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Rheological behavior and microstructural properties of crude oil and emulsions (water/oil-oil/water)

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ABSTRACT

An experimental study on crude oil (from the Tin Fouye Tabankort oil field in southern Algeria) was carried out. This study allowed us to understand the rheological behavior of this crude oil with these different emulsions and how it reacts under the effects of temperature and the inversion of its phase from E/H to H/E. So we measured the rheological characteristics by tests flow and dynamic mode at different temperatures from 10 °C to 50 °C and at different water concentrations (20.40.50.60 and 70%) at a fixed temperature of 20 °C. The increase in temperature results in a 31.84% reduction in the initial viscosity of the crude oil. The addition of the volumic fractions of water results in an increase in viscosity at the point of inverse, which will decrease the apparent viscosity of these emulsions where the emulsions (W/O) come from (O/W). This crude oil and their emulsions exhibit a non-Newtonian behavior with shear thinning. The dynamic analysis depends on the temperature and the percentages of water added to the crude oil. At the end, a microscopic analysis was added to verify the relationship between the shape and diameter of the water droplets in each emulsion and the viscosity variation.

KEYWORDS

Crude oil; emulsion; inversely of the phase; rheology; viscosity

1. Introduction

Today, knowledge about crude oil and its characterization is a necessary step because this crude oil is the main source of energy demand in the world, with a presentation of 37% compared to other forms of energy (Souas, Safri, and Benmounah 2020). It is rarely found that crude oil finds itself alone; it is usually produced with water, which creates several complications during its manufacture. This mixture of crude oil and water is in the form of an emulsion, and the majority are water-in-oil (W/O) emulsions, Water-in-oil (W/O) emulsions are obtained with molecules that are rather hydrophobic, whereas oil-in-water emulsions (O/W) are produced in

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the presence of hydrophilic molecules (Xia, Lu, and Cao 2004; Leal-Calderon and Schmitt 2008). Emulsions of crude oil and water can be encountered at many stages during the drilling, producing, transporting, and processing of crude oils and in many locations, such as hydrocarbon reservoirs, well bores, surface facilities, transportation systems, and refineries (Langevin et al. 2004). Emulsion is a two-phase system composed of two liquids that do not mix uniformly; one of them is constantly dispersed as globules in the second phase (the continuous phase) (Raya et al. 2020; Umar et al. 2018). Emulsion is defined as a mixture of two mutually immixible liquids, one of which is dispersed as very small droplets in the other, In the production field, water-in-oil emulsions (e/h) are called direct emulsions (because they are the most common) and oil-in-water emulsions (h/e) are known as inverse emulsions. However, it should be borne in mind that one can find much more complex systems, such as multiple emulsions (e/h/e or h/e/h) (Dalmazzone 2000). The formation of emulsion in crude oil is a spontaneous process related to the interaction of components of crude oil such as asphaltenes, saturated, aromatics, and risins (Malkin et al. 2018). The formation of this emulsion is a serious challenge for the oil industry because these emulsions cause a resistance to the flow, especially in the thermal conditions, because of the complex rheology of the fluids, which causes major problems such as high pressure drops, loss of energy, corrosion of transport systems, and poisoning of catalysts during roundups (Kolotova et al. 2018; Maia Filho et al. 2012). A thorough knowledge of the rheology of emulsions is useful to minimize many difficulties during the process, such as: refining, transportation, and production. The rheological properties of the emulsions and their industrial uses are governed by variables such as temperature, chemical composition, and the size of the dispersed phase droplets, which can be divided into three groups: microemulsions (0–100 nm), miniemulsions (100–1000 nm) and macroemulsions (0.5–100 μm) (Windhab et al. 2005; Leal-Calderon, Thivilliers, and Schmitt 2007), Many studies have been conducted, where some researchers have studied the water effect in crude oil. Some of the other papers presented an experimental study of the effect of hydrocarbon segregation on the rheological evaluation of oil emulsions in concentrated water (dos Santos, Bannwart, and Loh 2014). Researchers have also presented a method for accurately estimating the variation in kinematic viscosity of emulsions (W/O) with temperature and water density fraction; they concluded that the effective viscosity of water-in-oil emulsions depends mainly on the volume fraction of the dispersed phase and temperature, along with several minor effects, such as shear rate, droplet size distribution, viscosity, and density of oil (Farah et al. 2005). Other researchers presented an experimental study on the effects of phase ratios, temperature, stirring

speed, and viscosity on the average droplet diameter of water-in-oil emulsions. Three types of crude oil were tested in their study. The experimental parameters tested in the study were phase ratios of 20–80% and 50–50% (w/o) emulsions, temperatures of 25–90 °C, and stirring speeds of 500–2000 rpm. They concluded that the viscosity of W/O emulsions increased with an increased phase ratio, a decrease in temperature, and an increase in stirring speed. They also concluded that the average droplet diameter of W/O emulsions greatly depends on the viscosity as well as the behavior of the emulsions, whether they are Newtonian or non-Newtonian (Anisa and Nour 2010). Researchers (Mekkaoui et al. 2017) studied the rheological behavior of four samples of Algerian Sahara crude oil with the effects of temperature and seawater. The experiments showed that the addition of seawater to the oil led to a change in the rheological behavior of the crude oil; the domain viscoelasticity increased with the increase in the percentage of seawater in the crude oil. Researchers have demonstrated that the water of the Lias geological formation has a strong effect on the rheological behavior of emulsions and on the microstructure compared to that of aqueous phase emulsions. From the above (Eddine Djemiat, Safri, and Benmounah 2018), we conclude that each of the chemical properties of water, the composition of the oil, the percentage of water produced with the production of the oil, the temperature, as well as the diameter of the water droplets, have an effect on the emulsion's viscosity. In fact, the viscosity of oil is an indispensable property in the design of oil pumping stations and the various installations that accompany them. However, most studies have been conducted for light crude oil emulsions and water (W/O) without having the effect of the inverse of the phase transition from W/O to O/W on the viscosity of the mixture and their point of inverse, therefore there are limited data on rheological properties in this type of emulsion. The purpose of this section is to determine the viscosity of the oil in the presence of different concentrations of water at different temperatures. The effect of temperature on Algerian light crude oil was studied using an AR 2000 rheometer from the TA instrument, as well as the effect of water concentrations and their inversion point as emulsions (W/O) become emulsions (O/W) on the dynamic and microscopic properties that affect the viscosity of emulsions (W/O) and (O/W).

