

The Influence of Temperature on the Rheological Behaviour of Some Raw and Additivated Crude Oils

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This study aims to present the results obtained by performing lab tests regarding the influence of temperature on the rheological behaviour of crude oil both pure and mixed with additives samples. The rheological behaviour of crude oil, pure or additivated, were studied in terms of viscosity – temperature and shear stress – temperature to understand the flow behaviour of these fluids.

Keywords: crude oil, rheological behaviour, additive, viscosity, shear stress, shear rate

Rheological behaviour describes the materials behaviour in terms of their deformation following an external load action. It is well known that a force applied to a body can result in the body position change or, in specific conditions, in the body volume and shape change. As a first approach, the rheological behaviour of the fluids aims their behaviour from the viscosity point of view. Viscosity is one of the most important physical properties of the fluids, perceived as a resistance to fluids flow. This is the essential characteristic that makes the difference between perfect and ideal fluids and the real ones, representing fluid models used in the fluids dynamics.

By definition, viscosity is the fluids property to prevent flow due to tangential stresses development. Tangential stresses also named as shear stresses, symbolized τ , are proportional to velocity gradient normal to the flow direction, dv/dy , named as strain rate / shearing rate, for Newtonian fluids is described by Newtonian's law [1-5]

$$\tau = \mu \frac{dv}{dy} \quad (1)$$

where μ , proportionality factor, is called dynamic viscosity.

Fluids like water, clear mineral oils and other liquids used in technics and different practical applications meet equation (1) and they are called Newtonian fluids. It is very important to know the influence of the status parameters upon viscosity. Generally, for liquids, viscosity rapidly decreases with temperature and slightly increases with pressure. These influences also occurs in case of crude oil, when its knowledge is even more important as it is well known that they affect the flow through porous medium (reservoir), tubing and pipelines, and also the manufacture process [6, 7].

In nature, as in the technique, many fluids have a non-Newtonian behaviour when, generally, viscosity decreases with the strain rate, a characteristic which can be temporary or permanent. In case of a non-Newtonian behaviour, the relation between shear stress and shearing rate is either non-linear or the variation curve does not pass through the origin.

Flow behaviour of the non-Newtonian liquids depends either on the stresses applied to them or on their duration [8-10]. Thus, the Newtonian fluid can be described by a rheological equation in form of the reference (1) but where the concept of apparent viscosity is used, μ_{ap} , a factor

depending on a mechanic variable, shear stress or time, respectively [3, 11, 12],

$$\tau = \mu_{ap} \frac{dv}{dy} \quad (2)$$

It is important to know rheological properties of the fluids, for foresight of the fluids physical properties evolution in or after processing, of designing, to a correct sizing of technological, exploitation, transportation and storage plants and equipment.

This paper presents the results of the study regarding rheological behaviour of a non-paraffinous crude oil, A type, and of a paraffinous crude oil, C type, and also the rheological behaviour of an A type crude oil, additivated with compounds as C type crude oil, Petrosin, carboxymethyl cellulose (CMC), carbon tetrachloride (TCC), methyl ethyl cellulose (MEC), in different concentrations.

Experimental part

Experimental works were performed at the General Hydraulics laboratory of Petroleum - Gas University of Ploiesti, using a RHEOTEST 2 device. The used measurement system was adequate to the device with two coaxial cylinders. Substance to be analyzed lies in their annulus space. Tangential stress, τ , shearing rate, dv/dy and dynamic viscosity, μ , were determinated based on the recordings during the tests [1-3].

The crude oils analyzed samples are from Romanian territory. Since high viscosity crude oils determine special problems both at the extraction process and during the transport activity, a high viscosity crude oil was used during the tests but also a less viscosity one, subsequently used as an additive.

Samples consisted of 10 mL substance to be analyzed and the concentric cylinders system was used.

The most important physicochemical properties of the analyzed crude oils are presented in table 1.

The following substances were used as additives: carboxymethyl cellulose (CMC), petrosin, carbon tetrachloride (TCC), methyl ethyl cellulose (MEC).

