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Improvement of rheological properties of Algeria crude oil by addition of extra-light crude oil and a surfactant agent

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ABSTRACT

Effect of surfactant and extra-light crude oil addition on the rheological behaviors of an Algeria crude oil in order to improving its flowability were studied at low temperature. These rheological properties include steady flow behavior, yield stress and viscoelastic behavior. An AR-2000 rheometer was employed in all of the rheological examination tests. Results show that Toluene and extra-light crude oil addition causes a strong reduction in viscosity, the yield stress and can effectively increase of crude oil transport capacity. The toluene addition gets its best flow capacity and lowest viscosity at 6%. The extra-light crude oil addition obtains its best flow capacity and lowest viscosity at 50%. The viscoelasticity character of the crude oil has indicate a significantly influence by the addition of Toluene and extra-light crude oil.

KEYWORDS

additive; apparent viscosity; crude oil; viscoelasticity character; yield stress

1. Introduction

After oil recovery, transporting crude oil to export or pre-refining stations is a major challenge. The complexity of petroleum comes from the oil composition in terms of surface active molecules contained in the crude, such as asphaltenes, resins and naphthenic acids (Alvarez 2008). Asphaltenes and resins are the two main components in the heavy and polar fraction of petroleum fluids. It is widely assumed that the asphaltene molecules in oils agglomerate to form micelle-like clusters (Badger and Schobert 1998). Interactions between these clusters contribute towards the viscosity of the oils. By breaking these agglomerates, apart viscosity will be reduce. These deposition problems are not only produced during the operation of heavy oil With a high asphaltenes content, but also in the case of oils that are poor in asphaltenes (0.3–0.5%), as in the Hassi Messaoud field in an Algerian (Malika 2008). This phenomenon seriously affects the transport operations and generates a significant increase in costs due to the prevention and disposal of deposits. In order to improve the flow properties of crude oil, pretreatment is necessary for transportation of these asphaltanic crudes through the pipeline. The transport in the form of oil-in-water (O/W) emulsions (Hemmingsen et al. 2005), enhanced (EOR) or improved oil recovery (IOR) through thermal processes (Mowla and Naderi 2006). The main difficulty with using these methods is the selection emulsifier and high cost of the heating technique especially over long distances of pipelines. The adding of copolymers, surfactant agents named (DRA) and the blending of crude oil with a distillate fraction or with extra-lighter oils are the most common techniques to optimize the conditions of transport and mobility of heavy oil at the surface or reservoir

Table 1. Sample characteristics of crude oils used in this study

Parameters	DJOWA crude oil	CTFN crude oil
Asphaltenes (%)	0.4	1.5
Liquid density (26°)	0.801	0.847
Tanker Vapor Recovery TVR-(35.5°)	351	339
Basic sediment and water (BS&W) (%)	0.05	0.05

conditions include the crude oil asphaltting. The basis of these methods lies in the fact that as the apparent viscosity of crude oil is reduced significantly; the crude oil will be easier to pump. In this sense, more recent studies have been carried out on the effect of extra-light crude oil or surfactants on rheological properties of crude oil or synthetic crude oil. The effect of several additive such as poly alkyl acrylates and methacrylate copolymers (Ritter et al. 1989) alkyl esters of styrene-maleic anhydride copolymers (Koch and Long 1987), alkyl acrylate-alkyl maleate copolymers (Noda and Kuzutani 1989) ethylene-vinyl acetate copolymers (Song, Huang and Pan 1989) alkyl fumarate-vinyl acetate copolymers (Borthakur et al. 1995), the Sodium Dodecyl Benzene Sulfonate (SDBS) as a surfactant (Rassoul and Hadi 2007; Djemiat et al. 2015) are some of the flow improver and pour point and depressant of crude oil. These authors have found that the viscosity, the yield stress and the pour point were significantly influenced by the additive concentration and the temperature. An other study has been realized by (Badger and Schobert 1998) on viscosity reduction of crude oil by addition of several dispersants with differing physical and chemical properties. It has been shown that the viscosity of extra heavy crude oils can be reduced to a greater extent using some additive compounds (Acetophenone, ethylbenzene, Toluene), when compared to using the conventional diluent kerosene (Badger and Schobert 1998). According to (Ghannam et al. 2012). The addition of 10% light crude oil to the heavy crude oil causes a strong reduction in the viscosity of the heavy crude oil. These authors have found that the rheological parameters were significantly influenced by the light crude concentration and the temperature. The main objective of this study is to investigate the rheological properties of Algerian crude oil as well as its mixture of toluene and extra-light crude oil.

