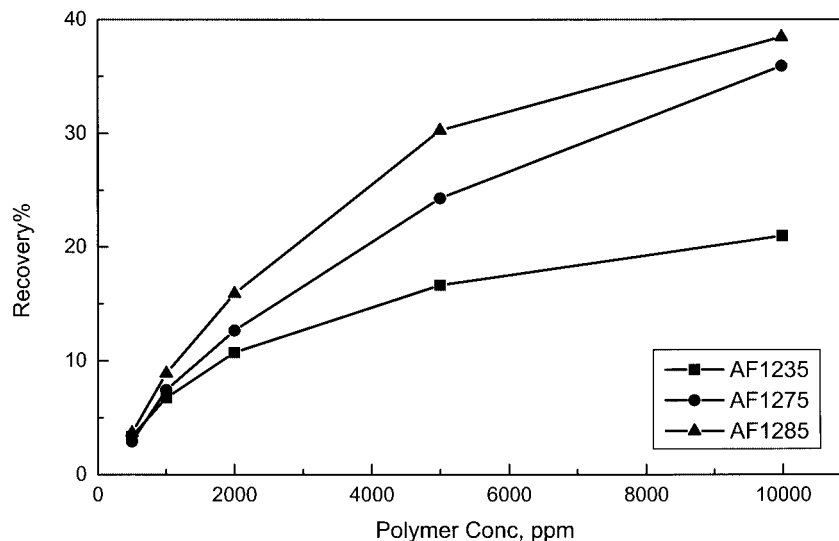


Figure 7 Recovery behavior of Alcoflood aqueous solutions.

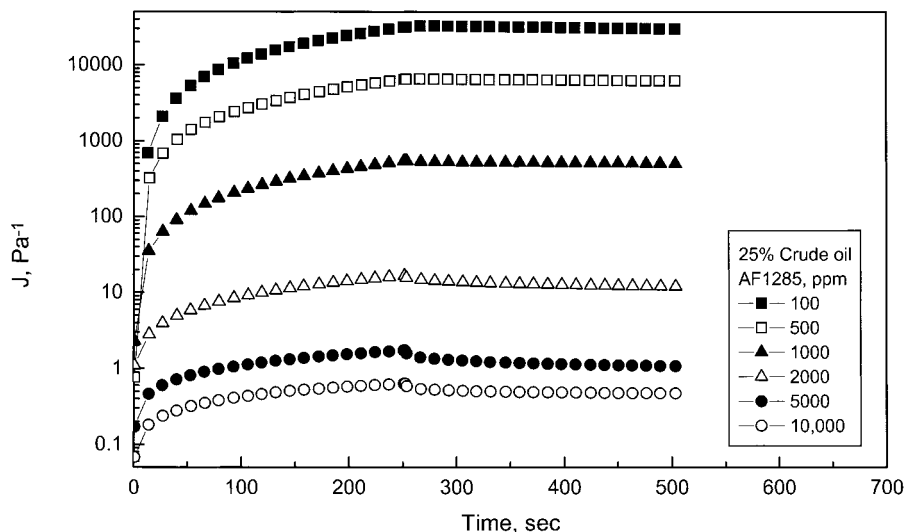


Figure 8 Compliance behavior of crude oil-AF1285 emulsion.

is far from the behavior of AF1235. This is due to the intrinsic viscosities of AF1285 and AF1275 being much closer and higher than the intrinsic viscosity of AF1235.

