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Rheological Characterization of Algerian Crude Oil and Emulsions Water / Oil

D. Benyerou*, M. Mekkaoui , L. Hammadi, N. Boudjenane, M. Belhadri

Rheology Laboratory, Transportation and Handling of Complex Fluids (LRTTFC), Faculty of Architecture and Civil Engineering, Department of Hydraulics, University of Science and Technology of Oran (USTO-MB) BP 1505 Oran-EL-M 'naour 31000, Algeria

**Corresponding author. Tel.: +213 555 33 95 98; Benyerou31amri@gmail.com*

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Abstract. In this paper, a fine rheological characterization was performed for five types of crude oil from the Algerian Sahara and several water / oil emulsions.
This study allows us to obtain more knowledge about the rheological behavior of these samples and provides us with information on their storage and transport in pipes. Three qualities of water were used, seawater, drinking water and groundwater sources.
The tests were carried out at a temperature of 23 °C using a sophisticated rheometer with cone-plate geometry (the RS600 RheoStress from ThermoHaake). The perturbing effects such as sliding, evaporation, fracturing and digging were well controlled.
The study shows that the rheological behavior of the five types of crude oil is Newtonian, however, that emulsions of volume concentrations of 30%, 50% and 70% of water is non-Newtonian with the existence of a threshold constraint.
The Bingham, Herschel-Bulkley and ostwald De Waele models were used and adjusted so to correctly represent the rheological behavior of these materials.

***Keywords*.** Oil, Oil-water emulsions, Rheological behavior, Stress level, Shear stress, Shear rate.

INTRODUCTION

It is known that crude oil plays a vital role in the global energy supply. The main parameters to identify the crude oil are: specific gravity (API), density (d) and sulfur content (S) (Salhi, 2010).
According to their respective mean values (38 <API <44, 0.806 <d <0.830 and 0.2% <S <0.3%), Algeria's crude oil is classified as light oils (Aomari, 1998). Therefore, its transport necessitates fairly complex networks (Zaki, 1997).
The main objective of this work is to obtain the rheological parameters of samples of crude oil and its water-based emulsions. This study allows us to determine the behavior of the mixture during transport and know the kind of pumps that could be used to transport it.

MATERIALS AND METHODS

Device used

The rheological behavior of different samples was studied using a RS 600 stress rheometer with a shear rate imposed in a Cone-plane geometry. (C60/T2 °: 60 mm diameter, 2-degree angle, gap 0.105 mm). The pressure was adjusted to 2.5. The temperature was maintained constant at 23 ° C. The device has a Peltier temperature control system which allows for a very fast response to temperature changes.

Material used

Five types of light crude oil were used for the preparation of emulsions water / oil with three qualities of water: sea water, drinking water, groundwater sources. Samples of light crude oil were taken from various oil fields in Algeria.
The emulsions were prepared at various concentrations of water (30%, 50% and 70%) at the temperature of 23 ° C. The perfect homogenization was achieved by stirring the mixture for one hour with a magnetic field. The pH of the emulsions was determined by means of a pH meter probe.

Method used

For the five types of crude oil and water emulsions / oil, a speed ramp from 0.05 to 200 s^{-1} is applied to the samples for 600s. To ensure reproducibility of the results two tests are performed for each concentration.

RESULTS

Physicochemical analysis (Table 1, 2)

Drinking water: has good physicochemical quality, the obtained results are within drinking water standards and no anomaly has been reported.
Underground source water: has high mineralization such as SO_4 sulphate, chloride Cl, hydrometric title HT and conductivity.
Sea water: has high mineralization such as SO_4 sulphate, chloride Cl, hydrometric title HT and conductivity. Pollution parameter such as organic matter has been reported. Toxic health endpoints do not meet drinking water standards such as Barium Ba^{+2} or Phenol.

Table.1. Physicochemical analysis results of drinking water.

	Organoleptic	
Parameter	Samp (drinking, source, sea)	Std CMA (NA)
odor	/	4 (Dilution_IE_104)
taste	/	4 (Dilution_IE_104)
color (Pt-Co)	0	25 Colorimetric

Table. 2. Physicochemical analysis results of underground source water and sea water.