2. Materials and samples preparations

The crude oils samples, CTFN crude oil with density 847 kg/m³ and DJOWA crude oil with density 801 kg/m³ at 26 °C, from TFT sector-Tin Fouye Tabankort/South Algeria. The physicochemical properties of these samples are detailed in Table 1.

The compound toluene was selected as a surfactant in this work. This additive is chosen for its good effectiveness in improving the flow characteristics (Badger and Schobert 1998). In order to prepare the studied samples, the CTFN crude oil was mixed with different concentrations of surfactant and with DJOWA crude oil in order to prepare samples of 50 mL. The samples were homogenized by shaking it in an incubator shaker model Heidolph MR3001k at 250 rpm at 15 °C for 30 min to form homogeneous mixture.

2.1. Apparatus and tests procedure

All rheological tests were carried out using AR-2000 rheometer with geometry couette (Figure 1).

The test procedure used in this study is: the crude oil samples will be subjected to a pre-shear of 1000 s⁻¹, to erase its memory. All the samples will be subjected to a pre-shear for 60 s with a shear rate of 0.15 s⁻¹, for a correct homogenization of the sample (Al-Roomi et al. 2004). The samples are then left to settle for 2 min to homogenize temperature before the test begins before the acquisition procedure of data is started. All the rheometer tests were carried out at low temperature 15 °C.



Figure 1. AR-2000 Rheometer measuring instrument.

3. Results and discussion

3.1. Rheological behavior of untreated crude oil

The rheological data, of the CTFN crude oil and DJOWA crude, is illustrated in Figures 2 and 3. The flow curves at high shear rates exhibit similar patterns where a gradual increase of shear stress is observed with the increase of shear rate. The flow curves show clearly the non-Newtonian pseudo-plastic character of the crude oils (Figure 2). Indeed, there is no flow when the applied shear stress is lower than a critical value (called yield value). At a limited shear stress, the dissipated energy is high enough to overcome the yield stress and start flow which is reflected by increasing the shear stress. (El-Gamal and Gad 1997).

In Figure 3, the experimental results show the existence of two different regions: one at a low shear rate and the other at a high shear rate. The apparent viscosity of the oil decreases

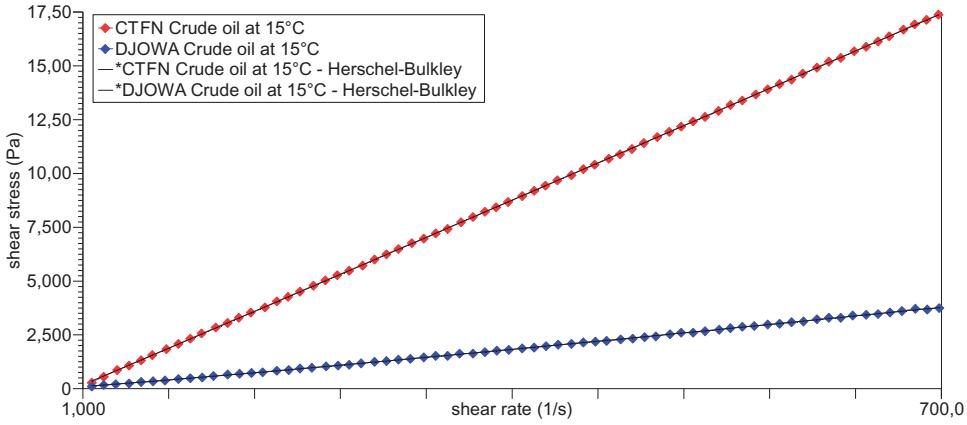


Figure 2. Flow curve of CTFN and DJOWA crude oil at 15 °C.

