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Research article

Extra heavy crude oil viscosity and surface tension behavior using a flow enhancer and water at different temperatures conditions

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A R T I C L E I N F O

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A B S T R A C T

Research reports reveal the importance of applying various substances to enhance extra-heavy crude oil pipeline transportation. During the crude oil conduction process, shearing occurs in the equipment and pipe accessories, producing a water-in-crude emulsion associated with forming a rigid film by adsorbing natural surfactant molecules in the droplets water, leading to increased Viscosity. This study presents the effect of a flow enhancer (FE) on the behavior of the Viscosity of an extra heavy crude oil (EHCO) and in emulsions formed with 5% and 10% water (W). The results revealed the effectiveness of the 1%, 3%, and 5% flow enhancer in lowering the Viscosity and presenting a Newtonian flow behavior which will help reduce the cost of heat treatment during the transportation of crude oil through the pipeline.

1. Introduction

The petroleum reserves in Mexico and the world are mainly heavy and extra-heavy crude oils, it is estimated that the unconventional crude oil reserves account for around 70% of the world's energy resources derived from fossil fuels [1,2]. Refining unconventional oils produce fewer proportions of liquefied petroleum gas (LPG), gasoline, kerosene, and diesel (as high-added value products) [3]. After refining, multiple uses can be given to heavy oil and the generated residues.

A complex mixture of hydrocarbons constitutes Crude oil, according to their chemical structure is classified into paraffin and isoparaffins, naphthenes, aromatics and unsaturated, and nitrogen, sulfur, and oxygen compounds. These compounds are also classified according to solubility and polarity as Saturates, Aromatics, Resins, and Asphaltenes (SARA) [4]. One characteristic of crude oil is its Viscosity, which is very important in treating and handling crude oil, from the reservoir to the surface, its conduction through pipelines, and transportation to the refining facilities. The classification of the different crude oils is based on their value of degrees API, which is a method of measuring the density or specific gravity based on the comparison of the density of oil with the same volume of water under the same conditions of pressure and temperature [5]. The classification of crude oils according to the above properties

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are light (° API> 22, Viscosity <100 mPa s), heavy (° API 10–22, viscosity> 100 mPa s) and extra heavy (° API <10, Viscosity> 10 000 mPa s [4,6]. Heavy crude oil refers to high viscosity and low API gravity oil. High Viscosity is attributed to the content of resins, asphaltenes and viscoelastic network among them [7–9]. Serious problems due to high Viscosity presents the transportation of heavy and extra-heavy crude, from the point of production of the wells, separation batteries to the point of storage and refinery. The oil industry faces a great challenge to transport these heavy oils through pipes, and porous media almost always require additional energy to make them more fluid and manageable, such as adding heat or using Viscosity reducing products or flow improvers.

Different techniques have been used to improve flow and reduce Viscosity. The addition of surfactants or polymers, water as an annular fluid, dilution with lighter crudes, emulsification with surfactant, and thermal remediation are used to improve flow [10–12]. Various fluids are commonly used to reduce Viscosity, such as light crude oil, naphtha, diesel, and others, as well as gases, mainly CO_2, but the addition of diluents might precipitate asphaltenes and cause plugging and fouling problems [13–16]. Interesting topics on viscosity reduction in heavy and extra-heavy crudes have been reported.