Physicochemical (Apparatus+volume)				
Parameter	Drinking water	Underground source water	Sea water	Std CMA (NA)
PH	7.90	7.24	8.02	6.5 à 8.5
Temperature °C	18.4	18.4	18.5	<25<
Conductivity (µs/cm)	1423	9080	54400	2000
Salinity	0.7	5	35.6	1
O_2 $*10^{-3}$(g/l)	7.4	7	7.7	8.5
Turbidity(NTU)	2	0.989	0.26	5
TDS	711.50	4540	27200	/
M.O $*10^{-3}$(g/l)	0.13	0.88	6.19	3
TA (F°)	0	0	0	/
TAC (F°)	10.4	36	11	/
Carbonate CO_3^{2-} $*10^{-3}$(g/l)	0	0	0	/
Bicarbonate HCO_3^- $*10^{-3}$(g/l)	158.652	561.384	366.12	/
TH (F°)	44	187	710	200
Calcium Ca^{++} $*10^3$(g/l)	56.11	43.2	1090.176	200
Magnesium Mg^{++} $*10^{-3}$(g/l)	72.83	428.16	1063.02	150
Chloride Cl-$*10^3$(g/l)	216.9	3268.49	19001.2	500
Nitrite $NO_2^-$$*10^{-3}$(g/l)	0.006	0.016	0.005	0.1
Nitrate $NO_3^-$$*10^{-3}$(g/l)	5.43	1.019	0	50
Ammonium NH_4^+ $*10^{-3}$(g/l)	0.03	0.003	0.239	0.5
Chrome hexa valent Cr^{6+} $*10^{-3}$(g/l)	0.01	0.009	0.025	0.05
Sulfate $SO_4^{2-}$$*10^{-3}$(g/l)	493.45	974.5	3229.5	400
Ortho phosphate $PO_4^{3-}$$*10^{-3}$(g/l)	0	0.01	0	0.5
Iron Fe^{3+} $*10^{-3}$(g/l)	0.09	0.03	0	0.3
Manganese Mn^{2+} $*10^{-3}$(g/l)	0	0	0	0.5
Copper Cu^{2+} $*10^{-3}$(g/l)	0.06	0.3	0.174	1.5
Aluminium AL^{3+} $*10^{-3}$(g/l)	0	0	0	0.2
Phosphore P $*10^{-3}$(g/l)	0	0.0306	0	/
Zinc Zn^{++} $*10^{-3}$(g/l)	2.09	0.59	0.13	5
Dry Residue (g/l)	1.236	7.295	50.46	/
Silica SIO_2	/	21	8	200
Barium Ba^{+2} $*10^{-3}$(g/l)	4	100	800	1
MES $*10^{-3}$(g/l)	118	250	997	/
Hydrocarbons	0	0	0	/
Phenol (µg/l)	0	0	0	10

Rheoligical characteristics of crude oil

Five samples of light crude oil were used to investigate their rheological properties at room temperature of 23 ° C using the Rheo-stress rheometer 600 (Fig.1).

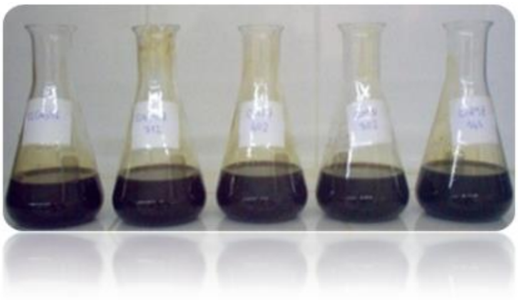

Fig.1. Five crude oil samples from Algerian Sahara oil fields.

Figure 2 shows the evolution of the shear stress as a function of shear rate of the five crude oil samples (A, B, C, D and E), from Hassi MESSOUD oil field.
The five samples are adjusted by the Newton model.

