Rheological Behaviors of Crude Oil in the Presence of Water

Madjid Meriem-Benziane, and Hamou Zahloul

***Abstract*—**The rheological properties of light crude oil and its mixture with water were investigated experimentally. These rheological properties include steady flow behavior, yield stress, transient flow behavior, and viscoelastic behavior. A RheoStress RS600 rheometer was employed in all of the rheological examination tests. The light crude oil exhibits a Newtonian and for emulsion exhibits a non-Newtonian shear thinning behavior over the examined shear rate range of 0.1–120 s-1. In first time, a series of samples of crude oil from the Algerian Sahara has been tested and the results expressed in terms of $\tau=f(\dot{\gamma})$ have demonstrated their Newtonian character for the temperature included in [20°C, 70°C]. In second time and at T=20°C, the oil-water emulsions (30%, 50% and 70%) by volume of water), thermodynamically stable, have demonstrated a non-Newtonian rheological behavior that is to say, Herschel-Bulkley and Bingham types. For each type of crude oil-water emulsion, the rheological parameters are calculated by numerical treatment of results.

***Keywords*—**Crude oil Algerian, Emulsion, Newtonian, Non-Newtonian, viscosity.

I. Introduction

CRUDE oil is a mixture of aliphatic hydrocarbons, aromatic, oxygen, nitrogen and sulphur. It may contain resins, asphaltenes. With a density of 0806 and a sulphur content of 0.6%, the Algerian oil is of a good quality in the international markets. The resinous and aromatic molecules accumulate at the oil-water interface to contribute to the emulsion stability, [1]. These components form a rigid layer around the water droplets in order to prevent their coalescence by establishing a physical barrier [2]. Indeed, the water content of an emulsion oil-water plays an important role in the performance of the petrochemical units. To keep the viscosity of the emulsion water-heavy oil, less than to the value required by the specification (around 400 cP) in the transport pipeline, content close to the 60-75% in volume of the bituminous dispersed phase is acceptable. Beyond 70%, the viscosity becomes very high. The determination of the optimum temperature of emulsification has been among the interesting research subjects in chemical engineering during the last decades [3].

The stirring time or bubbling by steam should be properly chosen in order to accelerate the complete emulsification solutions, regardless of their concentration [4]. The injection of water in reservoirs, containing large quantities of oil in the residual state, will give stable oil-water emulsions. Their destabilization is a technical challenge for scientists. At the solid state, other fine substances such as naphthenic acids, contribute to the emulsions stabilization [5]. The analysis of the interfacial tension and modulus of elasticity is not sufficient to predict the stability of oil-water emulsions [6]. It has been well recognized that the aggregation state of asphaltenes is very decisive in the formation of stable crude oil- water emulsion [7].

It is worth mentioning that the classification of crude oils reflect their origin as well as other geochemical parameters [8]. This work focuses on the tests for establishing rheograms relating to the crude oils from three areas of the Algerian Sahara. Such curves allow us to determine the rheological characteristics and the influence of temperature on the viscosity of crude oil to size the installations equipment. The analysis of the influence of water concentration on the rheology of emulsions has been discussed using synthetic samples with variable water content. The results allow the enhancing of the performance of the refining stations.

II. Experimental Procedure

A. Sample Preparation

Our object in this study is to analyze the rheological behaviours of the samples of crude oil from different areas of the Algerian Sahara (Hassi Bakra and Hassi El-Gassi). To determine the behavioural law fluid, we used a rheometer to establish the variation curves of shear stress versus shear rates. After characterization of the rheological behaviour of crude oil, the next part of the work is the preparation of emulsions whose the composition is similar to those frequently encountered in the petrochemical industry. The rheological tests were performed at 20 °C for all crude oil-water emulsion at different concentrations (30%, 50% and 70%). Depending on the concentration of water, the description of the rheological behaviour of emulsions (oil-water) can be modelled according the rheology principal laws of complex fluids.

B. Equipment Used

For each test, maintaining the desired temperature is obtained by a temperature controller type DC30. The pH of emulsions is determined by a pH-meter with calomel electrode, HANNA Instruments-213 type. To study the rheological behaviour of different samples of crude oil and emulsions, we exploit the performance of the rheometer

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'Rheostress 600' which consists of two coaxial cylinders, type Z40 DIN (Fig. 1). Using the compressor, the rheometer operates at a pressure of 2.5 bar.