Results and discussions

By the performed tests and calculations, the influence of temperature upon the viscosity and shear stress was

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Properties Crude oil type	t	ρ	ν	μ	Paraffin content
	°C	kg/m ³	10 ⁻⁶ m ² /s	10 ⁻³ Pa·s	%
A	19	890	1044.94	930	< 1
C	19	820	10.79	8.85	paraffinous

Table 1
PHYSICO-CHEMICAL PROPERTIES OF THE ANALYZED CRUDE OILS

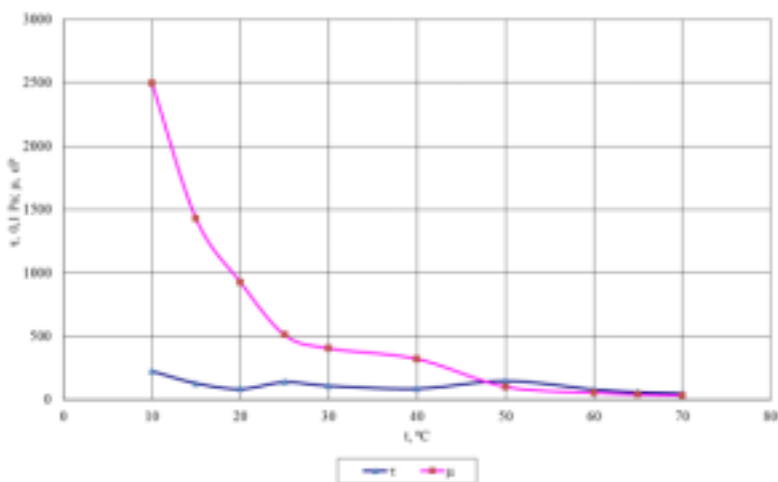


Fig. 1. Dynamic viscosity / shear stress - temperature rating, for an A type crude oil

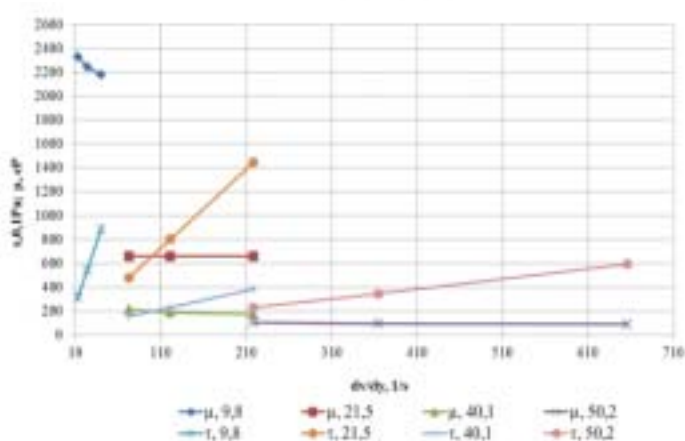


Fig. 2. Rheogram of type A crude oil at different temperatures: 9.8, 21.5, 40.1, 50.2°C

studied. The obtained results are presented in graphical form.

Crude oil of A type

Figure 1 indicates dynamic viscosity / shear stress - temperature rating, for an A type crude oil.

Note that dynamic viscosity decreases with temperature increasing, much more pronounced at temperatures up to 30°C, as this decreasing is very low at higher temperatures, over 60°C.

Variation of shear stress also indicates a down trend by temperature increasing. The two peaks presented on the chart at 25 and 50°C correspond to the rotating speed modification (growth) and therefore to the shearing rate.

Figure 2 presents the rheograms of the A type crude oil at different temperatures. Shear stress - shearing rate linear variation indicates a Newtonian behaviour of the analyzed crude oil. Although, at a more careful analyse it can be noticed that, at the temperature increasing, the crude oil behaviour deviates from the classic Newtonian behaviour described by reference [2, 5]. Shear stress - shearing rate linear variations do not intersect the origin, indicating an initial shear stress. This type of rheological behaviour corresponds to the Bingham model described by the equation:

$$\tau = \tau_0 + \eta \frac{dv}{dy} \quad (3)$$

where τ_0 is initial / retaining shear stress (tangential stress for the movement initiation, stress / flow limit) and η is chart slope and which is called stiffness coefficient (plastic viscosity or mobility) [4, 5, 12].