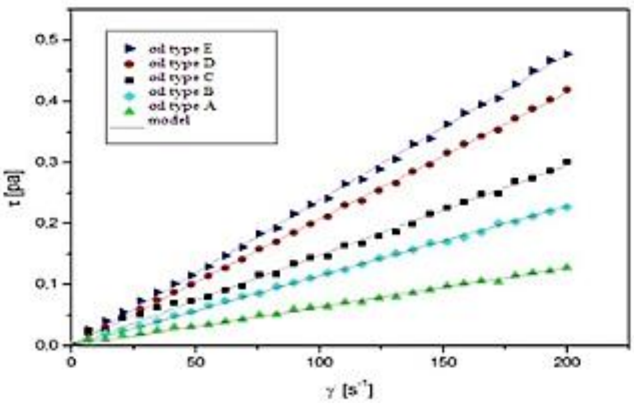

Fig.2. Flow curve for crude oil at ambient temperature of 23°c.

Table 3 summarizes values of the Newtonian viscosity of the five samples. It is observed that sample A is less viscous than the others. We also observe that the five samples have a pH <7.

Table.3. Physical parameters of crude oil samples.

Samples of oil	Type A	Type B	Type C	Type D	Type E
Viscosity	0.00042	0.00068	0.00072	0.00133	0.00154
Density	0.83	0.80	0.78	0.76	0.79
pH	4.57	4.46	4.20	3.28	4.85

- Effect of temperature

Table 4 summarizes the evolution of Newtonian viscosity values of the five samples with temperature. It is observed that all the samples studied are Newtonian fluids.
It can also be noted that the decrease in viscosity is proportional to the temperature increase. Indeed, the increase in temperature facilitates the transport of crude oil in the pipes.

Table. 4. Variation of viscosity as a function of temperature for the five crude oil samples.

T (ºC)	20	40	60	80	100
η (pa.s) de type A	0.002215	0.001259	0.001161	0.001105	0.0008045
η (pa.s) de type B	0.001544	0.001431	0.001396	0.001080	0.00044
η (pa.s) de type C	0.001913	0.001740	0.001384	0.001322	0.0004016
η (pa.s) de type D	0.002381	0.002070	0.001478	0.001140	0.00063
η (pa.s) de type E	0.002303	0.001745	0.001665	0.00142	0.00104

Rheological properties of emulsions (oil-water)

This part of the study is devoted to experimental results of the Rheological parameters for crude oil and its emulsions : oil / sea water, oil / drinking water and oil / underground source water at different concentrations (30%, 50%, 70 %).

It can be seen from rheograms of figures (3, 4, 5, 6 and 7), that the most appropriate models for the behavior of emulsions at these concentrations are those of Ostwald de Waele, Bingham and Herschel-Bulkley. The latter clearly shows the existence of a threshold stress.

The power law also known as Ostwald de Waele law can be expressed as follows :

$\tau = K\dot{\gamma}^n$ (1)

With $0<n<1$

For the other emulsions rheological behavior becomes plastic, with the existence of a flow threshold point. Bingham and Herschel-Bulkley models best describe this rheological behavior depending on the type of oil and the quality of water used.

$\tau = \tau_0 + \eta_B\dot{\gamma}$ (2)

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

We can observed that in the previous figures the shear stress decreases with increasing salinity of the water. We also notice a change in the rheological behavior of oil. This change is most likely caused by chemical reactions within oil-water mixtures. The flow model changes from Newtonian to non-Newtonian model.

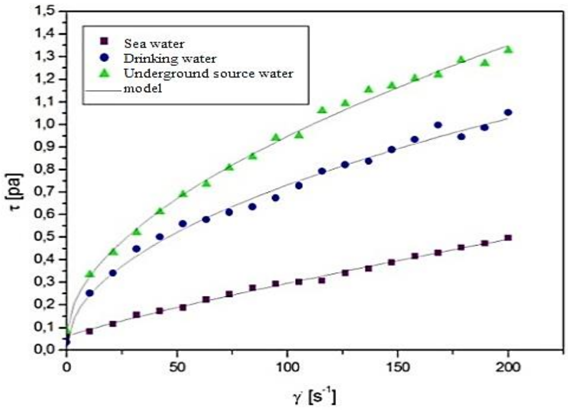

Fig.3. Rheogram for three water qualities emulsions with a concentration of 30% oil (type a) and 70% of water.