[8] reported magnetic copper ferrite nanospheres use and reuse (CFNS). These nanospheres rheology were evaluated from 300 to 1500 mg/L in the first cycle, leading to the highest degree of viscosity reduction of 18% at 500 mg/L. Changes in the extra-heavy oil microstructure were observed according to the decrease in elastic and viscous moduli upon CFNS addition. [17]; reported petroleum rheological behavior with and without SDBS (Sodium Dodecyl Benzene Sulfonate) in steady shear and oscillatory mode. The effect of the shear rate, the temperature (20 °C, 30 °C and 50 °C), and the additive concentration on the rheological parameters were studied. At a low shear rate, Petroleum exhibited a non-Newtonian behavior, described by the Herschel–Bulkley model. High values-shear rate gradient produces Newtonian behavior, influenced the rheological properties of crude oil by SDBS. [18]; reported the effect of a flow improver formulated by biodiesel plus petroleum-derived organic compounds, changing the Northern Mexico extraheavy crude oil. The results indicated a change in the interaction of asphaltenes and epoxidized ester by their polar-nature and interaction with nonpolar compounds with parts of the chemical compounds added and the amphiphilic character. The flow enhancer showed his active principle to decrease viscosity. Alomair and Almusallam [19]; reported different reducing Viscosity of heavy crude oil blending techniques with light crude oil or light fraction (as kerosene or diesel), at atmospheric/pressure condition, decreasing 4000–500 mPa s, but showing an asphaltenes precipitation phenomena. Hexanol in toluene delays or stops asphaltenes reducing the flocculent nanostructures by adding 1.2–2 wt %. [6]; presented the effect of esters on the petroleum Viscosity; results showed a positive effect by substantially reducing viscosity of the crude oil at low temperatures, furthermore reported that the increase in the water content of synthetic formation in the emulsified system presented an increase in Viscosity. Storage temperature can affect emulsion stability [20]. [21]; presented complex viscosity and phase-angle measurements for Athabasca bitumen and Maya crude oil using a rotational Rheometer over the temperature range of (200–410) K. Both showed Newtonian at higher temperatures. Athabasca bitumen and Maya crude oil can be solid-like materials up to (260–280) K and (230–240) K, respectively. Athabasca bitumen is a non-Newtonian shear-thinning fluid up to (310–315) K, whereas Maya crude is a shear-thinning fluid up to (280–285) K; furthermore, Maya crude oil presented a thixotropic behavior. Temperature is a key factor for good flow behavior of heavy crude oil in terms of viscosity-shear rate [22]. [23] reported the influence of temperature on the rheological properties of crude oil. Above 40 °C petroleum shows good flow behavior when heated: The high paraffin wax content and an average wax-resin ratio can explain this behavior. [24], showed a study about reducing the viscosity of crude oil using silica and alumina nanoparticles. The dynamic rheological test conditions were the shear rate ($<100\ s^{-1}$) and the oscillated temperatures (40–70 °C). [25], demonstrated that temperature increase is associated with a decrease in viscosity and Newtonian behavior of the crude oil. Pseudoplastic or shear thinning viscosity behavior was perceived at low shear rates ($10\ s^{-1}$) and with increasing temperature (298–348 K). [26], investigated the oil/water emulsion rheology using a stabilizing. They reported that the emulsions showed Newtonian behavior at high shear rates (above $1000\ s^{-1}$) and shear thinning viscosity behavior at low shear rates ($<50\ s^{-1}$). Shear rates between 0.01 and $100\ s^{-1}$ are commonly used in the oil industry. These shear rate changes comprise the displacement of the oil from its source rock to the reservoir rock, which is called oil migration, after, the oil is transported from the well to the area of separators through pipeline connection and pumping equipment. After the crude oil is conveyed to different sites for further treatment, the fluid is finally sent to the storage tanks of a refinery or to a shipping port. Most of the rheological data literature on crude oil is for material steady-shear functions for a steady-shear flow approximation. This study presents the effect of a flow enhancer (FE) on the behavior of the Viscosity of an extra heavy crude oil (EHCO) and in emulsions formed with 5% and 10% water (W), due that Viscosity is of crucial importance for production, pipeline transport and refining operations. The results revealed the effectiveness of the 1%, 3%, and 5% flow enhancer in lowering the Viscosity and presenting a Newtonian flow behavior which will help reduce the cost of heat treatment during the transportation of crude oil through the pipeline. Non-conventional oil requires an additional demand to ensure its fluidity within an acceptable flow rate for be transportated, because of composition complexity conditions generating high costs by energy consumption. FE is presented as an option to ensure fluidity within an acceptable flow rate to transport non-conventional (heavy oil and extra heavy oil).

2. Experimental section

This work used northeast Mexican Republic extra-heavy crude oil. The EHCO/FE mixtures and W/EHCO/FE emulsion were formed. The flow enhancer was a biodiesel chemical based on esters of fatty acids.

