THERMAL IMPACT OF ALGERIAN CRUDE OIL DURING FLOW IN PIPE-LINES

Madjid Meriem-Benziane1*, Mustapha Douani2, Hamou Zahloul1, Mansour Belhadri3
1Mechanical engineering department, University of Chlef Po Box151, Chlef 02000, Algeria
2Chemical engineering department, University of Chlef Po Box151, Chlef 02000, Algeria
3Laboratory of Rheology, transport and Treatment of the complex rheology, University of science and technology- Mohamed Boudiaf, Po Box1505, El M’Naour, Oran-31000 Algeria
*Correspondence author: Fax: + 213 27 72 17 94 Email: mbmadid2001@yahoo.fr

ABSTRACT
This paper deals with the study of the rheological properties of Algerian crude oils and emulsions at different temperatures. Therefore, it is mandatory to get rheological properties to propose adapted solutions. The experimental results obtained with a rheometer can be used to predict the crude oil transport characteristics. The emulsions rheograms shows a non-Newtonian behaviour which can be described by the Herschel-Bulkley and the Bingham models. The obtained results are presented and discussed.

INTRODUCTION
The crude oil properties are classified according to the observed behaviour between the shear stress and shear rate into two main categories: Newtonian and non Newtonian properties. Newtonian cases are defined as those exhibiting a direct proportionality between shear stress and shear rate while for the non-Newtonian fluids, the relation between the shear stress and the shear rate is non linear [1, 2]. 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, [3]. These components form a rigid layer around the water droplets in order to prevent their coalescence by establishing a physical barrier, [4, 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, 8]. Several studies have been performed on the rheological properties of different kinds of crude oils [9, 10].

The formation of emulsion is another problem that occurs in the petroleum industry. Indeed, crude oil is often mixed with water when it comes out from a well. As the oil–water mixture passes over chokes and valves, mechanical input leads to the formation of water-in-oil (W/O) emulsions [11]. 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. 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, [12]. Beyond 70%, the viscosity becomes very high.

Prediction of the viscosity of oil/water emulsions is an important task for oil field development and petroleum transportation [13].

The proposed study focused on the tests for establishing rheograms relating to the crude oils from three regions 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 (30%, 50% and 70%) 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.

EXPERIMENTAL PROCEDURE

Sample preparation: The principal object in this study is to analyze the rheological behaviours of the samples of crude oil from different regions of the Algerian Sahara (Hassi Messaoud, Hassi Bakra and Hassi El-Gassi). To determine the behavioral law fluid, we used a rheometer to establish the variation curves of shear stress versus shear rates of different temperatures. After characterization of the rheological behaviour of crude oils, 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 modeled according the rheology principal laws of complex fluids.

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 ‘Rheostress 600’ (Germany) which consists of two coaxial cylinders, type Z40 DIN (Figure 1). Using the compressor, the rheometer operates at a pressure of 2.5 bars.

Rheology characteristics of Algerian crude oils: The analysis of results relating to crude oil, expressed by the functional relationship \( \tau = f(\dot{\gamma}) \), through the figures 1, 2 and 3, allowed us to conclude that its rheological behaviour is quasi-Newtonian based on the rheogram profile which is a straight line passing through the axis origin.

Shear stress as a function of shear rate, for different temperatures, was measured and compared with, Newtonian model given by equation (1).
\[ \tau = \mu \dot{\gamma} \]  
(1)

Where, \( \mu \) is viscosity of fluid and \( \dot{\gamma} \) is shear rate.

**Thermal impact of the viscosity of crude oils:** 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 figures 4, 5 and 6. 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:

\[ \log \mu = A + \frac{B}{T} \]  
(2)

Where \( A \) and \( B \) are constants characteristic of each oil and temperature \( T \) in (K). You can access to their values by plotting, in an appropriate coordinate system, \( \log(\mu) = f(1/T) \). The graphical curves presenting the relation \( \log(\mu) = f(1/T) \) are assigned in figures 5, 6 and 7.

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 1.

<table>
<thead>
<tr>
<th>Crude Oils</th>
<th>A</th>
<th>B</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hassi El-Gassi</td>
<td>2.004</td>
<td>439.6</td>
<td>0.981</td>
</tr>
<tr>
<td>Hassi Bakra</td>
<td>1.662</td>
<td>556.9</td>
<td>0.9121</td>
</tr>
<tr>
<td>Hassi Messaoud</td>
<td>1.600</td>
<td>561.2</td>
<td>0.9040</td>
</tr>
</tbody>
</table>

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 samples from Hassi Messaoud and Hassi EL-Gassi wells respectively.

**RHEOLOGICAL BEHAVIOUR OF EMULSIONS**

At different 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.