Creep-recovery behavior of oil-water emulsion

The creep-recovery behavior of crude oil-water emulsion for the oil concentration range of 0-75% is reported in Figure 5. The compliance measurement of crude oil-water emulsion decreases gradually with crude oil concentration. The compliance of 25% crude oil-water emulsion reaches 34,221 Pa⁻¹ at 250 s of applied stress. However, this value decreases to 31,848 and 27,034 Pa⁻¹ for 50 and 75% crude oil-water emulsion respectively. After 250 s of applied stress in the

creep mode, the applied stress is released and the recovery mode is reported over time for another 250 s. Figure 5 shows a linear gradual recovery response till the end of the test period. The compliance values of the three tested emulsions at 500 s are 33,571, 30,433, and 25,140, respectively. Therefore, the recovery % can be defined as

$$\text{recovery \%} = (J_{250} - J_{500}) \times 100 / J_{250} \quad (2)$$

The recovery % of the tested emulsions is 1.9, 4.4, and 7% for 25, 50, and 75% crude oil-water emulsions, respectively. These values of very low recovery % reflect the elastic portion within the crude oil-water emulsions. Therefore, these emulsions of crude oil-water are considered to display viscous behavior. The

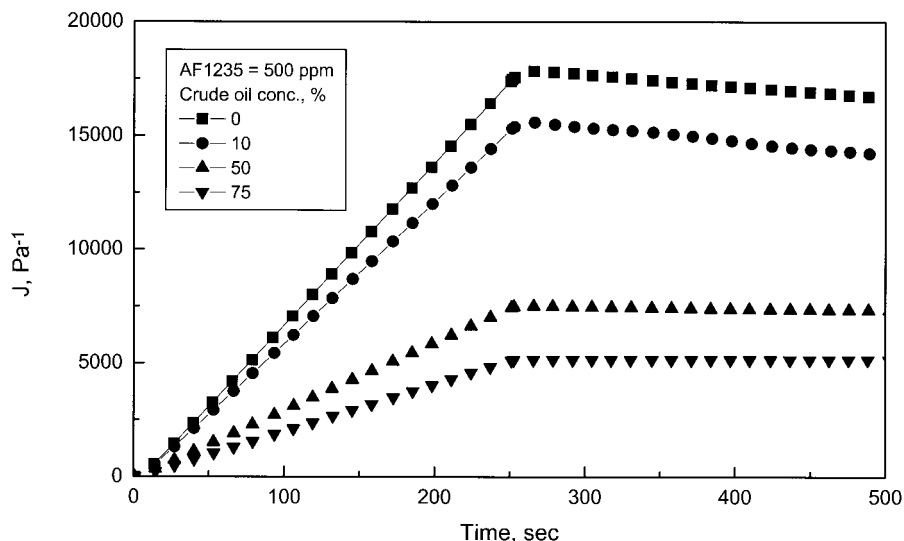


Figure 9 Compliance behavior of crude oil-low concentration of AF1235 emulsion.

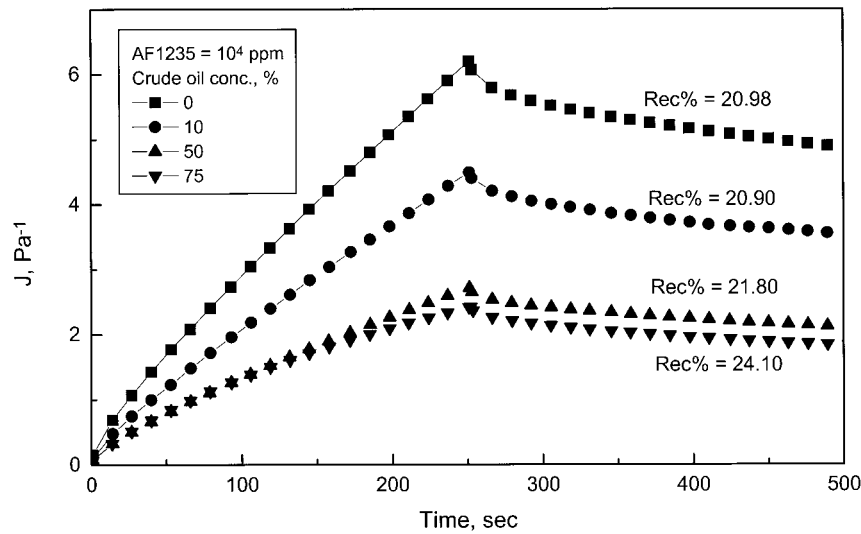


Figure 10 Compliance behavior of crude oil-high concentration of AF1235 emulsion.