Fig. 1 Presentation of the rheometer 'Rheostress 600'

III. Experimental Results

A. Rheological Behaviour of Crude Oil

From the results relating to crude oil, given by the functional relationship $\tau = f(\dot{\gamma})$, through the Figs. 2, and 3, we can conclude that the shape of rheograms is a straight line passing through the axis origin. Therefore, the behaviour of crude oil is Newtonian, which can be modelled by the equation:

$$\tau = \mu \dot{\gamma} \qquad (1)$$

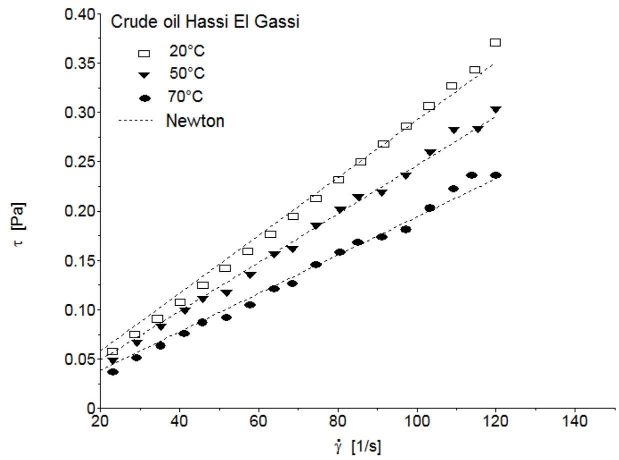

Fig. 2 Rheogram crude oil Hassi El-Gassi at different temperatures

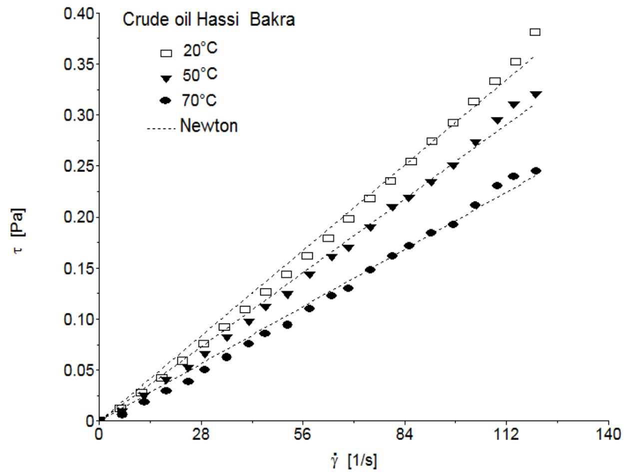

Fig. 3 Rheograms crude oil from Hassi Bakra at different temperatures

B. Influence of Temperature on the Viscosity of Crude Oil

For different temperatures including the interval [20, 70°C], we analyzed the variation of shear stress with shear rate using the rheometer described above. For different crude oils, this interdependence is deducted from rheograms presented in Figs. 2 and 3. Indeed, the increase in temperature is reflected by a consequent decreasing in the viscosity of crude oil. The results show that the viscosity of crude oil varies strongly with temperature and this relationship is described by a law of the form:

$$\log \mu = A + \frac{B}{T} \qquad (2)$$

where A and B are constants characteristic of each oil and T, is the temperature in Kelvin. You can access to their values by plotting, in a appropriate coordinate system, $\log \mu = f(1/T)$. The graphical curves presenting the relation $\log \mu = f(1/T)$ are assigned in Figs. 4 and 5.

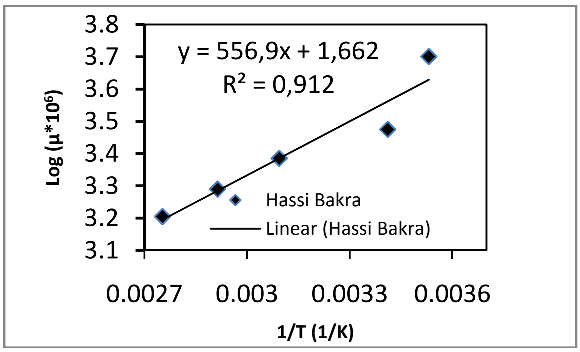

Fig. 4 Variation of the viscosity of crude oil from Hassi Bakra depending on the temperature

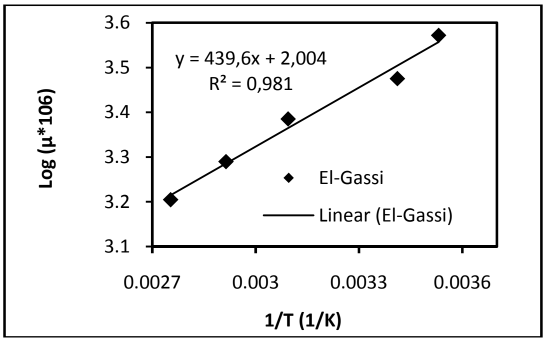

Fig. 5 Variation of the viscosity of crude oil from Hassi EL GASSI depending on the temperature

By numerical treatment of data using the least squares method, the values of the constants A, B and the standard deviation (R^2) are shown in Table I.