2. Experimental

2.1. Materials and test methods

The crude oil sample used in this study was taken from a region in southern Algeria. At a temperature of 25 °C, the sample was characterized by a density of 0.788 and a zero-shear viscosity of 0.0149 Pa.s at 20 °C, 32.7 of

gravity ($^{\circ}$ API), 332 valor of tanker vapor recovery (TVR) (g/cm^2) at 35.5°C and a valence of 0.05 valor of basic sediment and water (BS & W %). The SARA analysis of the crude oil shows percentages of 1% asphalt and 24.411% wax by the ASTM method, the rheological measurements were made using an AR-2000 rheometer from TA Instruments (Couette geometry diameter 14 mm) which operates at a pressure of 2 bar with attached computer software (Rheology Advantage Data Analysis Program, TA). A trinocular optical microscope (optika-B-500 Tpl) equipped with a type camera (HIROCAM MA88-500 5.0 ME GA PI XEL) and image analysis software (TS View) was used to determine the distribution of droplet sizes.

After initiating the rheological experiments, the crude oil used in this investigation was agitated for 30 s to remove any residual memory. We made up 50 ml samples of [(20/80); (40/60); (50/50); (60/40); and (70/30)] emulsions of distilled water and crude oil. These emulsions are stirred at room temperature for 20 min at 350 rpm. Pre-shearing at 50 S^{-1} for 60 S is the standard procedure for homogenizing all samples. The applied shear rate ranges from 0.01 S^{-1} to 700 S^{-1} and the emulsions will be allowed to stabilize for 10 S before the data gathering process begins. Flow and dynamic rheological experiments on crude oil were performed at temperatures of 10, 20, 30, 40, and 50°C , while testing on emulsions of crude oil and distilled water was done at a constant temperature of 20°C .

3. Results and discussion

3.1. Effect of temperature and shear rate on the rheological behavior of crude oil

In this study, we worked on the knowledge of the effect of temperature and shear rates on the main rheological parameters of crude oil (apparent viscosity and shear stress). [Figure 1](#) presents the effect of different temperatures (10°C , 20°C , 30°C , 40°C , and 50°C) with a shear rate ranging from 0.01 to 700 S^{-1} . The results show that dynamic viscosity decreases strongly with the increase in temperature from 10°C to 50°C (Ghannam and Esmail 2006) and to express this reduction well, the degree of viscosity reduction is introduced and can be calculated using equation (Hasan, Ghannam, and Esmail 2010; Sami, Ibrahim, and Abdulrazaq 2017).

$$\text{DVR \%} = \left[\frac{\text{initial value} - \text{final value}}{\text{initial value}} \right] \times 100 \quad (1)$$

[Table 1](#) displays the percentages of dynamic viscosity reduction. With an increase of 0 to 31.84% in degree of reduction (DVR), it can be stated that as the temperature rises, the bonds between the solid particles of crude oil,