recovery % of Alcoflood polymer aqueous solutions of AF1235, AF1275, and AF1285 for a 2000-ppm polymer concentration is 10.8, 12.7, and 15.9%, respectively. Figure 4 shows nonlinear recovery behavior for polymer aqueous solutions, which demonstrates viscoelastic behavior in comparison to crude oil-water emulsions. Figure 6 shows the compliance measurement at 250 s versus polymer concentration for the three tested Alcoflood materials. The compliance value decreases gradually with polymer concentration over 0 to 10^4 ppm. Also, AF1235 reports the highest compliance among the three tested polymers over the whole concentration, whereas the compliance measurements at 250 s for AF1275 and AF1285 are very close to each other. Figure 7 shows recovery % versus polymer concentration for the three Alcoflood polymers. In

general, recovery % increases gradually with polymer concentration and increases strongly for AF1235, AF1275, and AF1285, respectively. This conclusion can be attributed to the intermolecular interactions of the Alcoflood polymer within the aqueous phase. This means that the elastic characteristics increase significantly in the order of the AF1235, AF1275, and AF1285.

Creep-recovery behavior of oil-Alcoflood emulsion

Figure 8 shows the creep-recovery behavior of crude oil-Alcoflood polymer in terms of compliance versus time for a wide range of polymer concentrations. Figure 8 shows this behavior for 25% crude oil-AF1285 as a typical example of other emulsions. The compliance

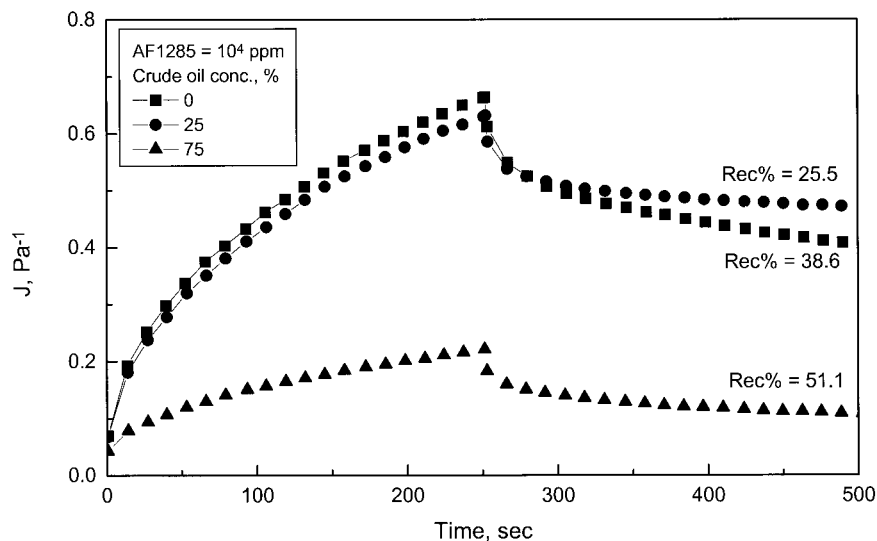


Figure 11 Compliance behavior of crude oil-high concentration of AF1285 emulsion.