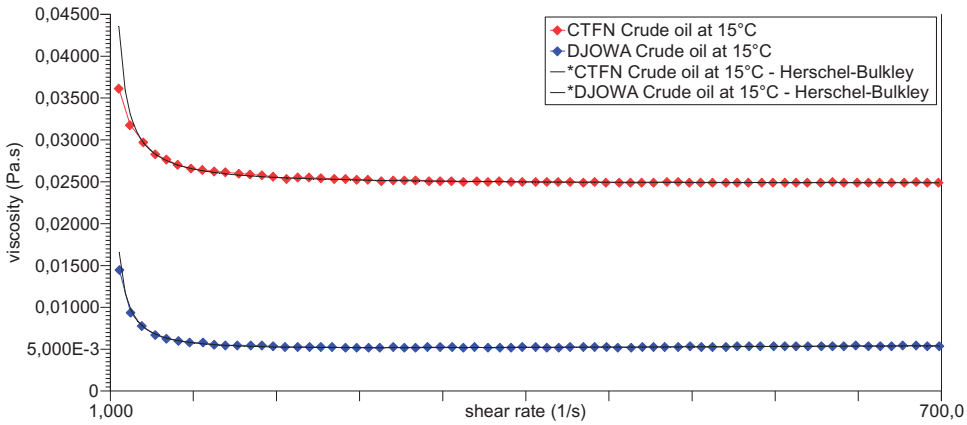


Figure 3. Viscosity curve of CTFN and DJOWA crude oil at 15 °C.

significantly in the first region until the shear rate is greater than 350 s⁻¹. While for the high values of shear rate (more than 350 s⁻¹), the apparent viscosity is stabilized and remains constant. It is clear that the viscosity of the CTFN crude oil is greater than the viscosity of DJOWA crude oil. It was also found experimentally that, at equal shear rates; the shear stress of the sample (crude oil CTFN) is higher than that of the solutions (Djowa crude oil). Therefore less amount of energy is given to the decrease in the viscosity of the sample DJOWA crude oil.

3.2. Modeling of rheological properties

The rheological behavior of crude oils was considered a crucial parameter in the design of a pipeline. To study the samples of the mixture crude oil and the crude oil containing the surfactant, it is necessary at first, to identify the rheological behavior of untreated crude oil. The rheological modeling was carried out using different rheological models. Four different rheological models namely the (Casson 1959), the (De Waele 1923), the (Herschel and Bulkley 1926) model and the (Bingham 1922); the rheological parameters of crude oil studied are given in Table 2.

$$\tau = \tau_c + k\dot{\gamma}^n \quad (1)$$

Table 2. Rheological parameters in the case of various models

Temperature 15 °C					
regions	Rheological Model	Error standard	Rheological parameters		
			rate index (n)	K (Pa.s)	yield stress (Pa)
CTFN crude oil	De Waele	2.62785	/	/	/
	Casson	1.89737	/	/	/
	Bingham	1.18674	/	/	/
	H-B	1.0539	1,004	0,02403	0.2968
DJOWA crude oil	De Waele	9.22619	/	/	/
	Casson	577.956	/	/	/
	Bingham	9.07339	/	/	/
	H-B	3.46317	1,093	2,853E-3	0,1179
CTFN crude oil+ 50% DJOWA crude oil	De Waele	4.07117	/	/	/
	Casson	3.01093	/	/	/
	Bingham	1.90217	/	/	/
	H-B	1.61573	1,009	0,01347	0,2070
CTFN crude oil+ 6% Toluene	De Waele	4.23493	/	/	/
	Casson	2.22015	/	0,01470	0,02159
	Bingham	4.15769	/	/	/
	H-B	2.64435	/	/	/

Where: (τ_c): Herschel yield parameter; (k): Consistency index; (n): index of structure

$$\tau = K\dot{\gamma}^n \quad (2)$$

Where: (K): De Waele Constants; (n): index of structure.

$$\tau^{1/2} = k_1 + k_2\dot{\gamma}^{1/2} \quad (3)$$

Where: (k_1): Casson yield parameter, (k_2): Casson viscosity parameter.

$$\tau = \tau_c + k\dot{\gamma} \quad (4)$$

Where: (τ_c): Bingham yield parameter; (k): Consistency index.