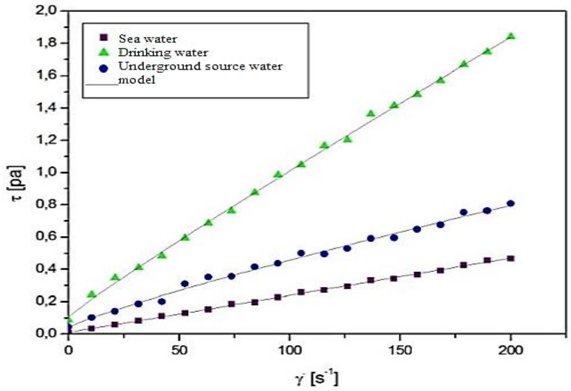

Fig.4. Rheogram for threee water qualities emulsions with a concentration of 30% oil (type b) and 70% of water.

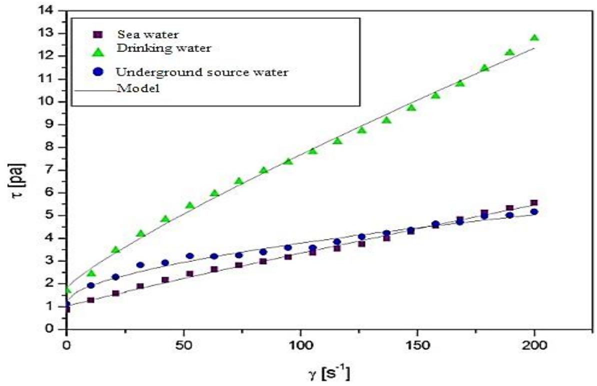

Fig.5. Rheogram for three water qualities emulsions with a concentration of 30% oil (type c) and 70% of water.

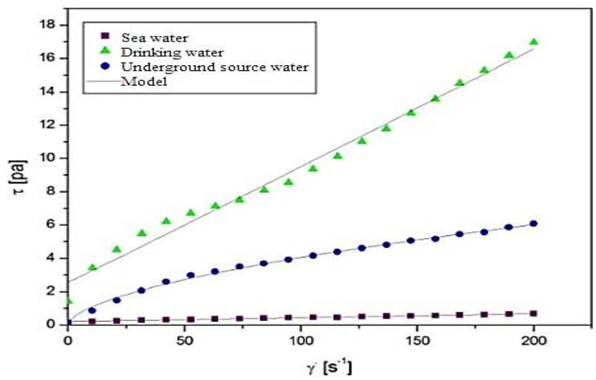

Fig.6. Rheogram for three water qualities emulsions with a concentration of 30% oil (type d) and 70% of water.

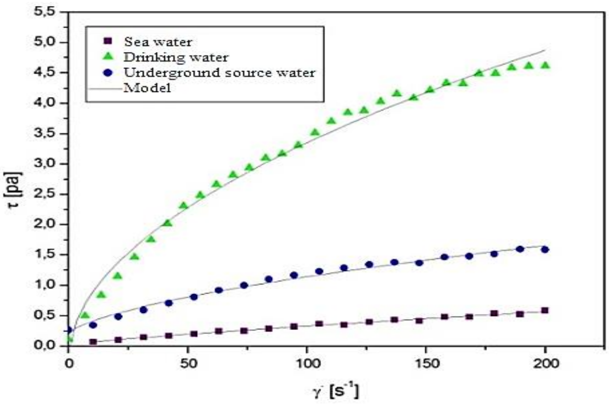

Fig.7. Rheogram for three water qualities emulsions with a concentration of 30% oil (type e) and 70% of water.

MICROSCOPY ANALYSIS OF EMULSIONS

Figure 8 shows the size distributions of oil emulsions drops, emulsion stability and including the formation films on droplets. Factors that affect the stability are (temperature, droplet size and pH). The emulsions of petroleum products generally have diameters of droplets exceeding 0.1 microns and may reach 100 microns.