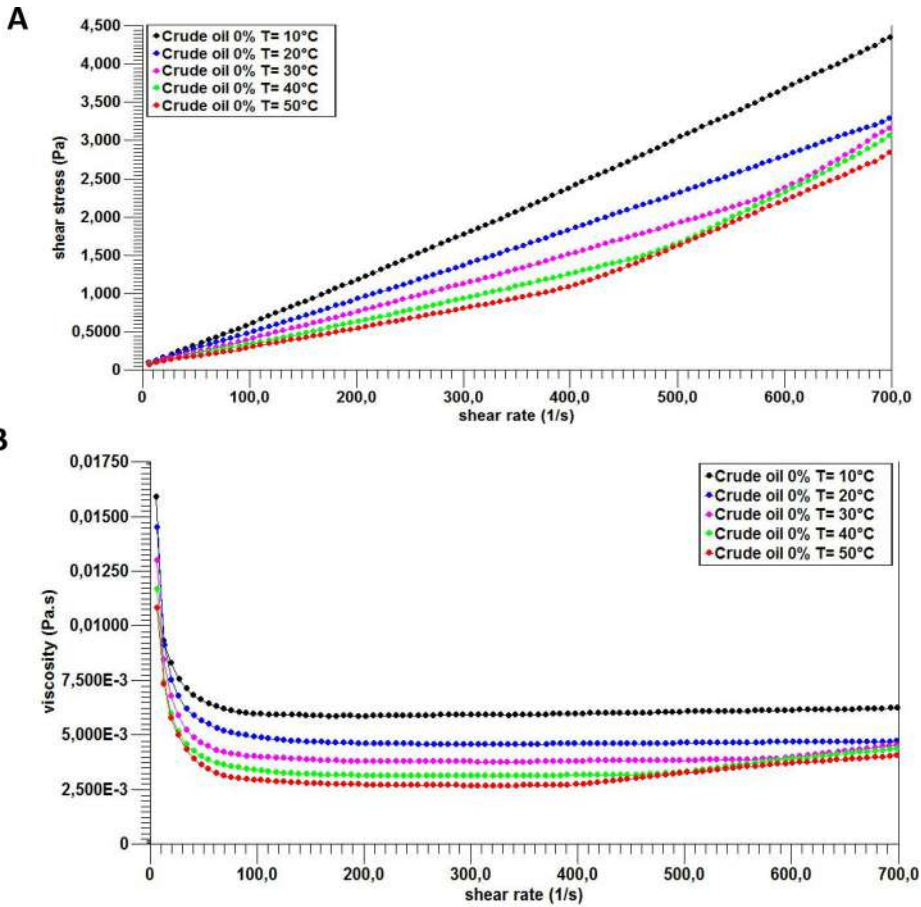


Figure 1. Flow curves of the crude oil at different temperatures, (a) viscosity (b) shear stress.

Table 1. DVR% of crude oil versus temperature.

| T (°C) | 10 | 20 | 30 | 40 | 50 |
|--------|----|------|-------|-------|-------|
| DVR % | 0 | 8.70 | 18.28 | 26.48 | 31.84 |

such as asphalt, resins, waxes, etc., are affected because the high molecular weight components of crude oil do not have the opportunity to agglomerate and form aggregates, resulting in a decrease in the viscosity of crude oil (Ghannam et al. 2012). In addition, as the shear rate increases, these molecular chains detangle and reorient parallel to the propelling force, diminishing the crude oil's viscosity (Kumar, Banerjee, and Naiya 2016).

3.2. Effect of water concentration on crude oil behavior

An understanding of the mechanism of the formation of emulsions and their rheological behavior is essential to ensuring the control of their manufacture and processing (Dalmazzone 2000). A series of rheological tests of these emulsions have been prepared at a fixed temperature of

20 °C. The influence of the water added to the crude oil has been presented in Figure 2. These figures show the curves of viscosity and shear stress as a function of shear rate. Note that the addition of the percentages of distilled water from 0% to 20%, 40%, and 50% increased the viscosity. The increase in the fraction of water leads to a rise in the hydrodynamic forces, which are caused by the increase in the number of water droplets, and therefore there will be an increase in the apparent viscosity of these emulsions (Khan 1996; Ariffin, Yahya, and Husin 2016).

For a percentage of emulsion of 60%, a higher viscosity is present in the shear rate range of $0.01\text{--}130\text{ S}^{-1}$, and for values greater than 130 S^{-1} , the viscosity decreases above the percentage viscosity of 50%. For the 70% emulsion, the viscosity decreases even more by 60%, and at this stage, it can be said that there is a phase inversion above the 60% emulsion, and the point of inverse reaches the maximum value at this percentage (Zhang, Chen, and Xu 2019), So a water-in-oil (W/O) emulsion turns into an oil-in-water (O/W) emulsion because, at this stage, the dispersed droplets

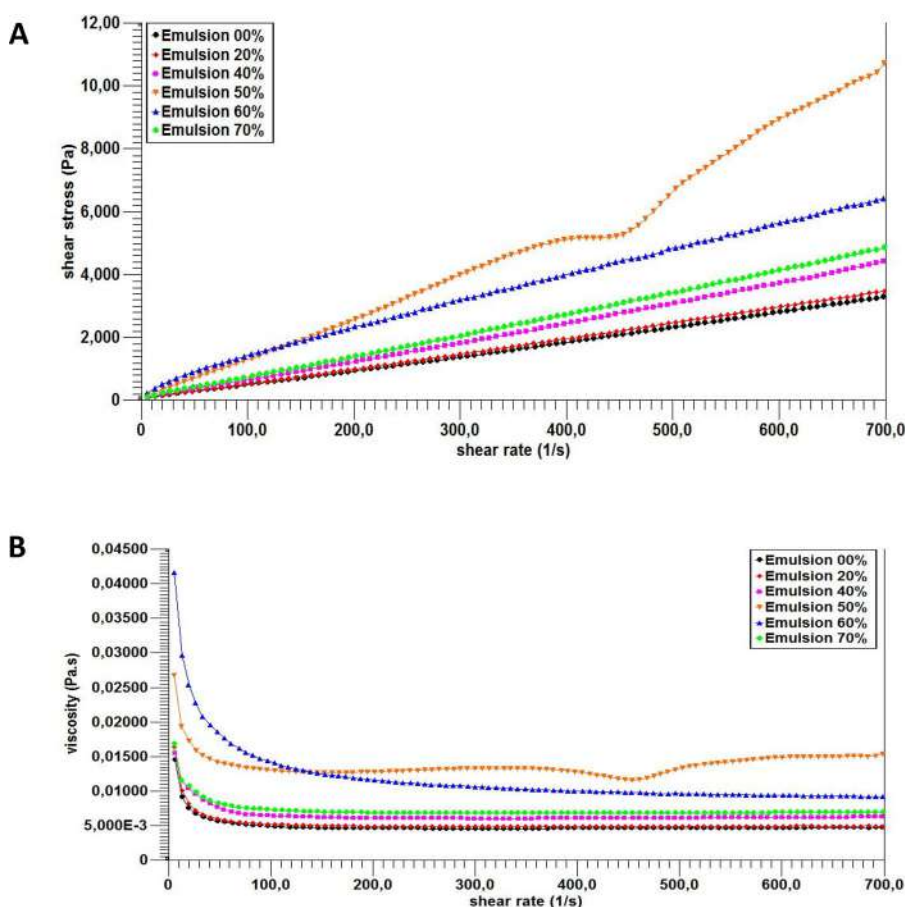


Figure 2. Flow curves of different emulsions at 20 °C, (a) viscosity (b) shear stress.