The rheological models calibrated the results of different samples and it was found that they were obeying the De Waele model with a weak behavior index and a yield stress. Depending on the crude oil sample, the rheological behavior was distinguished as Herschel–Bulkley model for samples of CTFN crude oil, DJOWA crude oil and blend (CTFN crude oil +50% DJOWA crude oil), Casson model for sample (CTFN crude oil +6% Toluene).

3.3. Rheological behavior of treated crude oil

3.3.1. Steady flow behavior: (CTFN crude oil/DJOWA crude oil)

The flow tests and the rheological characterization are carried out according to the protocol defined previously. Figures 4 and 5 shows the flow and viscosity curves of the systems (CTFN crude oil/DJOWA crude oil).The results obtained show that addition to a small amount of DJOWA crude oil can reduce the viscosity and the shear stress of the CTFN crude oil.

It has been observed that the effect of extra-light crude is an increasing function of the concentration, but for a solution concentration of 50% of very light crude, it is noted that any additional addition of extra-light crude oil does not modify the viscosity.

Probably the reduction of apparent viscosity of CTFN crude oil by addition the addition of extra-light crude oil (DJOWA) can be attributed to its high API gravity and its effectiveness in the dilution of heavy crude oil, which can alter the stability of asphaltene leading to flocculation of asphaltene (Argillier et al. 2006) suggested that the breaking of the colloid system of the heavy crude oil through asphaltene precipitation will have a definitive effect in the crude oil viscosity reduction.

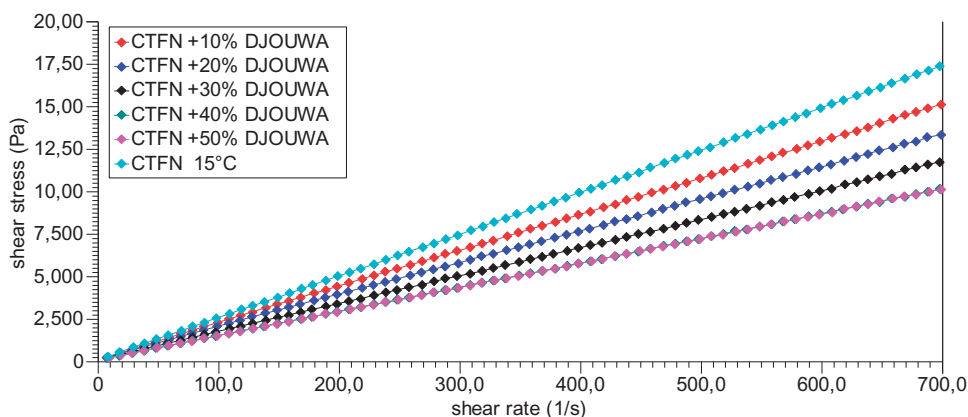


Figure 4. Flow curves of the treated crude oil (CTFN crude oil/DJOUWA crude oil).

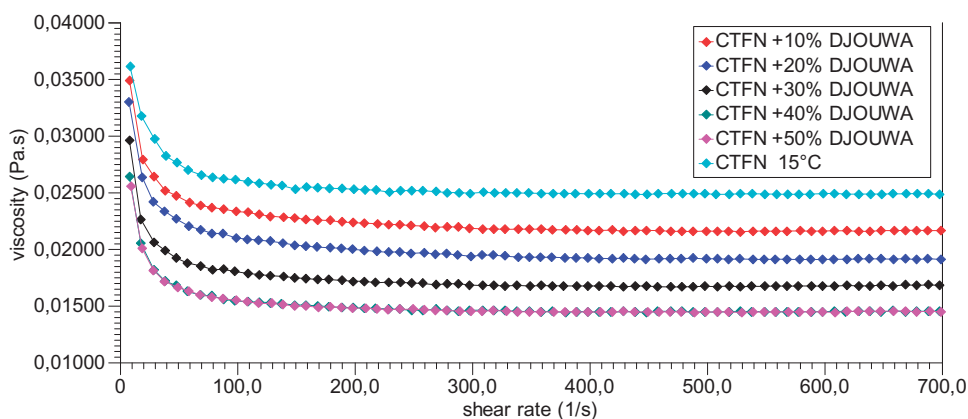


Figure 5. Viscosity flow of the treated crude oil (CTFN crude oil/DJOUWA crude oil).