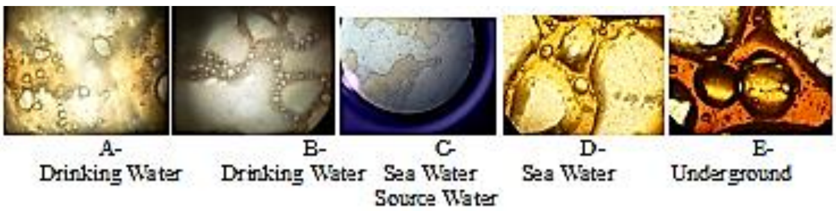

Fig.8. Droplets microscopic view (70% oil and 30% water).

CONCLUSION

This study showed that the water content in oil emulsions from different regions of the Algerian Sahara is important in the oil industry in its various production stages. This content can be of the order of 30%, 50% or 70% by volume of water. Water content in oil emulsions is specifically important for the different pumping operations (flow in pipelines).

From the results obtained, it can be stated that flow curves of emulsions are modeled by the "power" laws with two different indices of behavior: The first, less than one and the second higher than one with a threshold stress. Therefore emulsions are of non-Newtonian plastic-type fluids. They can be represented by models such as the Herschel-Bulkley model, Bingham and ostwald De Waele.

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APPENDIX

Table.1. Rheological parameters of a-type emulsions with three water qualities at a 30% oil and 70% water concentration

	Type A					
CV water (%)	Calibrated model	pH	τ_0 (Pa)	K (pa.s^2)	n	R
Sea water	Herschel-Bulkely	7.58	0.3305	0.0649	0.2490	0.9823

Drinking water	Herschel-Bulkely	8.11	0.7347	0.233.	0.8736	0.9945
Water from an underground source	Ostwald de Wade	7.98	/	0.1329	0.5954	0.9941

Table. 2. Rheological parameters of b-type emulsions with three water qualities at a 30% oil and 70%water concentration

	Type B					
CV water (%)	Calibrated model	pH	τ_0 (Pa)	K (pa.s^2)	n	R
Sea water	Herschel-Bulkely	7.46	0.0874	0.0078	0.8629	0.9961
Drinking water	Herschel-Bulkely	7.98	0.2509	0.0532	0.9388	0.9863
Water from an underground source	Ostwald de Wade	7.70	0.0909	0.0119	0.5708	0.9812

Table. 3. Rheological parameters of c-type emulsions with three water qualities at a 30% oil and 70% water concentration

	Type C					
CV water (%)	Calibrated model	pH	τ_0 (Pa)	K (pa.s^2)	n	R
Sea water	Herschel-Bulkely	7.85	1.0110	0.0310	0.9170	0.9920
Drinking water	Herschel-Bulkely	7.59	1.7970	0.1199	0.8451	0.9977
Water from an underground source	Ostwald de Wade	7.90	1.727	0.1294	0.7817	0.9821

Table. 4. Rheological parameters of d-type emulsions with three water qualities at a 30% oil and 70% water concentration

	Type D						
CV water (%)	Calibrated model	pH	τ_0 (Pa)	K (pa.s^2)	n	η_p	R
Sea water	Herschel-Bulkely	7.75	1.5460	/	/	0.0883	0.9954
Drinking water	Herschel-Bulkely	8.22	1.6633	0.2850	0.6423		0.9855
Water from an underground source	Ostwald de Wade	8.01	0.2400	0.2400	0.5755		0.9847

Table. 5. Rheological parameters of e-type emulsions with three water qualities at a 30% oil and 70% water

	Type E					
CV water (%)	Calibrated model	pH	τ_0 (Pa)	K (pa.s^2)	n	R
Sea water	Herschel-Bulkely	7.57	0.1838	0.0571	0.5027	0.9952
Drinking water	Herschel-Bulkely	7.70	0.2966	0.2601	0.5079	0.9847
Water from an underground source	Ostwald de Wade	7.98	/	0.2192	0.5538	0.9863

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