We note that the three samples exhibit similar rheological behaviours for different temperatures. In addition, it is worth mentioning that the sample of Hassi Bakra is characterized by its high viscosities towards to the sample from Hassi EL-Gassi.

TABLE I
VALUES OF MODEL CONSTANTS $\log(\mu * 10^{+6}) = f(1/T)$ FOR DIFFERENT CRUDE OILS

Crude Oils	A	B	R2
Hassi El-Gassi	2.004	439.6	0.9810
Hassi Bakra	1.662	556.9	0.9121

IV. RHEOLOGICAL BEHAVIOR OF EMULSIONS

At various percentages of water and volumetric flasks, we have prepared emulsions crude oil-water, using a magnetic stirrer bar, for ten minutes, in order to obtain homogeneous emulsion. The study of liquid-liquid equilibrium and the influence of temperature on the partition coefficient of the phases is the crucial step in choosing the appropriate solvent (liquid-liquid extraction). The process of water injection, in wells, for the recovery of residual oil depends on the feasibility of the liquid-liquid extraction operation. Once the thermodynamically stable emulsion is obtained, we determine the rheological parameters by using the rheometer described above. Thus, to analyze the physicochemical aspect of emulsions, we left to decant for a period of 24 hours in flasks after stirring. The tests have shown the impact of the presence of water on rheology of emulsions.

A. Modelling the Rheology of Emulsions

At T=20 ° C, a series of experiments was conducted to analyze the function $\tau = f(\dot{\gamma})$ for the emulsions prepared above. For different concentrations in water and to identify the model more representative of the rheological behaviour of these emulsions, it is interesting to plot the rheograms $\tau = f(\dot{\gamma})$ given in Figs 6 and 7. Such results have revealed a non-Newtonian behaviour for the emulsion water-crude oil from Hassi Bakra. However, the modelling of crude oil is the basis of this analysis and we propose a power law with many parameters for the characterization of these emulsions. The first point that emerges is that the model includes a threshold stress that bodes no doubt that the fluids obey to the Herschel-Bulkley and Bingham models. Indeed, these models assume that such fluids are schematically, at rest, a rigid three-dimensional structure capable to resist to stresses less than to the threshold stress.

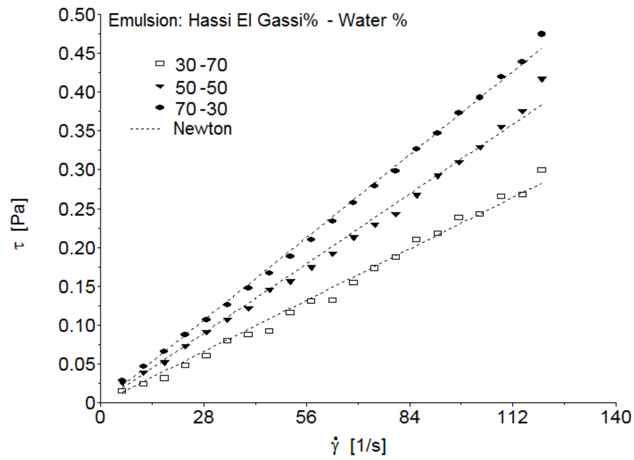

Fig. 6 Rheograms emulsion of crude oil BAKRA type ONMZ 712 at different water contents

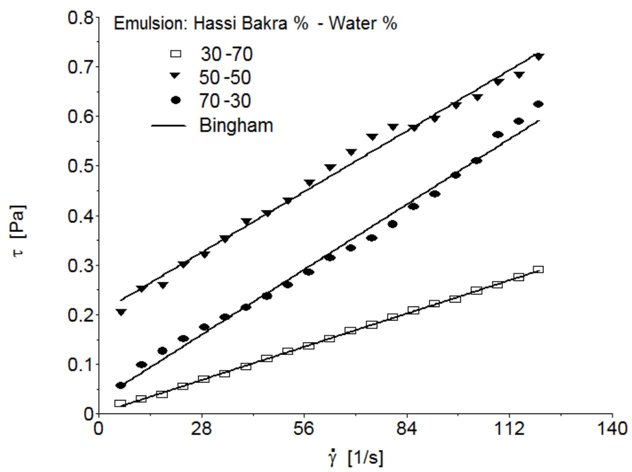

Fig. 7 Rheograms emulsion of crude oil Hassi El-Gasse at different water contents