begin to fuse and form larger droplets. In fact, these droplets will take on a larger volume surface, and this will lead to the reduction of the specific surface, and once the amount of droplets is reduced, the apparent viscosity of the emulsion is reduced (Wong et al. 2015; Wang and Li 2018). We conclude that the apparent viscosity increases as the percentage of the water content increases; however, this viscosity decreases when the water content increases more and exceeds the phase transition point, so we have a phase inversion and the continuous phase will change from oil to water (Shi et al. 2018).

3.3. Rheological modeling of crude oil and these emulsions

The viscosity curves of the crude oil and of these emulsions clearly show the rheo-thinning fluid character at a low shear rate. Indeed, this crude oil has reacted as a non-Newtonian fluid and has a shear thinning behavior in which the viscosity gradually decreases at shear rates below 100 S^{-1} , and at shear rates above 100 S^{-1} , the viscosity stabilizes and remains constant. It should be noted that the viscosity of the crude oil depends on the shear rate, and this means that the crude oil flow rate suffers from high resistance at lower shear rates, unlike when shear rates increase and the long chain of hydrocarbons get unraveled and reoriented parallel to the applied driving force, and therefore there will be a reduction in the viscosity of the crude oil (Banerjee et al. 2015). Due to the existence of different amounts of crude oil components such as asphalt, aromatics, and waxes, the behavior of crude oil can change from non-Newtonian at low temperatures to Newtonian at high temperatures (Meddour and Souas 2022). It can also be observed that the flow curves of crude oil emulsions and distilled water show the existence of two different parties when the shear rate is in the range of $(0.1 \text{ to } 90) \text{ S}^{-1}$. We note the decrease of the apparent viscosity during this interval, but after this interval the apparent viscosity remains constant for the emulsion percentages of 20%, 40%, and 70%. In the high shear rate range, we noted the non-linear effect for the emulsion percentage of 50%. This effect may be due to the orientation of the droplets in shearing and the rupture of the intergouttelette bonds. The stability of the apparent viscosity of the emulsion 60% starts in the value of 200 S^{-1} of shear rate, and this delay of stability compared to other percentages of emulsion 20%, 40%, 50% and 70%, and perhaps because of the reverse point of the phase. To understand the variations in the rheological parameters of crude oil and these emulsions, we prepared a series of modeling analyses with four different rheological models.

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

$$\tau = \tau_0 + K\dot{\gamma}^n \quad (3)$$

$$\tau = \tau_0 + \eta\dot{\gamma} \quad (4)$$

$$\sqrt{\tau} = \sqrt{\tau_0} + \sqrt{(\dot{\gamma}\eta)} \quad (5)$$

where τ = resulted shear stress (Pa), k = the consistency index (Pa sⁿ), $\dot{\gamma}$ = the assigned shear rate (s⁻¹), n = the flow behavior index, τ_0 = the apparent yield stress (Pa), η = the apparent viscosity (Pa s). The Power law model (Waele 1923), the Herschel-Bulkley model (Herschel and Bulkley 1926), the Bingham model (Bingham 1922) and the Casson model (Casson 1959) are presented in Eqs (2)–(5), respectively.

After adjusting the crude oil rheological data with these four rheological models, the results prove that the Herschel–Bulkley model (3) gave the best fit with a regression coefficient of 0.999 for all temperatures. In Table 2, the adjustment parameters of this rheological model can be found, and we can say that the values of the index of behavior (n) are greater than 1, and that this index increases significantly with the increase of the temperature (Djemiat et al. 2015).

Also, the rheological behavior adjustment data of the emulsions are presented in Table 3. The results of this modeling show that the Herschel-Bulkley model (3) always improves the experimental data of this crude oil with deferential emulsion concentrations from 20% to 70%. It can be said that the rheological parameters of the best Herschel-Bulkley adjustment model (3) vary with the type of emulsion and the percentage of the quantity of water added to the emulsion. It is noted that the index n is greater than 1 for the emulsions at 20% and 40%, 50% and 70%, with a decrease up to 0.83 for the emulsion at 60% due to this point of inverse phase. The resulting shear stress also varied with emulsion type because we notice an increase in this parameter when the emulsion is water-oil (the emulsions of 20%, 40%, and 50%). After the parameter degrades to the inverse of the phase, the emulsion becomes oil/water at 60% and 70%. So we can judge that the rheological parameters depend on and vary depending on the type and percentage of emulsion.