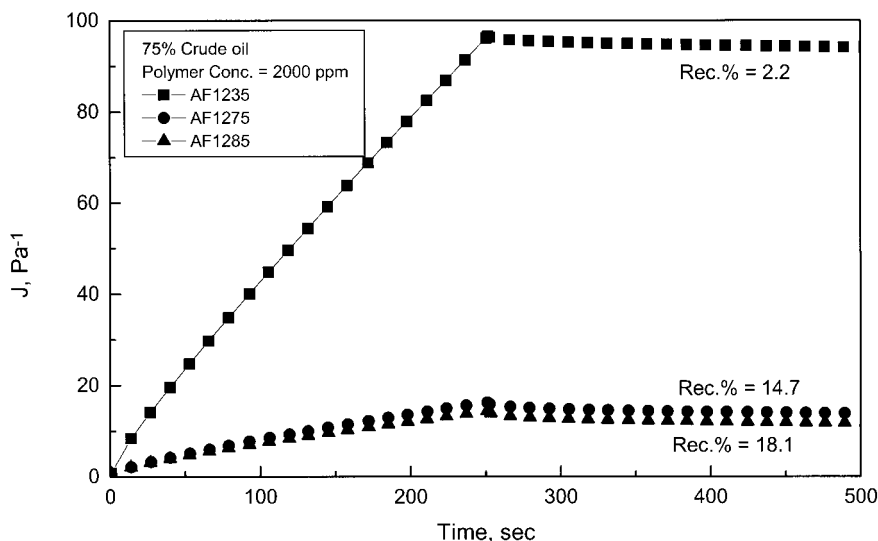


Figure 12 Effect of 2000 ppm of different Alcofloods on emulsion compliance behavior.

measurements of crude oil–polymer emulsions are a very strong function of polymer concentration. The compliance decreases significantly with polymer concentration over the range of 100–10⁴ ppm. The role of crude oil within the emulsion is discussed in Figures 9–11 to investigate the function of crude oil in viscous and viscoelastic different environments. Figure 9 shows viscous behavior of a low concentration of AF1235; the crude oil emulsions demonstrate high values of compliance that reach to 17,500 Pa⁻¹ for 0% oil concentration. The addition of crude oil decreases gradually the reported values of compliance up to 75% crude oil. Figure 10, in the presence of 10⁴ ppm AF1235, shows the viscoelastic behavior of crude oil–AF1235 emulsions. The emulsion in this case demon-

strates a much lower value of compliance with a significant recovery part. The addition of crude oil lowers gradually the compliance values and slightly increases the recovery part. Therefore, the addition of crude oil enhances slightly the elastic portion of the crude oil–polymer emulsion. Figure 11 shows a different type of emulsion behavior for crude oil–AF1285 in the presence of 10⁴ ppm polymer concentration. This emulsion shows strong viscoelastic behavior with a significant portion of the elastic part. The addition of 25% crude oil slightly modifies the creep–recovery response. However, the addition of more crude oil will significantly lower the compliance measurements and increase the recovery % from 38.6 for no oil added to 51.1% in the presence of 75% oil added.

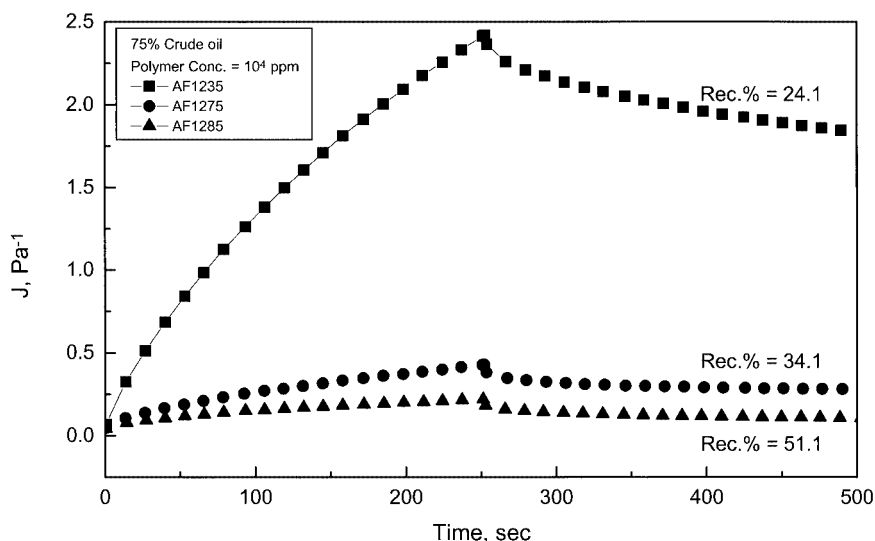


Figure 13 Effect of 10⁴ ppm of different Alcofloods on emulsion compliance behavior.