2.1. Characterization of crude oil and mixtures

The crude oil sample and mixtures were characterized according to the procedures established in the standards of the American Society for Testing and Materials (ASTM). Determined properties were determined: API gravity [27], density [28] the oil sample density was determined at 25 °C by the pycnometer method, asphaltene content [29], Interfacial Tension (ISO 1409) using Automatic surface tensiometer TEN 202, and Viscosity using a RheolabQC model Anton Paar Rheometer with a concentric cylinder geometry. Flow enhancer and water effect on extra-heavy crude oil rheological properties were assessed through dynamic rheological measurements. The concentrations of FE and W were evaluated by adding different content according to Table 1. The rheological measurements were assessed on a shear rate range of 0.01–100 s^{-1} at 25, 30, 40, and 60 °C, which was done in triplicate.

2.2. Mixtures preparation

To characterize the extra heavy crude oil with a flow enhancer and water were made mixtures to different ratios, as shown in Table 1. Before the measurements, stirred the mixtures were manually for 20 min. After stirring, the sample was placed in the rheometer cylinder and allowed to stand for 5 min to evaluate its rheological properties.

3. Results and discussion

The extra-heavy crude oil sample obtained a density of 1.021 g/ml, 6.95° API, 35 282 mPa s (25 °C) and asphaltenes content of 22.5%. These values classify it as an extra-heavy crude accord with references values [4]. A test was carried out to compare the density of the extra-heavy crude oil with the water, showing an unstable behavior, suspended at the bottom or sometimes in the upper part, the crude was observed.

The interfacial tension between the flow enhancer and crude oil are presented in Table 2 (see Fig. 1). The force to separate the interfacial film with a platinum ring was measured, ensuring that the ring is fully submerged in the extra-heavy crude oil (see Fig. 2). The resulting separation force was equal to the interfacial tension.

The interfacial tension at the interface of the crude oil and the flow enhancer at 25 °C presents a value of 84.3086 mN/m. As the temperature increases, the interfacial tension decreases, observing values for 30, 40, and 60 °C of 65.8926, 55.2121, and 45.6296 mN/m, respectively; this behavior is due to the disorder created by the increase in molecular agitation promoted by the increase in temperature.

Interfacial tension occurs because a molecule near an interface has different molecular interactions than an equivalent molecule within the crude oil fluid. Surfactant molecules are preferentially located at the interface, lowering the interfacial tension. In this case, the oil contains surfactant components in the heavy fractions; these natural surfactants are resins, maltenes, and asphaltenes. Increasing the temperature reduces the adsorption of natural surfactants and decreases the Viscosity of the external phase, the stiffness of the interfacial film, and the surface tension.

Flow enhancer and water effect on extra-heavy crude oil rheological properties were assessed. The samples were measured at a constant temperature of 25 °C, 30 °C, 40 °C and 60 °C.

Fig. 3 shows the rheograms of EHCO with the flow enhancer at 25 °C. The EHCO initially presented 35 282 mPa s to 25 °C. The behavior of a pseudoplastic fluid is observed for EHCO because the Viscosity decreases with increasing shear rate. With a shear rate between 39.8 s and 1 to 46.4 s-1 there is a marked decrease in Viscosity from 21586 mPa s to 1041.1 mPa s until reaching a viscosity of 49.756 mPa s at 100 s-1. EHCO (25 °C) exhibits a decrease in Viscosity, this trend is associated with shear thinning [30,31], which is the non-Newtonian behavior of fluids whose Viscosity decreases under shear stress. According to Heldman [32] and Mezger [33]; it can be considered synonymous with pseudoplastic behavior.

Heavy crude oils have high viscosity due to the presence of high molecular weight molecules. The viscosity physical property is associated with the shear rate because crude oil has less resistance to flow as the shear rate increases due to the chains of the resins and asphaltenes being oriented in parallel form when disentangling [34].

Al-Wahaibi et al. [31] reported viscosity measurements of oil-water emulsions stabilized with Triton X-100 at temperature conditions from 20 °C to 70 °C with increments of 10 °C and shear rates between 27 and 2700 s^{-1}. They concluded that shear thinning in crude oil occurred in all tests, with a more effect at 20 °C, where a decrease in viscosity, from 1920 to 1190 mPa s, was observed with a shear rate $<349\ s^{-1}$.