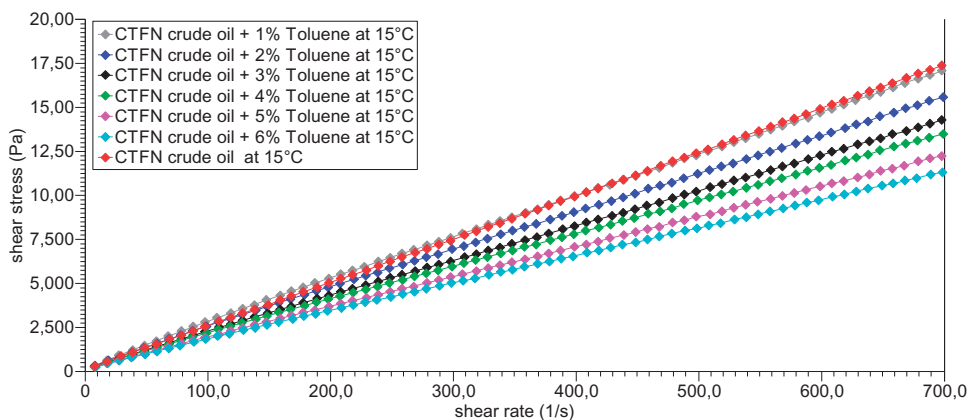


Figure 6. Flow curves of the treated crude oil with different concentration of toluene.

3.3.2. Steady flow behavior: (CTFN crude oil/Toluene)

The results of the apparent shear stress and viscosity of (CTFN crude oil/Toluene) at different concentrations (1–6%) are given in Figures 6 and 7.

According to these figures, it has clearly seen that the viscosity decreases with addition of the toluene. The reduction of viscosity is probably due to the presence of π electrons in the ring may

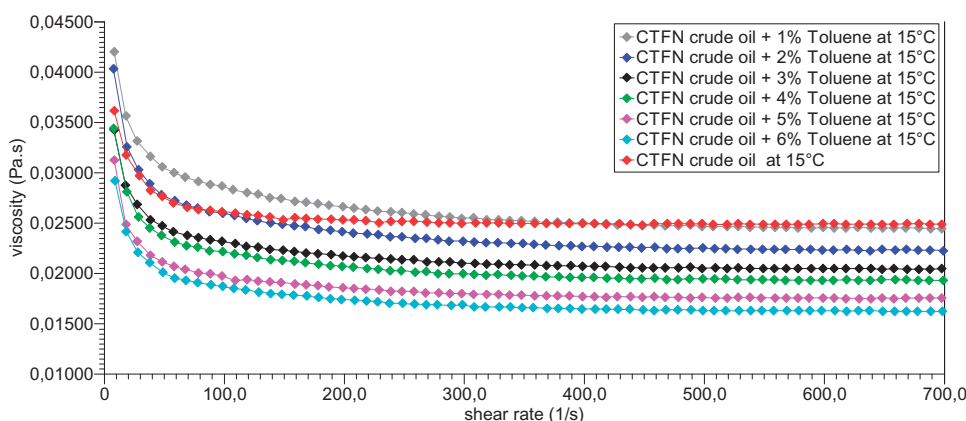


Figure 7. Viscosity flow behavior of the treated crude oil with different concentration of toluene.

play a role in the interaction between the compounds added and the π electrons in the poly-aromatic systems of the asphaltene agglomerates (Badger and Schobert 1998).

3.4. Yield stress measurements

An analysis based on the Herschel–Bulkley model was used to determine the yield stress for each sample at different concentrations of additives. The yield stresses of different samples are shown in Figures 8 and 9.