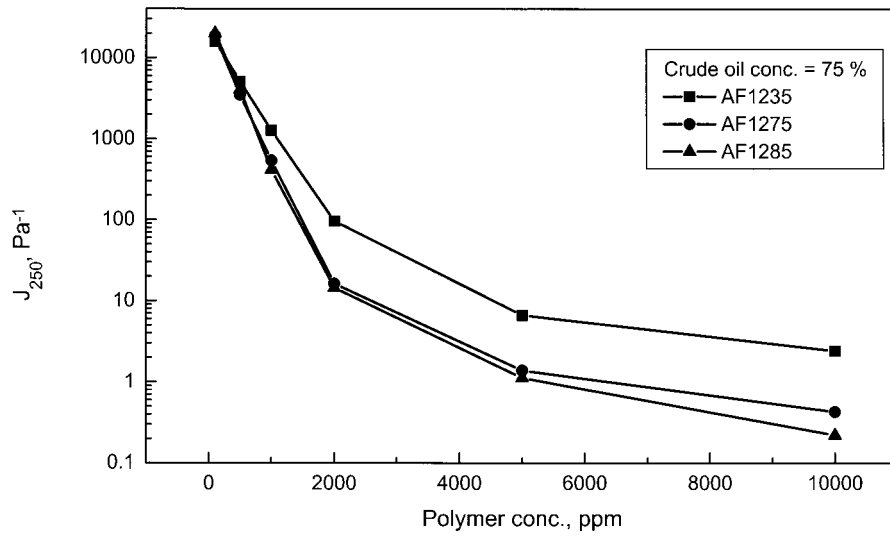


Figure 14 J_{250} versus polymer concentration for crude oil–Alcoflood emulsions.

Creep–recovery of different Alcoflood polymer emulsions

The compliance measurements of AF1235, AF1275, and AF1285 for 75% crude oil emulsion are presented in Figures 12 and 13 for polymer concentrations of 2000 and 10^4 ppm, respectively. Figure 12 shows that the emulsion of AF1235 demonstrates higher compliance than the other two polymers with almost 2.2% recovery, which can be considered viscous behavior for low polymer concentration. The other two emulsions demonstrate much lower compliance values, with recovery % of 14.7 and 18.1%, respectively. Therefore, the emulsions of AF1275 and AF1285 demonstrate viscoelastic behavior even at low concentrations of polymer. Figure 13 shows a similar effect for polymer concentration of 10^4 ppm. The AF1235 emulsion shows viscoelastic behavior with 24.1 recovery %. The other two emulsions show much less compliance in comparison with AF1235 emulsion. AF1275 and AF1285 emulsions show viscoelastic behavior with recovery % of 34.1 and 51.1, respectively.

Figure 14 shows the effect of AF1235, AF1275, and AF1285 on the 75% crude oil emulsion compliance

measurements at 250 s versus a wide range of polymer concentrations (100 – 10^4 ppm). In general, the compliance measurement decreases gradually and significantly with polymer concentration. For low concentrations of polymer up to 500 ppm, no significant differences are reported for the three Alcoflood polymers. Beyond this polymer concentration, AF1235 crude oil emulsion reports much higher compliance than the other two polymers because AF1235 has much lower average molecular weight than the other two Alcoflood polymers. The crude oil emulsions of AF1275 and AF1285 report similar behavior up to a polymer concentration of 2000 ppm. However, for higher concentrations, it is noticed that AF1275 emulsion causes a slightly higher compliance value than the AF1285 emulsion. Tables I–III report the compliance value at 250 s for the three Alcoflood crude oil emulsions. These tables show that the presence of crude oil decreases the compliance measurements significantly for all Alcoflood materials due to the internal interaction between crude oil and Alcoflood polymer molecules, which reduce the fluidity behavior of these types of emulsions.