The heavy fraction (resins and asphaltenes) of extra-heavy crude oil at a low shear rate can present interactions between their chains and possible entanglements (see Fig. 4); can be associated this behavior with the Viscosity of the fluid. When an increase in a shear rate is applied to the fluid, a rearrangement of the molecular groupings and the interactions between the chains of the macromolecules could occur, giving rise to specific changes in Viscosity. If the shear stress increases, a rearrangement can be achieved, producing a fine-tuning and alignment of the asphaltenes and resins chains. Alignment change creates an abrupt decrease in the Viscosity of the fluid like a pseudoplastic fluid as observed for EHCO at 25 °C. This behavior is related to what was reported Chen et al. [30] about the influence of shear rate on the rheology of colloidal suspensions. Particles can organize into layers, becoming ordered by

Table 1
Extra heavy crude oil, flow enhancer, and water ratios.

Sample	EHCO:FE	Sample	EHCO:W	Sample	EHCO:W: FE
EHCO	100	EHCO+5%W	95:5	EHCO+5%W+3%FE	92:5:3
EHCO+1%FE	99:1	EHCO+10%W	90:10	EHCO+5%W+5%FE	90:5:5
EHCO+3%FE	97:3			EHCO+10%W+3%FE	87:10:3
EHCO+5%FE	95:5			EHCO+10%W+5%FE	85:10:5

Table 2
Interfacial tension extra-heavy crude oil + flow enhancer.

Temperature (°C)	Interfacial tension en mN/m
25	84.3086
30	65.8926
40	55.2121
60	45.6296

Fig. 1. Density behavior of extra heavy crude oil and water.

Fig. 2. Interfacial tension test. This picture shows the interfase between the flow enhancer and the crude oil at 25 °C.

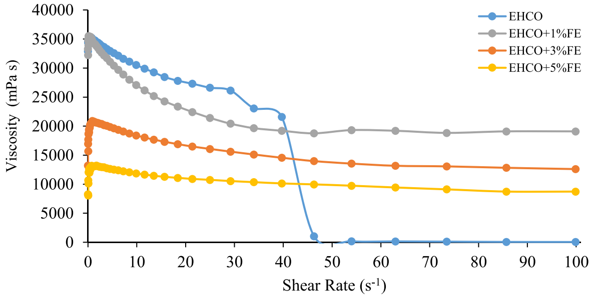

Fig. 3. Rheograms of extra-heavy crude oil with flow enhancer at 25 °C.

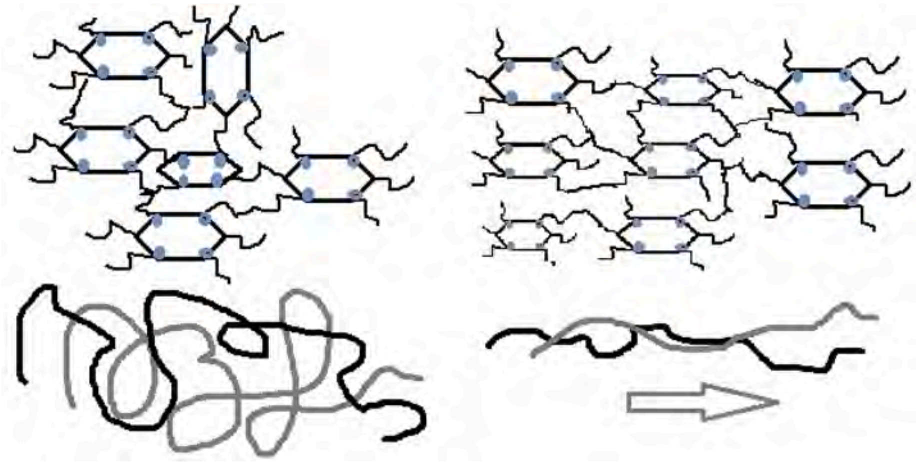

Fig. 4. Representation of behavior of heavy fractions of extra-heavy crude oil in increases shear rate.

the flow flowing with a lower resistance, reducing the suspension's Viscosity" [10,31,35].

The samples with flow enhancer at 25 °C show an effect similar to Newtonian fluid from a shear rate of 40 s^{-1} [36], in these samples the influence of the flow enhancer in the decrease in Viscosity is evident. Final Viscosity of 19102 mPa s, 12606 mPa s and 8734.8 mPa s were obtained with 1%, 3% and 5% (weight) of FE, respectively.