Plastic viscosity (rheogram slope) decreases with the temperature increasing, from 2.1 Pa·s at 9.8°C to 0.08 Pa·s at 50.2°C, while flow limit increases from 3.3 Pa at 9.8°C to 4.6 Pa at 50.2°C (at 21.5°C, the behaviour corresponds to the Newtonian fluids).

Representing dynamic viscosity - shearing rate charts (fig. 2) it can be also noticed that the analyzed crude oil behaviour corresponds to a Newtonian fluid only at 21.5°C, i.e. dynamic viscosity is not depending on the shearing rate (fig. 2).

For temperatures higher than 21.5°C or even less, we noticed that dynamic viscosity decreases with shearing rate increasing, a phenomenon corresponding to the Non-Newtonian behaviour of the fluids (figs. 2, 40.1°C & 50.2°C). The reason could be the impurities presence, especially water, even in small quantities (experimental data shown that the water presence in oil significantly influences their viscosity [7, 16]) or occurrence of structural changes in the crude oil.

C type crude oil

Figure 3 indicates dynamic viscosity / shear stress - temperature rating, for a C type crude oil.

Having a less viscosity, C type crude oil presents a less viscosity - temperature variation while tangential stress

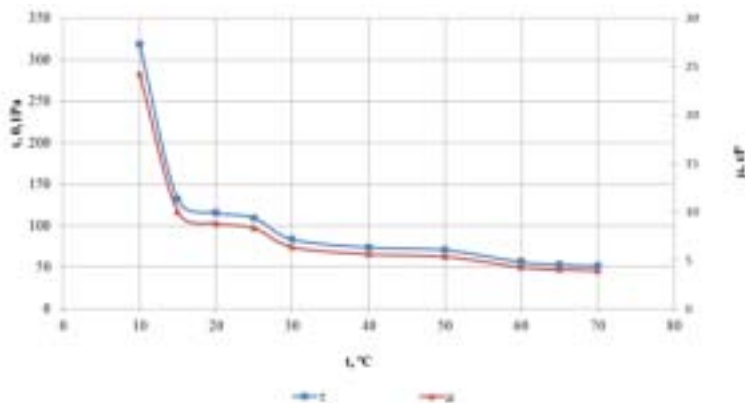


Fig. 3. Dynamic viscosity / shear stress - temperature rating, for a C type crude oil

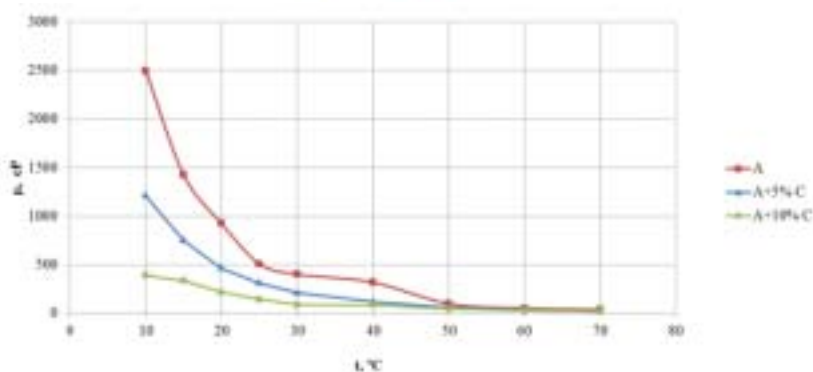


Fig. 4. Dynamic viscosity - temperature rating, for an A type crude oil additivated with C type crude oil