TABLE I
 J_{250} for Crude Oil–AF1235 Emulsion

Crude oil, %	0	10	50	75
AF1235, ppm				
100	35000	34832.1	23169.1	15917.2
500	17392.9	15320.5	7441.1	5111.2
1000	3398.1	3436.9	1801.7	1270.4
2000	281.8	298.4	140.0	96.5
5000	28.2	21.8	13.0	6.7
10000	6.2	4.5	2.7	2.2

TABLE II
 J_{250} for Crude Oil–AF1275 Emulsion

Crude oil, %	0	25	75
AF1275, ppm			
100	34000	33534.3	18646.3
500	12333.9	8758.6	3478.1
1000	2675.6	929.5	541.1
2000	160.2	27.7	16.3
5000	4.5	3.0	1.4
10000	1.3	0.983	0.429

TABLE III
 J_{250} for Crude Oil–AF1285 Emulsion

Crude oil, %	0	25	75
AF1285, ppm			
100	32000	31387.1	19904.5
500	14681.8	6456.3	4044.2
1000	2195.4	543.5	417.8
2000	132.9	16.7	14.5
5000	4.9	1.7	1.1
10000	0.663	0.432	0.221

Recovery behavior of crude oil–Alcoflood emulsions

Recovery behavior is investigated for all tested emulsions to study the effect of polymer concentration and type of Alcoflood. Figure 15 shows the role of Alcoflood polymer type on the recovery behavior of crude oil–Alcoflood emulsion in the presence of 75% crude oil. It shows that the type of Alcoflood strong dictates the recovery behavior of crude oil–polymer emulsion. AF1285 emulsion provides the highest recovery % while AF1235 emulsion achieves the lowest recovery % over the whole range of polymer concentration of 100–10⁴ ppm. Therefore, the elastic property of crude oil–Alcoflood polymer increases in the order of AF1235, AF1275, and AF1285.

Theoretical modeling of viscoelastic behavior

To understand the viscoelastic behavior of emulsions, which have a complicated chemical and physical internal structure, it is useful to study the emulsion responses under constant small shear stress over a period of time. Under this condition, the internal structure of an emulsion undergoes minimal deforma-

tion. The emulsion responses are characterized by two phases, the creep phase and the recovery phase (Figure 16a).

For Figure 16a, a constant stress τ_0 is applied at time equals zero and maintained for a period of t_0 . In response, the time dependence of creep compliance $J(t)$ can be given by

$$J(t) = J_0 + J_r(t) + J_v(t), \tag{3}$$

where J_0 is the instantaneous compliance, $J_r(t)$ is the retardation compliance, and $J_v(t)$ is the viscous flow compliance.

During the linear viscoelastic range, J_0 indicates the emulsion elastic property and it is reversible on the removal of the applied stress. The instantaneous elastic modulus E_0 can be calculated using the equation

$$E_0 = 1/J_0. \tag{4}$$

$J_r(t)$ represents the delayed elastic compliance and gradually decreases with time. This component shows elastic behavior and needs time to recover due to chain uncoiling.¹⁶ The viscous flow compliance, $J_v(t)$, represents the irreversible component of compliance. For viscoelastic emulsions, $J_v(t)$ increases gradually with time. Emulsions can be subjected to a shear stress, which lead to only a linear deformation after the instantaneous deformation, i.e., $J_r(t)$ is not available. At time t_0 , when the applied stress is released, the elastic compliance recovers instantaneously. However, the delayed elastic compliance recovers gradually with time. On the other hand, the viscous flow compliance will not be recovered.