The results presented indicate that the yield stress reduction is depended on the type of the additive used. Toluene achieves the best performance as yield stress depressant at a high concentration 5%, from this concentration, a loss of efficiency was observed may be ascribed by total dilution of the medium producing lower viscosity induced by the toluene.

The adding of Djowa crude oil, shows their efficiency as a yield stress reducer at the concentration range tested, nonetheless, it is interesting to note that in this concentration range, Djowa crude oil addition also loses its efficiency as yield stress reducer at optimum performance concentration at 50%. By comparing of toluene and DJOWA crude oil adding, degree of yield stress reduction increased with increase in concentration for the surfactant and extra light crude oil used in our study (Table 3). The highest degree of yield stress reduction ($DVR = 30.25\%$) was observed for extra-light Djowa crude oil at higher concentration (50%). For the toluene, the best performance as yield stress depressant ($DVR = 13.40\%$) was obtained at concentration 6%.

3.5. Flow simulations

The shear stress is considered an injection pressure or a flow of crude oil in pipelines. The enhancement of pressure drop can be calculated by use of the Blasius single phase flow equation. The enhancement of pressure drop, $E\Delta P$ (Urdahl, Fredheim, and Loken 1997); owing to enhancement in viscosity, in a single phase flow may be calculated by:

$$E\Delta P = n^{0.25} \quad (4)$$

Where n : is the viscosity of the liquid.

The pressure drop results for pure CTFN crude oil and for the crude oil containing (Toluene and DJOWA crude oil) at the same shear rate 500 s⁻¹ are shown in Table 4. As seen in Tableau. 4, when toluene or DJOWA crude oil is used then the measured pressure drop decrease gradually than pure crude oil (CTFN crude oil). The performance of DJOWA crude oil strongly depends on the concentration there is an optimum concentration to obtain the best efficiency.

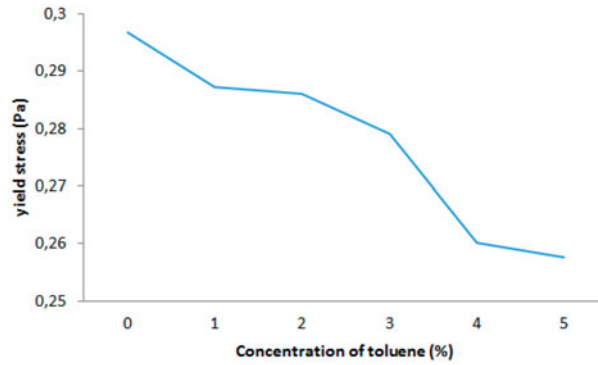


Figure 8. Effect of Toluene concentration on the yield stress of CTFN crude oil.

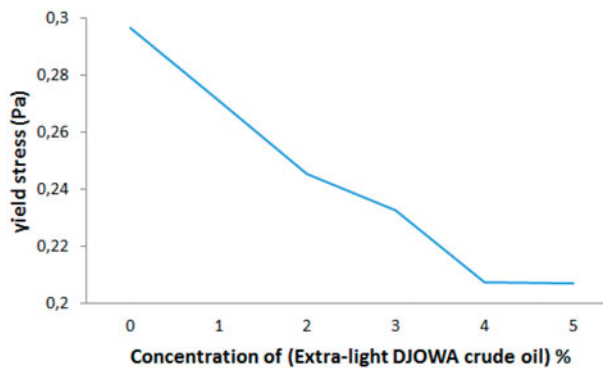


Figure 9. Effect of extra-light Djowa crude oil on the yield stress of CTFN crude oil.