3.4. Dynamic test

The purpose of these measurements was to determine how the morphology of crude oil and these emulsions functionally varied with the composition of the systems W/O and O/W. To study the viscoelastic character of crude

Table 2. Modeling analysis of Eqs. (2)–(5) for crude oil.

| T (°C) | τ_c (Pa) | K (Pa.S ⁿ) | n | R ² |
|--------|---------------|------------------------|-------|----------------|
| 10 | 0.0997 | 0.003137 | 1.100 | 0.9999 |
| 20 | 0.1042 | 0.002550 | 1.088 | 0.9999 |
| 30 | 0.1816 | 0.000497 | 1.317 | 0.9976 |
| 40 | 0.2428 | 0.000033 | 1.729 | 0.9968 |
| 50 | 0.2087 | 0.000018 | 1.811 | 0.9984 |

Table 3. Modeling analysis of Eqs. (2)–(5) for emulsion.

| Emulsion | Model | Rheological parameters | | | | |
|----------|------------------|------------------------|------------------------|---------|----------|-------|
| | | τ_c (Pa) | K (Pa.S ⁿ) | K1 | K2 | n |
| 00% | Power law | – | 0.00437 | – | – | 1.010 |
| | Herschel-Bulkley | 0.1042 | 0.00255 | – | – | 1.088 |
| | Bingham | – | – | 0.01744 | 0.004597 | – |
| | Casson | – | – | 0.00032 | 0.000027 | – |
| 20% | Power law | – | 0.00492 | – | – | 1.001 |
| | Herschel-Bulkley | 0.0914 | 0.00319 | – | – | 1.064 |
| | Bingham | – | – | 0.02410 | 0.00488 | – |
| | Casson | – | – | 0.04322 | 0.00368 | – |
| 40% | Power law | – | 0.00555 | – | – | 1.017 |
| | Herschel-Bulkley | 0.1128 | 0.00359 | – | – | 1.081 |
| | Bingham | – | – | 0.03586 | 0.00618 | – |
| | Casson | – | – | 0.00001 | 0.00005 | – |
| 50% | Power law | – | 0.00457 | – | – | 1.180 |
| | Herschel-Bulkley | 0.5498 | 0.00140 | – | – | 1.354 |
| | Bingham | – | – | 0.00021 | 0.01399 | – |
| | Casson | – | – | 0.00003 | 0.01393 | – |
| 60% | Power law | – | 0.03417 | – | – | 0.797 |
| | Herschel-Bulkley | 0.1670 | 0.26570 | – | – | 0.832 |
| | Bingham | – | – | 0.55880 | 0.00851 | – |
| | Casson | – | – | 0.13290 | 0.00672 | – |
| 70% | Power law | – | 0.00673 | – | – | 1.003 |
| | Herschel-Bulkley | 0.1163 | 0.00452 | – | – | 1.061 |
| | Bingham | – | – | 0.02633 | 0.006795 | – |
| | Casson | – | – | 0.03914 | 0.005434 | – |

oil and these emulsions, three parameters were measured that represent the effect of the axial stress or deformation on our sample. The elastic modulus G' , which represents the capacity of the material to store energy, the loss modulus G'' , which represents the ability of the material to dissipate energy, and the complex modulus G^* , which represents the total resistance of the substance against the applied stress, were in two regimes: viscous if ($G'' > G'$) and elastic if ($G'' < G'$) (Souas et al. 2018). These moduli are measured in a frequency range of 0.1–8 Hz and at a stress of 0.05 Pa for crude oil and another stress of 0.2 Pa for emulsions.

Figure 3 represents the relationship between the elastic modulus G' and the viscous modulus G'' as a function of the angular frequency of the crude oil at different temperatures. The result indicates that the increase in temperature has influenced the G'' but has no effect on the G' and this modulus just depends on the angular frequency (Djemiat et al. 2015). Figures 4–7 show that modulus G' and G'' depend on the angular frequency because, at frequencies lower than the characteristic value, the storage modulus G' is lower than the loss modulus G'' ($G' < G''$) in this case, the energy stored in the emulsions is 20%, 40%, 50%, and 70% lower than that lost by the cycle, it should be noted that these emulsions are in the state of a liquid type material (Kolotova et al. 2018), it should be noted that when the frequency exceeds the characteristic frequency, the storage modulus G' becomes superior to the loss modulus G'' ($G' > G''$), indicating that these emulsions have an essentially solid behavior due to the formation of a gel that has an

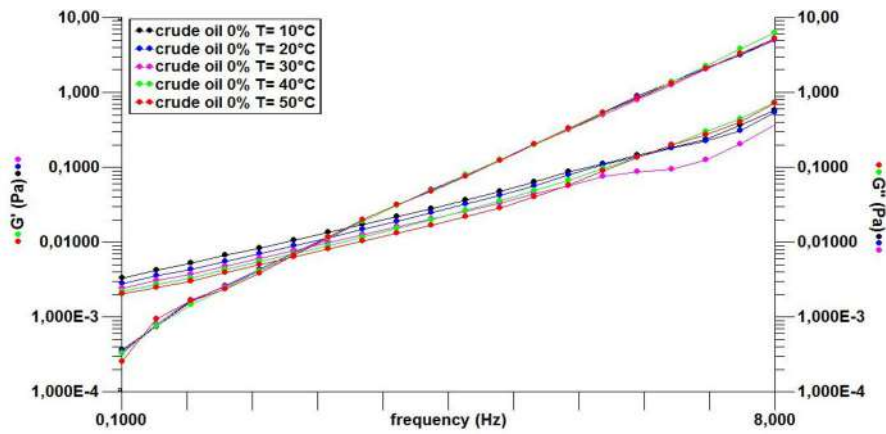


Figure 3. Loss and storage moduli of the crude oil at different temperatures.