Fig. 5. Rheograms of EHCO (extra heavy petroleum or crude oil) with flow enhancer at 1, 3 and 5% weight at 30 °C. EHCO presented 19 749 mPa s at 30 °C; the Viscosity decreases with increasing shear rate, the Viscosity remaining constant after reduction, this behavior corresponds to a pseudoplastic fluid, the change is observed between the shear rate of 46.4 s^{-1} to 63.1 s^{-1} drastically decreasing the Viscosity from 14 884 mPa s to 101.12 mPa s respectively, until reaching a viscosity of 36.748 mPa s at 100 s^{-1}. Samples with a flow improver at 30 °C behave similar to a Newtonian fluid (from a shear rate of 40 s^{-1}), in these samples the influence of the flow enhancer on the decrease in Viscosity is evident. Viscosities are obtained at 100 s^{-1} of 12 781 mPa s, 8731.3 mPa s and 6357.6 mPa s with 1, 3 and 5% of FE respectively.

It is noticeable in Figs. 3 and 5 for EHCO at 25 °C and 30 °C, how the viscosity behavior decreases dramatically with increasing shear rate. A different behavior presented the rheograms of the samples with content of flow enhancer.

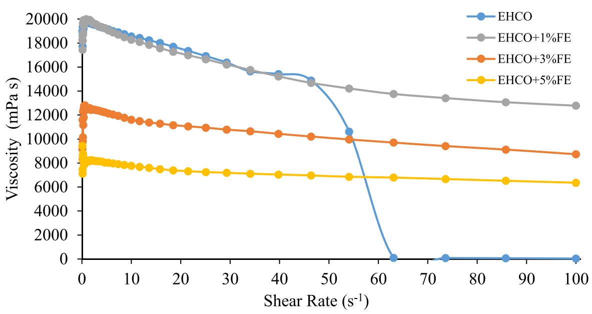

Fig. 5. Rheograms of extra-heavy crude oil with flow enhancer at 30 °C.

The rheograms of EHCO with flow improver at 1, 3 and 5% weight at 40 °C are observed in Fig. 6. Initially, a similar trend in Viscosity is observed for EHCO and EHCO+1%FE, this decrease in Viscosity can be related to the influence of FE and the increase in temperature, following very different trends concerning EHCO with temperatures of 25 °C and 30 °C where the Viscosity changed drastically with relating to the increase in shear rate. The viscosity tendency for EHCO+3%FE and EHCO+5% FE shows Newtonian behavior and final viscosities of 4188.5 mPa s and 3036.6 mPa s. Viscosity rheograms for EHCO with FE at 40 °C showed better performance stability in the decrease in Viscosity.

Fig. 7. Shows the 60 °C rheograms of the extra heavy crude oil with flow enhancer at 1, 3 and 5% weight. The final viscosities were to EHCO (1435 mPa s), EHCO+1%FE (1406.2 mPa s), EHCO+3FE (1096.6 mPa s) and EHCO+5%FE (814.48 mPa s). The viscosity behavior in these samples is very similar to a Newtonian fluid, keeping the Viscosity constant. Increasing the amount of flow improver and the temperature at 60 °C is associated with this behavior.

The behavior of rheograms of Viscosity of the samples of the water emulsions (5%) in extra-heavy crude oil (W/EHCO) is observed in Fig. 8. EHCO+5%W at 25 °C presents an increase of 63.64% in the Viscosity according to the initial viscosity value of the extra-heavy crude oil. This increase is associated with the content of asphaltenes, which are considered natural surfactants. The emulsion is stabilized by forming asphaltene layers around the water in oil droplets. Asphaltenes can form rigid cross-linked structures and elastic films, stabilizing emulsions [37]. Water is stabilized by an interface composed of asphaltenes viscoelastic and mechanically strong film [38].

The initial EHCO+5% W viscosity was 57 737 mPa s until reaching a viscosity of 23 829 mPa s at 59.2 s^{-1}. Viscosity shear rate 100 s^{-1} was not obtained due to the conditions and the geometry used in this analysis. The influence of the temperature increase on the decrease in Viscosity for EHCO +5%W at 30 °C, 40 °C and 60 °C is notable: 17 780 mPa s, 7972.5 mPa s and 1964.5 mPa s respectively, the behavior is very similar that of a Newtonian fluid and may be related to the decrease in the stiffness of the interfacial film and the reduction of the adsorption of natural surfactants such as resins and asphaltenes present in petroleum.