Table 3. Evolution of yield stress and its reduction rate as a function of additives

Yield stress (Pa)						
without Additive	Concentration of Toluene (%)	with additive	% reduction of yield stress	Concentrations of DJOWA crude oil (%)	with additive	% reduction of yield stress
0.2968	1	0.2872	3.23	10	0.2711	8.65
	2	0.2860	3.63	20	0.2452	17.83
	3	0.2791	5.96	30	0.2327	21.59
	4	0.2602	12.33	40	0.2071	30.22
	5	0.2576	13.20	50	0.2070	30.25
	6	0.2570	13.40	/	/	/

Table 4. La chute de pression en fonction de la viscosité pour différentes concentrations

Shear rate (s^{-1})	Concentration of Toluene (%)	Viscosity (Pa.s)		Concentration of DJOWA crude oil %	Viscosity (Pa.s)	
			EΔP (Pa)			EΔP (Pa)
500	0	0,02493	0.397	0	0,02493	0.397
500	1	0,02469	0.396	10	0,02164	0.383
500	2	0,02251	0.387	20	0,01917	0.372
500	3	0,02050	0.378	30	0,01676	0.359
500	4	0,01946	0.373	40	0,01451	0.350
500	5	0,01764	0.364	50	0,01450	0.347
500	6	0,01628	0.357	/	/	/

Table 5. Performance du débit en fonction des concentrations en additifs

Concentrations of Toluene (%)	Shear rate $\dot{\gamma}$ (s ⁻¹)	Flow rate (l/s)	Concentrations of DJOWA crude (%)	Shear rate $\dot{\gamma}$ (s ⁻¹)	Flow rate (l/s)
0	408,2	320,43	0	408,2	320.43
1	408,2	320,43	10	468,6	367.85
2	447,6	351,36	20	527,4	413.69
3	497,8	399.77	30	607,9	477.20
4	527,5	414.08	40	697,4	547.45
5	577,8	453.57	50	698,6	548.40
6	628,0	486.70	/	/	/

The experimental results (Figures 5 and 7) show the existence of two different regions: one at low and the other at high shear rate. For the high shear rate values, the apparent viscosity is stabilized and remains constant and the behavior of the liquid becomes Newtonian, in this second region where the crude studied can be described by the Newtonian model the enhancement of flow rate, (Q), owing to enhancement in viscosity, can be described by:

$$\dot{\gamma} = \frac{4Q}{\pi R^3} \quad (5)$$

Where: ($\dot{\gamma}$): shear rate; Q: volume flow rate applied in the cell, R: cell radius

Table 5 reports the measures of shear rate of CTFN crude oil at various additive concentrations at the same shear stress (10 Pa). From Eq. (5), we can calculate the flow rates corresponding to differentes shear rate. According to these results, it is clearly seen that the flow rate increases with addition of the toluene surfactant and DJOWA crude oil concentration. This study showed that treatment of CTFN crude oil with lighter crude oil alone is sufficient for improving the flow behavior and facilitate its flow mobility through the pipeline. On addition of 50% DJOWA crude oil, the flow rate of CTFN crude oil increased from 320.43 to 548.40 l/s. In the case of Toluene treated CTFN crude oil, the flow rate was increased to 486.7 l/s from 320,43 l/s by addition of 6% of toluene.

4. Viscoelastic behavior of studied crude oil (study in dynamic mode)

To study of the viscoelastic nature of the crude, two parameters were measured, the elastic modulus G' and the viscous modulus G'' . Figure 10(a,b) shows the evolution of G' and G'' of the treated crude oil a function of the frequency.

The measurement results show that the viscous modulus, G'' reaches values that are higher than the values of the elastic modulus G' at different samples and the throughout the tested frequency. The viscous modulus of the CTFN crude oil decreases significantly by the addition of 6% of toluene and 50% of DJOWA crude oil as can be seen in the Figure 10(a). This figure (Figure 10(a)) illustrates that the viscous modulus takes lower values with the addition of 50% of Extra-light crude oil compared to values of profile with addition of 6% of toluene. This concentration (50% of Extra-light) corresponds to the lowest values of viscosity shown in Figures 5 and 7. (Ghannam et al. 2012). Figure 10(b) illustrates clearly the great influence of the toluene on the elastic modulus (G') of CTFN crude oil. The elastic modulus increases significantly with addition of toluene, it is also clear that the addition of extra-Light has less effect on the CTFN crude oil viscoelastic behavior than the toluene. This difference can be attributed to the addition of DJOWA crude oil did not give the chance of the high molecular weight components of CTFN crude oil, such as asphaltenes, resins and wax to agglomerate and form aggregates, and consequently affecting the bonds between the solid particles and eventually reducing the oil elastic modulus.