**Modelling the rheology of emulsions:** A series of experiments, at T=20°C, was conducted to analyze the function \( \tau = f(\gamma) \) 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 \( \tau = f(\gamma) \) given in Figures 7, 8 and 9. Such results have revealed a non-Newtonian behaviour for the emulsions water-crude oil from Hassi Bakra and Hassi Messaoud respectively. 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. Once we exceed this stress, the structure is completely dislocated and the fluid flows. It was established that the rheological behaviour of emulsions is rheofluidiant type with a threshold stress. However, they are assimilated to a viscous fluid with a non-linear trend.
RESULTS AND DISCUSSION

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 (τ₀, n and k) and their determination is essentially based on the numerical treatment of experimental results using the least squares method. These tests were performed at T=20°C.

It may be noted that the behaviour is Newtonian for the emulsion water-oil from Hassi El-Gassi type (figure 7). 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. Given the strongly pronounced polarity of the water molecule and the saturated nature of the constituent species of petroleum, it can be argued that there is no chemical reactions that could affect the stability of coexisting phases.

For what relates to the emulsion water-oil from Hassi Bakra (figure 8), the rheological behaviour has been fitted by the model of Bingham fluid in its monodimensional form, which is given by the following relation:

\[ \tau = \tau_0 + \mu \cdot \dot{\gamma} \]  
(3)

Where, τ₀ is yield stress, μ is viscosity of emulsion and \( \dot{\gamma} \) is shear rate.

The results of these tests have established that τ₀ is a function of the aqueous composition of the emulsion. While giving the Bingham rheological behaviour, the extreme values of τ₀ are obtained for compositions close to 50%.

Their value depends mainly on the degree of homogeneity of the emulsion. The higher temperatures favor the crude oil solubilisation to form stable aqueous solutions.

For the temperature chosen, it is important to note a demixing of the phases is obtained when the stirring operation is completed. 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 figure 7 presenting τ = f(\( \dot{\gamma} \)), we conclude that the rheological properties of emulsions water-crude oil obtained from Hassi Messaoud (figure 9) are modelled by the Herschel-Bulkley equation whose expression is:

\[ \tau = \tau_0 + k \cdot \dot{\gamma}^n \]  
(4)

Where, τ₀ is yield stress, k is consistency coefficient, \( \dot{\gamma} \) is shear rate and n is power law exponent.

The testing of the different models (Herschel-Bulkley and Bingham), we determined the parameters whose values are assigned in the table 2.

Table 2

<table>
<thead>
<tr>
<th>Content in water</th>
<th>Hassi El Gassi</th>
<th>Hassi Bakra</th>
<th>Hassi Messaoud</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Newtonian</td>
<td>Bingham</td>
<td>Herschel-Bulkley</td>
</tr>
<tr>
<td>C_{w/v} (%)</td>
<td>µ (Pa.s)</td>
<td>µ (Pa.s)</td>
<td>τ₀ (Pa)</td>
</tr>
<tr>
<td>0.00</td>
<td>0.003141</td>
<td>0.002966</td>
<td>0.00000</td>
</tr>
<tr>
<td>30</td>
<td>0.003039</td>
<td>0.004960</td>
<td>0.002843</td>
</tr>
<tr>
<td>50</td>
<td>0.003199</td>
<td>0.004336</td>
<td>0.002010</td>
</tr>
<tr>
<td>90</td>
<td>0.002356</td>
<td>0.004392</td>
<td>0.001013</td>
</tr>
<tr>
<td>100</td>
<td>0.001000</td>
<td>0.001000</td>
<td>0.000000</td>
</tr>
</tbody>
</table>

We have shown that the emulsions obtained are very complex mixtures and the modelling of their rheological behaviour requires the introduction of thermodynamic models involving mixing rules such as NRTL, UNIQUAC, DEHEMA to predict their stability. However, the deviation from the ideal solution deserves the study of activity coefficient and the partition coefficient of water in the emulsions with high concentration in crude oil. At infinite dilution, the emulsion behaves similarly to the crude oil.

CONCLUSION

The analysis capacity of a recovering method of buried oil in the deposits as residual amounts, we have completed the preparation of synthetic samples of emulsions whose the basis is the crude oil from following areas from the Algerian Sahara: Hassi El Gassi, El Hassi Messaoud 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 [20-70°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 of the form \( \log(\mu) = f(1/T) \). The different emulsions have yielded results that are calibrated by rheological models obeying to the power law with a weak behaviour index and a threshold stress. Depending on the oilfield, we distinguished the following rheological behaviour:

1) Herschel-Bulkley model for the emulsion based on the crude oil from Hassi Messaoud;
2) Bingham model for emulsion-based on the crude oil from Hassi El-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.

**Keywords:** Rheology, Crude oil, Water-in-Oil emulsion, Newtonian, Non Newtonian, Stress, Viscosity.

**REFERENCES**

5. Benito, M., Carmen, P., and José, C., 2007, Interfacial properties of oil-in-water emulsions designed to be used as metalworking fluids, Colloids and Surfaces A, 305(2), pp. 112–119.