V. INTERPRETATION OF RESULTS

The experimental results, presented in rheograms form, have clearly established that crude oils have a Newtonian rheological behaviour. Each emulsion was characterized by rheological parameters (τ_0, n and k) and their determination is essentially based on the numerical treatment of experimental results using the least squares method (Table II).

These tests were performed at T=20 °C. In addition, the plotting of the figures 6 and 7 led us to select the appropriate model that describes as accurately as possible the rheological behaviour of the emulsions. It may be noted that the behaviour is Newtonian for the emulsion water-oil from Hassi EL-Gassi type.

However, it was noted that the emulsion has been separated into two phases after a very short period after arrest of the stirring operation and this independently of the water content.

For what relates to the emulsion water-oil from Hassi Bakra, the rheological behaviour has been fitted by the model of Bingham fluid in its monodimensional form, which is given by the following relation:

$$\tau = \tau_0 + \mu \,.\dot{\gamma} \quad (3)$$

The results of these tests have established that τ_0 is a function of the aqueous composition of the emulsion. While giving the Bingham rheological behaviour, the extreme values of τ_0 are obtained for compositions close to 50%. Their value depends mainly on the degree of homogeneity of the emulsion. The higher temperatures favour the crude oil solubilisation to form stable aqueous solutions. For the temperature chosen, it is important to note a demixtion of the phases is obtained when the stirring operation is completed.

TABLE II
UNITS FOR RHEOLOGY PROPERTIES

SYMBOL	QUANTITY	SI UNIT
τ_0	yield stress	Pa
n	flow index	-
$\dot{\gamma}$	shear rate	s-1
τ	shear stress	Pa
K	Consistency	Pa.sn
T	Temperature	°C

Indeed, for higher concentrations, it forms droplets that remain suspended without forming a true emulsion. Consequently, any measure of the threshold stress is affected by the composition of water and the rheological behaviour of such pseudo-emulsion coincides with what the preponderant component. From Fig. 7 presenting $\tau = f(\dot{\gamma})$, we conclude that the rheological properties of emulsions water-crude oil obtained from Hassi Messaoud are modelled by the Herschel-Bulkley equation whose expression is:

$$\tau = \tau_0 + k \,.\dot{\gamma}^n \quad (4)$$

The testing of the different models (Newton and Bingham), we determined the parameters whose values are assigned in the Table III.

TABLE III
VALUES OF MODEL PARAMETERS FOR THE THREE EMULSIONS VERSUS THE WATER CONTENTS

Content in water	Hassi El Gassi	Hassi Bakra	
	Newtonian	Bingham	
Cwater (%V)	µ (Pa.s)	µ (Pa.s)	τ0 (Pa)
0,00	0,002341	0,002986	0,00000
30	0,003803	0,004690	0,02843
50	0,003199	0,004336	0,20300
70	0,002356	0,002392	0,001034
100	0,001	0,001	0,0000

VI. CONCLUSION

The principal objective of this study is to investigate the rheological properties of the light crude oil as important as the mixture of light crude and water (emulsion). We have completed the preparation of synthetic samples of emulsions who's the basis is the crude oil from following areas from the Algerian Sahara: Hassi El Gassi and Hassi Bakra. For this purpose, we used emulsions with the following contents in water, that is to say 30%, 50%, and 70%. For a rheostress 600 type rheometer, the study is focused on the analysis of rheological behaviour of emulsions and the influence of temperature on the viscosity of crude oil in an interval spanning a large domain [10-90°C]. The rheograms $\tau = f(\dot{\gamma})$ have clearly established that crude oil has a Newtonian rheological behaviour regardless of its well genesis. With regard to its liquid state, the variation of the viscosity of crude oil can be described by a law (2).

The current study is carried out to investigate the rheological properties of the light crude oil and its mixture with water. The following conclusions can be made:

- Bingham model for emulsion-based on the crude oil from Hassi Bakra.
- The shape of the curves shows that the rheological behaviour depends on the percentage of water and the historical field of the crude oil.

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