The creep phase of crude oil–Alcoflood emulsions can be modeled using either the Maxwell fluid model

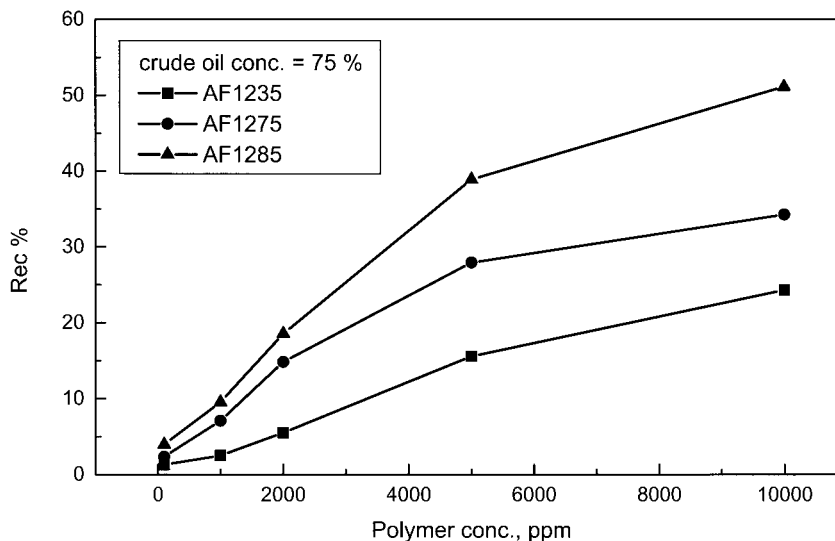
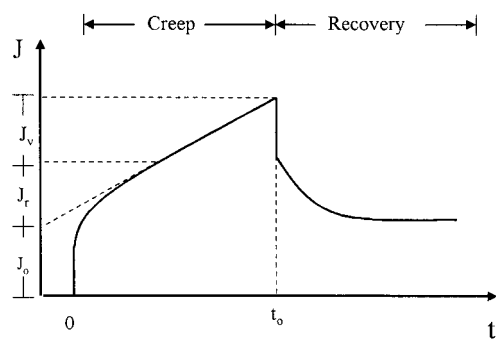
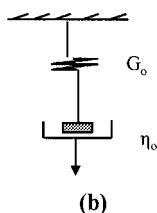


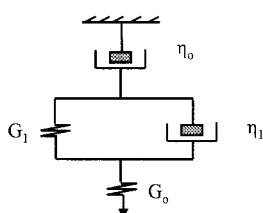
Figure 15 Recovery behavior of crude oil–Alcoflood emulsions.



(a)



(b)



(c)

Figure 16 Creep–recovery behavior for linear viscoelastic materials.

or the Burger model depending upon the availability of $J_r(t)$. The Maxwell model consists of a spring with modulus G_0 and dashpot with viscosity η_0 placed in series as in Figure 16b. The Maxwell model can be written as

$$\gamma(t) = (\tau_0/G_0) + (\tau_0/\eta_0)t. \quad (5)$$

The Burger model (Fig. 16c) consists of two springs with moduli G_0 and G_1 and two dashpots with viscos-

TABLE IV
Maxwell Model Analysis for 2000-ppm Polymer Emulsions

Polymer	Crude oil, %	G_0 , Pa	η_0 , Pa s
AF1235	25	0.447	0.974
AF1235	75	0.117	2.850
AF1275	25	0.271	10.470
AF1275	75	0.312	19.060
AF1285	25	0.241	19.990
AF1285	75	0.307	22.420

TABLE V
Burger Model Analysis for 10^4 -ppm AF1285 Emulsions

Crude oil, %	G_0 , Pa	η_0 , Pa s	G_1 , Pa	η_1 , Pa s
0	13.002	767.645	3.745	144.692
25	13.179	838.117	3.819	168.957
75	22.483	2429.344	13.431	527.868

ities η_0 and η_1 and can be described by the mathematical model as

$$\gamma(t) = (\tau_0/G_0) + (\tau_0/\eta_0)t + (\tau_0/G_1)[1 - \exp(-t/\lambda_1)], \quad (6)$$

where λ_1 is the relaxation time and is equal to (η_1/G_1) .