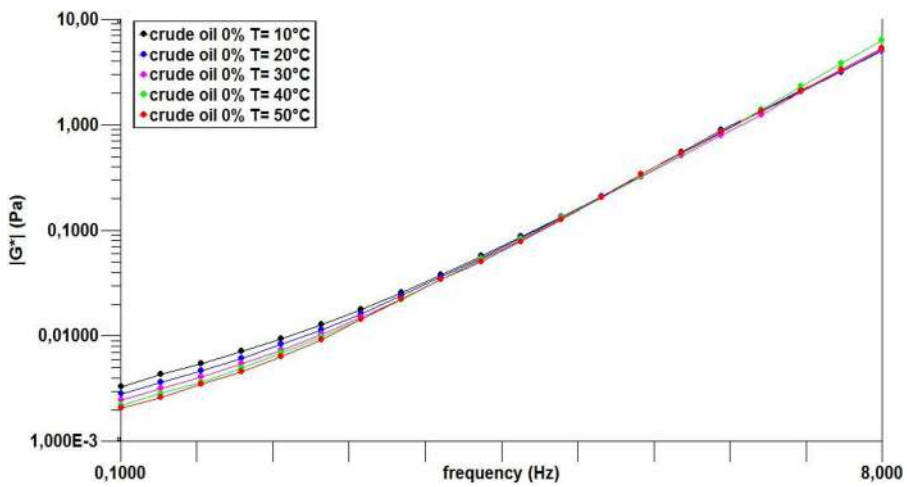


Figure 4. Complex modulus of the crude oil at different temperatures.

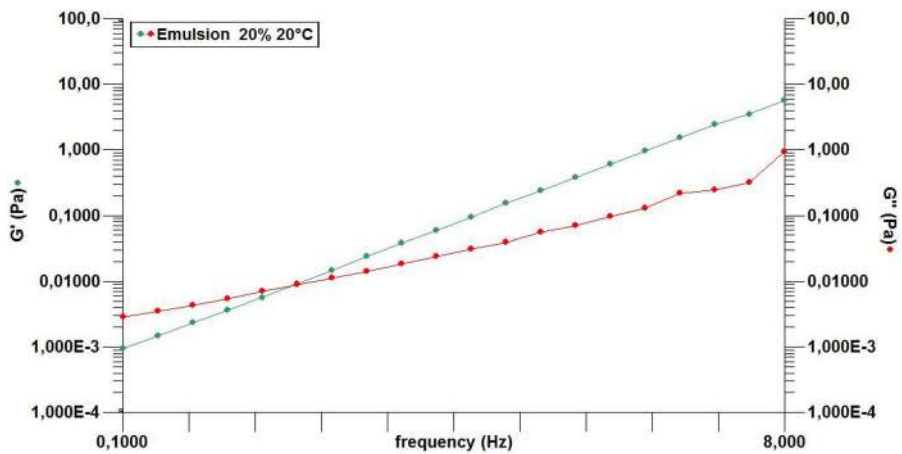


Figure 5. Loss and storage moduli of emulsion 20% at 20 °C.

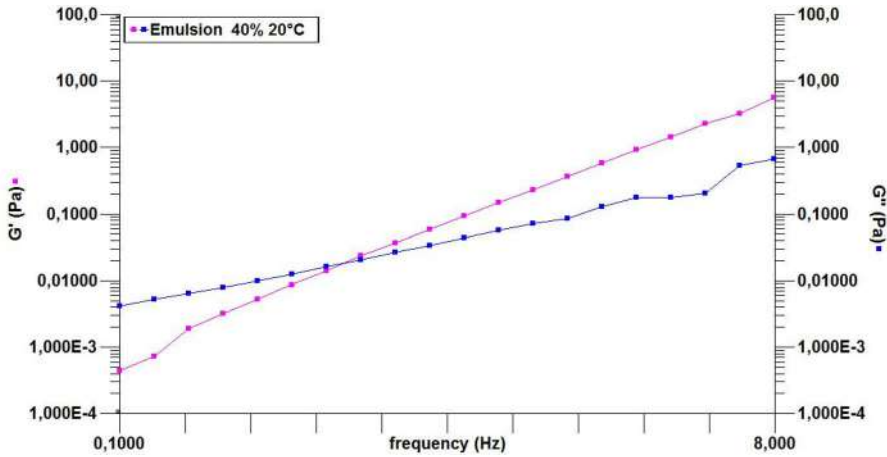


Figure 6. Loss and storage moduli of emulsion 40% at 20 °C.

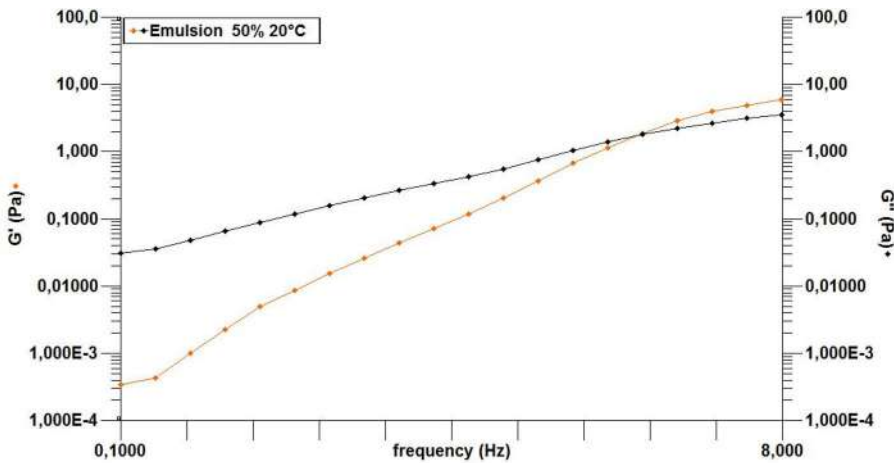


Figure 7. Loss and storage moduli of emulsion 50% at 20 °C.