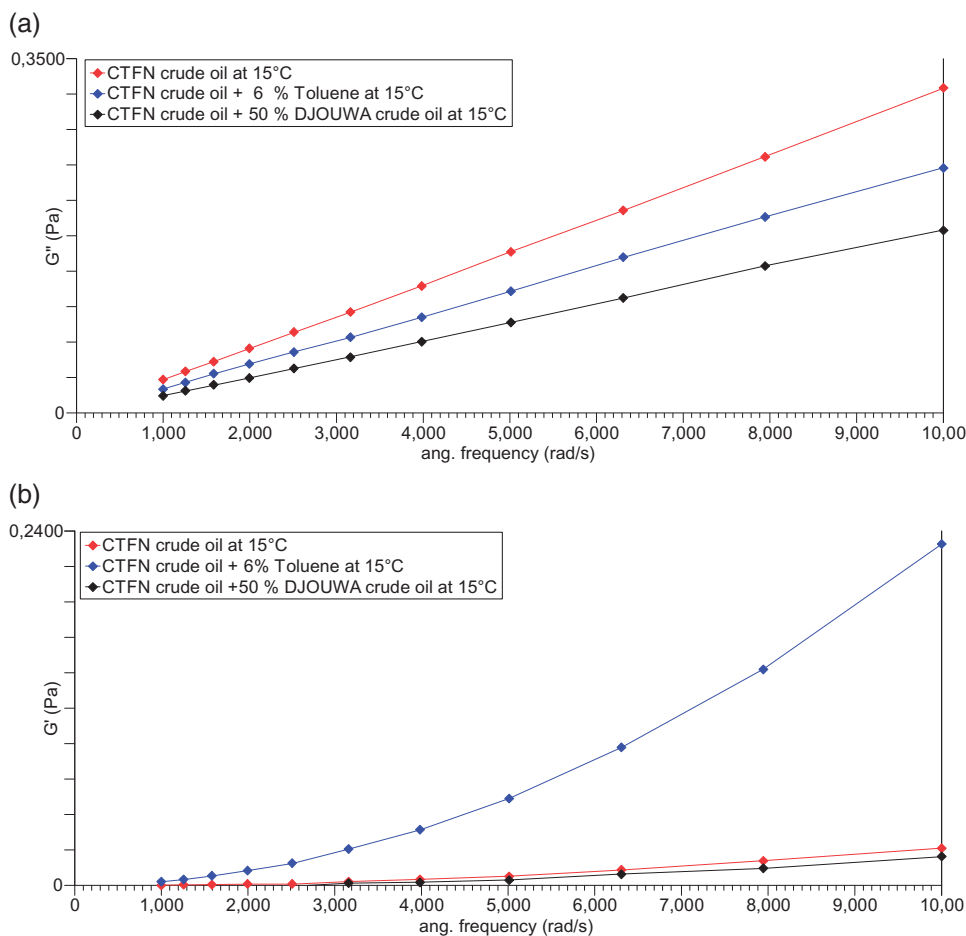


Figure 10. Viscous and elastic modulus at different concentrations of additives.

5. Conclusion

This paper has presented the rheological behavior of an Algerian crude oil and its mixture with extra-light crude oil and toluene. The results of the present experimental study can be summarized as follows:

1. The CTFN and extra-light crude oil behaves as a rheofluidifiant fluid following the rheological model of Herschel–Bulkley having a yield stress for the flow.
2. The addition of 50% extra-light crude oil and 6% of toluene to the CTFN crude oil causes a strong reduction in the viscosity.
3. The pressure drop decreases gradually than pure crude oil (CTFN crude oil).
4. The yield stress of the CTFN crude oil decreases with addition of the additives.
5. The flow rate of CTFN crude oil increased by addition of the additives.
6. The viscous modulus of the CTFN crude oil decreases significantly by the addition of 6% of toluene and 50% of DJOWA crude oil.
7. The elastic modulus of the CTFN crude oil increases with addition of 6% of toluene.

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