Increasing the amount of water to 10% in the EHCO increased the Viscosity of the analyzed samples. EHCO +10% W at 25 °C had a viscosity of 70 481 mPa s at 25 °C; this corresponds to practically twice the Viscosity concerning EHCO at 25 °C. Resins and asphaltenes plays the role of natural emulsifiers. These agents form an elastic membrane around the drops, a mutual attraction, preventing water-coalescense and gravity-decanting, causing an increase in Viscosity. Fig. 9 shows the trends of the rheograms; it is relevant to mention that EHCO+10% W at 25 °C and 30 °C the final viscosity response of the analysis was obtained at 52.6 s^{-1} and 70.85 s^{-1} (26 847 mPa s and 24 601 mPa s), due to the high Viscosity and use of geometry. The influence of temperature for the samples at 40 °C and 60 °C showed a behavior of a Newtonian fluid; the viscosities obtained were 10375 mPa s and 2349 mPa s, respectively, due to the reduction of the adsorption of natural surfactants in the drops of water impact on the reduction of Viscosity.

Figs. 10 and 11 show the rheograms of EHCO+5%W+3%FE and EHCO+5%W+5%FE. The flow enhancer effect in W/EHCO emulsions favors a decrease in the Viscosity at 25 °C as the shear rate increases; the observed pseudoplastic behavior. EHCO+5% W+3%FE and EHCO+5%W+5%FE at 25 °C presented a 49.08% and 66.65% reduction in Viscosity, respectively, according to EHCO+5%W. Samples at 30 °C, 40 °C, and 60 °C show Newtonian behavior. It is essential to recognize the flow enhancer's influence on the decrease in Viscosity in all samples containing 3% and 5% water.

Figs. 12 and 13 show the rheograms of EHCO+10%W+3%FE and EHCO+10%W+5%FE. The flow enhancer effect in W/EHCO emulsions favors a decrease in Viscosity at 25 °C, a pseudoplastic behavior as the shear rate increases can be observed for both samples. EHCO+10%W+3%FE and EHCO+10%W+5%FE at 25 °C presented a 56.20% and 71.43% reduction in Viscosity, respectively, according to EHCO +10% W. The flow enhancer and temperature improver effect lead to a Newtonian behavior for the samples at 40 °C and 60 °C.

The initial and final Viscosity of the samples at 25 °C, 30 °C, 40 °C and 60 °C is shown in Table 3. The effect of the 1%, 3%, and 5% flow enhancer on the Viscosity of the extra-heavy crude oil with temperatures between 25 ° C and 60 °C showed a Newtonian flow behavior from 40 s^{-1} and a final viscosity reduction percentage between 45% −75% at 25 °C, between 63% −81% at 30 °C, between 83% −91% at 40 °C and 96%–97% at 60 °C according to the EHCO (35282 mPa s). Samples with 5% and 10% water showed an increase in the initial Viscosity of 63.6% and 99.7% at 25 °C, reducing the Viscosity as the temperature increases. Water influences the stability of the emulsion by forming a resistant film of asphaltenes and resins around the water droplets, leading to an increase in Viscosity. The shearing in the equipment and accessories (pumps, valves, pipes, and elbows) produces the emulsion during the lifting, transport, and conduction on the surface of the crude oil. The samples with water and flow improver showed a reduction in Viscosity (>50%) in all cases.

4. Conclusions

The Viscosity of crude oil is sensitive to temperature. The low-temperature flow rheological properties can be improved appreciably on heating about 40°C–60 °C or used a flow enhancer based on esters of fatty acids.