From the Results and Discussion, it is found that the crude oil–Alcoflood polymer emulsions with polymer concentration ranges of 0 to 5000 ppm can be described by the Maxwell model. However, the crude oil–Alcoflood polymer emulsions with polymer concentration of 10^4 ppm show delayed elastic deformation in addition to the instantaneous deformation and viscous flow deformation. Therefore, the 10^4 -ppm Alcoflood polymer–crude oil emulsions can be described adequately with the Burger model. These results are concluded, as well, from the simulation analysis using the Maxwell and Burger models. These results are reported in Tables IV–VI.

Table IV shows the Maxwell parameters of η_0 and G_0 for crude oil–Alcoflood emulsions with polymer concentration of 2000 ppm. However, Tables V and VI show the Burger parameters of η_0 , G_0 , η_1 , and G_1 for different emulsions with polymer concentration of 10^4 ppm. The Burger parameters listed in Tables V and VI are much higher than that provided by Maxwell analysis (Table IV) due to the higher concentration of the polymer employed. Table V shows that the viscoelastic parameters increase significantly with the addition of more crude oil due to the strong intermolecular interaction between the molecules of crude oil and AF1285 polymer. The modeling analysis using the Burger model for emulsions of 75% oil and 10^4 ppm polymer shows that the degree of viscoelasticity increases significantly in the order of AF1235, AF1275, and AF1285 due to the elastic component of the emulsion increases in the same order. The predictions of the

TABLE VI
Burger Model Analysis for 75% Oil and 10^4 -ppm Polymer Emulsions

Polymer	G_0 , Pa	η_0 , Pa s	G_1 , Pa	η_1 , Pa s
AF1235	13.085	182.297	0.978	82.848
AF1275	20.038	960.450	8.457	324.242
AF1285	22.483	2429.344	13.431	527.868

Burger model agree very well with the results presented in Figure 12, i.e., the AF1235 emulsion is higher and far away from the behavior of AF1275 and AF1285. The crude oil emulsions of AF1275 and AF1285 show stronger viscoelastic behavior due to the uncoiling structures that formed within the emulsions, which causes a higher portion of elastic component for viscoelastic emulsion.

CONCLUSION

Creep–recovery experimental investigation is carried out to study the viscoelastic behavior of the crude oil–Alcoflood polymer emulsion. The following conclusions can be made:

1. The creep–recovery behavior shows that applied shear stress of up to 1.0 Pa will cause linear viscoelastic range;
2. The polymer concentration significantly influences the behavior and magnitude of the aqueous polymer compliance;
3. AF1235 Alcoflood polymer results in a higher compliance value than AF1275 and AF1285. The compliance decreases gradually with polymer concentration over 0–10⁴ ppm;
4. For polymer aqueous solution, recovery % increases gradually with polymer concentration and with the order of AF1235, AF1275, and AF1285;
5. The compliance measurement of crude oil–water emulsion decreases gradually with crude oil concentration. The crude oil–water emulsion exhibits linear recovery response with a maximum of 7% recovery for 75% crude oil–water emulsion. Therefore, crude oil–water emulsion shows viscous behavior;
6. The compliance of crude oil–Alcoflood emulsions decreases significantly with polymer concentration;
7. The presence of crude oil within a viscous or viscoelastic environment causes gradual reduction to compliance measurements and increases recovery %.
8. For a low polymer concentration of 2000 ppm, 75% crude oil emulsion of AF1235 shows viscous behavior, whereas the crude oil emulsions of AF1275 and AF1285 show viscoelastic behavior;
9. For a high polymer concentration of 10⁴ ppm, 75% crude oil emulsions of AF1235, AF1275, and AF1285 show viscoelastic behavior with recovery % of 24.1, 34.1, and 51.1, respectively;
10. Over the whole examined polymer concentration, AF1285 emulsion results in the maximum recovery %, whereas AF1235 emulsion results in the minimum recovery %. Therefore, the elastic property of crude oil–Alcoflood polymer increases in the order of AF1235, AF1275, and AF1285;
11. The Maxwell model can be used to simulate the viscoelastic behavior of crude oil–Alcoflood polymer emulsions over the polymer concentration range of 0 to 5000 ppm, whereas the Burger model covers the higher polymer concentration range.

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