elastic network in this case of the emulsions, and this rheological behavior is due to a network created between the dispersed phase droplets (Lertwimolnun and Vergnes 2005) indicating that these emulsions have essentially solid behavior due to the formation of a gel (Mekkaoui et al. 2017; Meriem-Benziane et al. 2012). Also, Figure 8 represents an increase in the loss module G'' compared to the storage module G' throughout the range of the frequency tested (0.1–8 Hz) for the emulsion containing 60% of water, this means that the energy stored in the 60% emulsion is less than the energy dissipated as heat, and this emulsion has a liquid-like behavior. In other words, the G' and G'' moduli are totally influenced by the network created between the water droplets dispersed in the crude oil. Note also the frequency dependence of the storage module G' and the loss module G'' for all emulsion concentrations; this frequency outperformance of G' and G'' is related to phase structures (Wang et al. 2005), Figure 9 shows an equality of

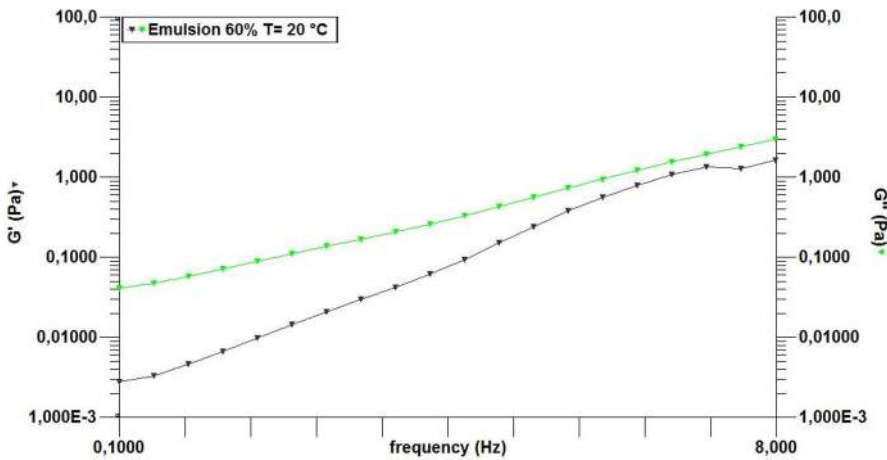


Figure 8. Loss and storage moduli of emulsion 60% at 20 °C.

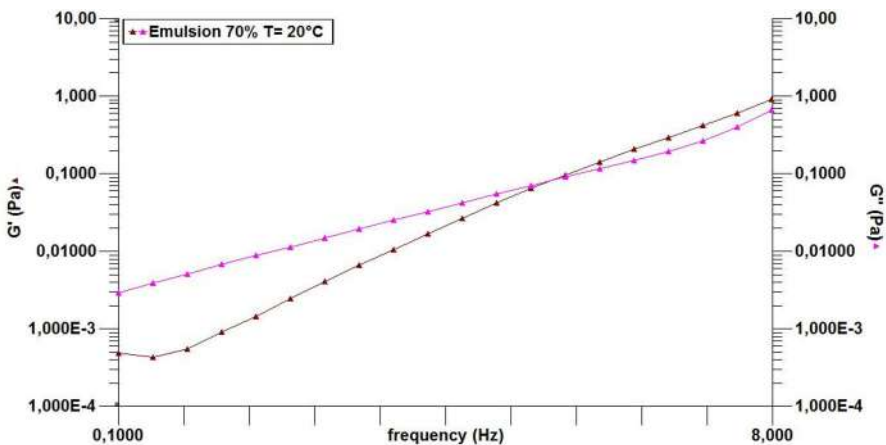


Figure 9. Loss and storage of emulsion 70% at 20 °C.

G^* for all temperatures, which means that the temperature has no effect on the total strength of the crude oil. In **Figure 10**, the measured G^* of the crude oil emulsions and the distilled water have been plotted, and we can see in this figure that the complex module takes high values when the water concentration increases more than 40%, 50%, and 60% and takes a lower value for the emulsion of 70% at the seam of this inverse phase because the results will take values close to the values of pure water. The obtained results show that the complex G^* module was influenced by the amount of water added to the crude oil.

3.5. Microscopic study

In this microphotographic analysis, we have worked with the direct method, which is useful with much greater confidence than other indirect techniques

(Sadeghi et al. 2013). An optical microscope, as previously mentioned, obtained this microphotographic analysis. Figure 11 Microphotographs of emulsions of 20–70% of the water in crude oil (W/O), the results show how the size of the droplets, the shape, and the space between these droplets of water vary from each percentage of emulsion to the other. Photo A of the 20% emulsion shows large droplets with an almost non-uniform distribution and a gap between them with an average diameter of **855.92 nm**; and when this percentage increases to 4%, we notice that the water droplets approach each other and begin to group with an average diameter of **521.78 nm**, as

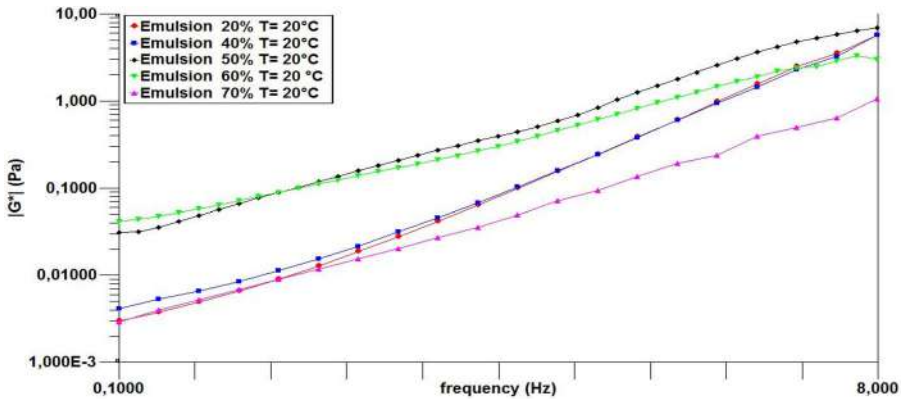


Figure 10. Complex modulus of different emulsions at 20 °C.