The decrease in viscosity and flow Newtonian behavior using 1%, 3%, and 5% flow enhancer is one of the objectives met with this study which will help lower the cost of heat treatment during transportation of crude oil through the pipeline. The addition of this flow enhancer can serve the purpose of pipeline transportation of extra-heavy crude. 1%, 3%, and 5% flow enhancer show profound decrease in the final viscosity (100 s^{-1}) percentage between 45%, 64%, and 75% at 25 °C. Adding 5 and 10% water to extra-heavy crude oil led to increased Viscosity above 60% and the formation of water-in-crude emulsions. This serious problem can arise during the recovery, treatment, and transportation, and refining of oil. The stability of these emulsions has been associated with forming a "Rigid film" at the oil-water interface. The behavior of emulsions is controlled by the properties of the asphaltenes and resins present in the adsorbed layer. The emulsions' complexity in oil depends on its composition, as are the molecules form in the interfacial phase,

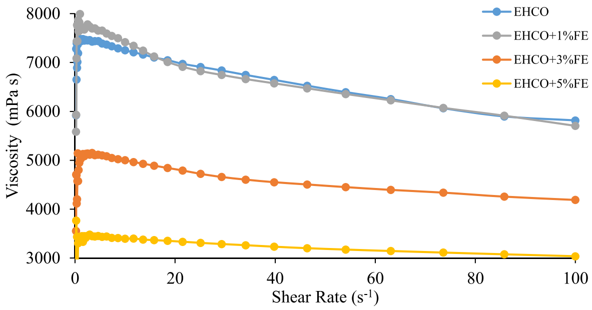

Fig. 6. Rheograms of extra-heavy crude oil with flow enhancer at 40 °C.

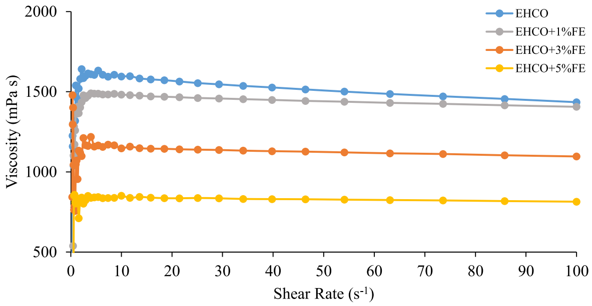

Fig. 7. Rheograms of extra-heavy crude oil with flow enhancer at 60 °C.

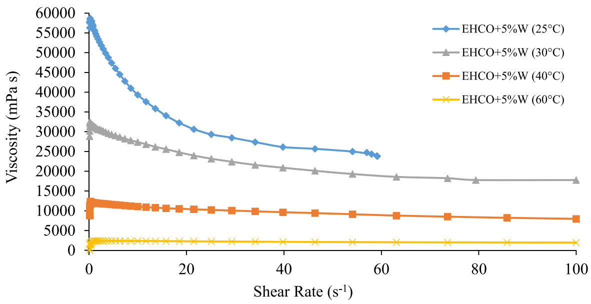

Fig. 8. Rheograms of extra-heavy crude oil with water (5%) at 25 °C, 30 °C, 40 °C, and 60 °C.

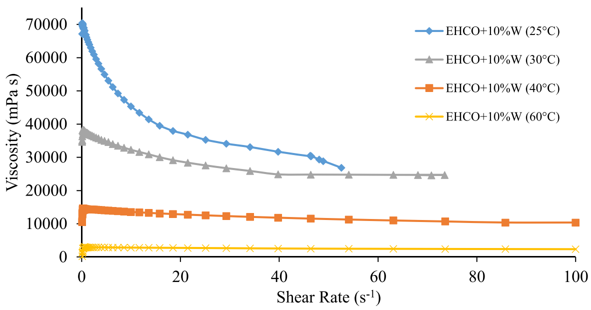

Fig. 9. Rheograms of extra-heavy crude oil with water (10%) at 25 °C, 30 °C, 40 °C, and 60 °C.

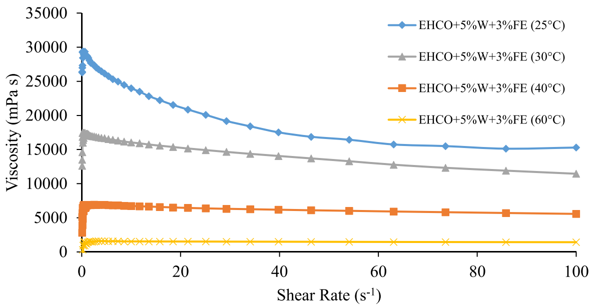

Fig. 10. Rheograms of extra-heavy crude oil/water (5%)/flow enhancer (3%) at 25 °C, 30 °C, 40 °C, and 60 °C.

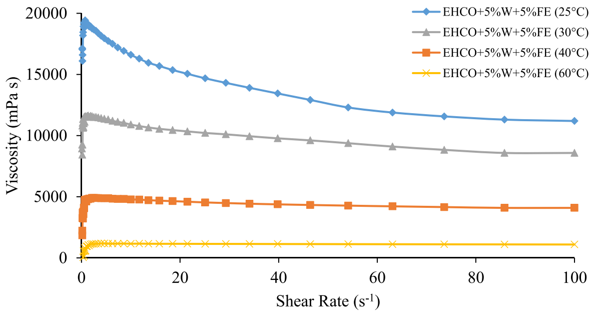

Fig. 11. Rheograms of extra-heavy crude oil/water (5%)/flow enhancer (5%) at 25 °C, 30 °C, 40 °C, and 60 °C.

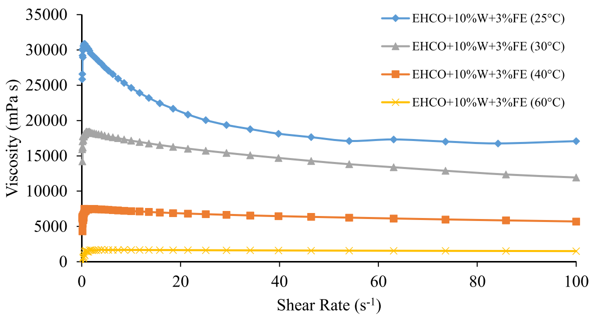

Fig. 12. Rheograms of extra-heavy crude oil/water (10%)/flow enhancer (3%) at 25 °C, 30 °C, 40 °C, and 60 °C.

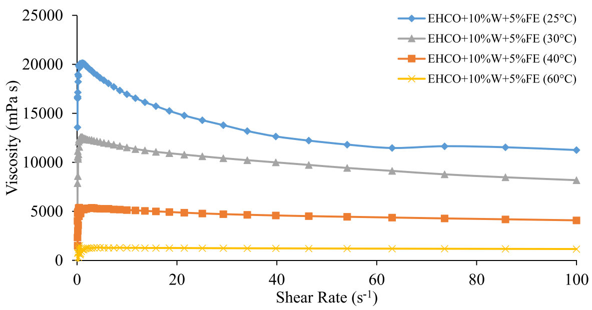

Fig. 13. Rheograms of extra-heavy crude oil/water (10%)/flow enhancer (5%) at 25 °C, 30 °C, 40 °C, and 60 °C.

Table 3
Initial and final Viscosity of samples to 25 °C, 30 °C, 40 °C and 60 °C.

Sample	Initial Viscosity (mPa s)				Final Viscosity (mPa s)			
	25 °C	30 °C	40 °C	60 °C	25 °C	30 °C	40 °C	60 °C
EHCO	35282	19749	7480	1642	49.756	36.748	5816	1435
EHCO+1%FE	35262	19653	7825.6	1490.6	19102	12781	5704.2	1406.2
EHCO+3%FE	20891	12811	5140.9	1478.9	12606	8731.3	4188.5	1096.6
EHCO+5%FE	13204	8649.6	3479.7	857.34	8734.8	6357.6	3030.6	814.48
EHCO+5%W	57737	32548	12373	2422.3	23829	17780	7972.5	1964.5
EHCO+10%W	70481	38349	14667	3070.9	26847	24601	10375	2349
EHCO+5%W+3%FE	29400	17500	6903.1	1585.6	15295	11453	5567.5	1418.5
EHCO+5%W+5%FE	19255	11625	4905	1172.4	11191	8577.4	4084.9	1088.7
EHCO+10%W+3%FE	30867	18437	7508.2	1708.6	17083	11937	5708.2	1510.2
EHCO+10%W+5%FE	20136	12618	5384.8	1493.6	11264	8188	4090.8	1162.6

mainly the amphiphilic molecules. However, the high Viscosity can counteract with the use of the flow enhancer and temperatures between 25°C and 40 °C, always considering the costs involved in applying substances and the amount of energy applied. This study is considered important for a future application in fluid flow transport, possible construction applications and a cost-benefit study.

Declaration of competing interest

The authors declare no conflict of interest.

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