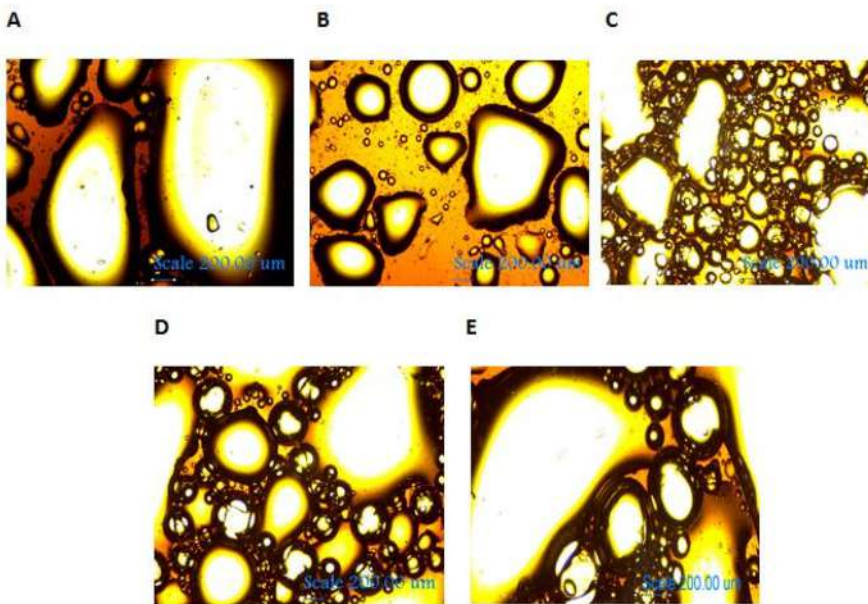


Figure 11. photomicrographs of different emulsion at 20 °C. (a) Photomicrograph for emulsion 20%, (b) photomicrograph for emulsion 40%, (c) photomicrograph for emulsion 50%, (d) photomicrograph for emulsion 60%, (e) photomicrograph for emulsion 70%

indicated in Photo B. The photo C represents the microphotography of the emulsion by 50%, and for this percentage, we note that the shape of the droplets becomes more spherical and are smaller, closer to each other, and form agglomerations. The average size of these droplets is **197.40 nm**, and this size of the droplets in the emulsions is affected by their high viscosity because the 50% emulsion is more viscous than other emulsions and more stable due to the friction increment between the droplets (Pajouhandeh et al. 2016). However, the particle size of the 60% emulsion droplets has an average diameter of **269.08 nm**, as shown in Photo D, which indicates that the droplet diameters begin to separate and enlarge because there is a reverse phase. In the photo E, the emulsion with 70% water has a widening of the diameters because the quantity of water becomes greater than that of crude oil, and at this stage the dispersed phase (water) transforms into the contained phase with an average diameter of **423.63 nm**. A coalescence of droplets occurs when smaller droplets gather to form larger ones, this process involves the elimination of thin interfacial films that separate the dispersed droplets, which reduces the number of droplets in high water cups (Yonguep et al. 2022). Therefore, it is suggested that the number of dispersed water droplets increases and the hydrogen bond increases with the increase in water cups from 20% to 50%; directly leading to an increase in hydrodynamic forces between the droplets and therefore an increase in viscosity, for emulsions from 60% to 70%, Water droplets in the dispersed phase begin to coalesce and form larger droplets, resulting in a decrease in surface area per unit volume. As a result, there is less friction between the droplets, which causes the viscosity to decrease when mixing with water above 50%. This may also be explained by the phase inversion that happens when W/O emulsions transform into O/W emulsions (Wong et al. 2018).

4. Conclusions

The Analysis of the rheological data of the crude oil of a region of the Algerian Sahara and of these emulsions allows us to conclude that: the viscosity of the crude oil decreased considerably with temperatures of the order of 10 °C, 20 °C, 30 °C, 40 °C and 50 °C. For crude oil emulsions and distilled water, viscosity increases to 50% after a decrease and the phase is reversed. This crude oil and emulsions behave as a viscoelastic fluid according to the Herschel-Bulkley law with a coefficient of 0.999, and the elastic modules G' and viscous emulsions G'' depend on the percentage of water added. The microstructure of the emulsions shows that each percentage of water added to the crude oil affects the size, shape and rhythm of the water droplets in these emulsions. In the end it can be said that: several parameters influence the rheological properties of crude oil and their emulsions

such as: components SARA, (resin, aromatic, asphaltene...), temperature, shear rate, the quantity of water added and the inverse of the phase of (E/H) in (H/E) influences properties and dispersed water droplets.

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Nomenclature

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|-----|-----------------------------------|
| W/O | water in oil emulsion (water/oil) |
| O/W | oil in water emulsion (oil/water) |
| TVR | valor of tanker vapor recovery |
| DVR | degree of viscosity reduction |
| Eqs | equations |