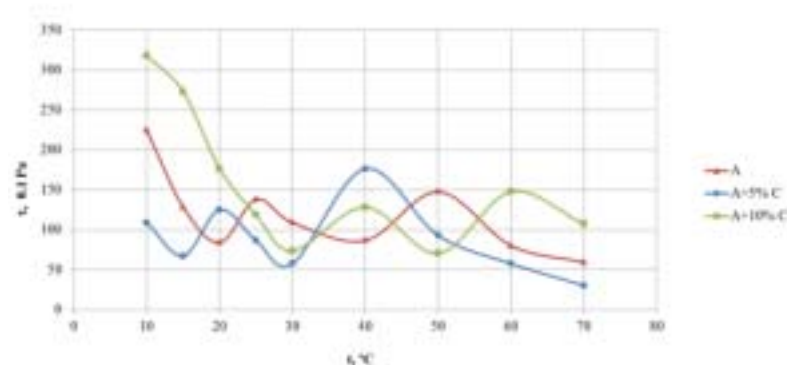


Fig. 5. Shear stress - temperature rating, for an A type crude oil additivated with C type crude oil

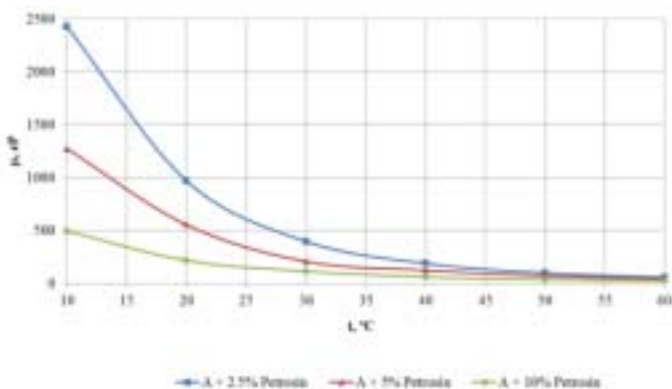


Fig. 6. Dynamic viscosity- temperature rating, for an A type crude oil additivated with Petrosin

presents a higher variation especially at temperatures less than 30°C ; at temperatures over 50°C , this variation becomes almost insignificant. This is the reason why C type crude oil was used as an additive for A type crude oil. There was followed the influence of C type crude oil upon the rheological behaviour of A type crude oil in the temperature range of $10 \dots 70^{\circ}\text{C}$.

A Type Crude Oil + C Type Crude Oil. Tests were performed for two types of additives: 5 and 10 % C type crude oil in A type crude oil, respectively. Viscosity - temperature variation is presented in figure 3 and shear stress - temperature variation is presented in figure 5, for both two situations. From the obtained data, it can be noticed that A type crude oil viscosity decreases with C

type crude oil concentration increasing (fig. 4) while shear stress has a different variation, a distinct trend couldn't be clearly identified. So, in case of 5 % concentration of C type crude oil, there was initially observed a shear stress decreasing for the same values of shearing rate, while for 10 % concentration we can notice shear stress increasing towards corresponding values of untreated A type crude oil. Picks on the shear stress variation curves are due to shearing rate modification (fig. 5).

A Type Crude Oil + Petrosin. Tests were performed for three different concentrations: 2.5, 5 and 10 %, respectively. Viscosities and shear stresses are presented in figure 6 and 7.

Figure 6 indicates that viscosity of the analyzed crude oil decreases with Petrosin concentration increasing when this concentration is over 5%.

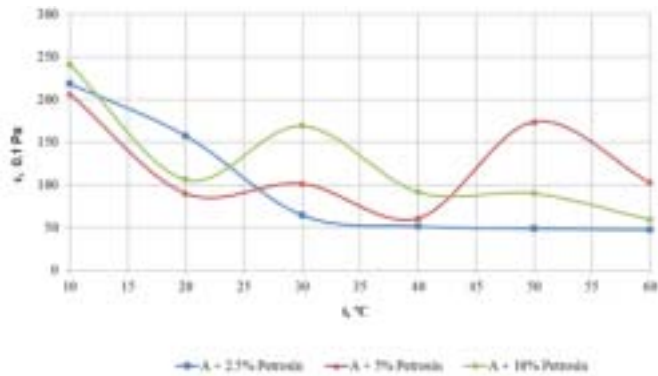


Fig. 7. Shear stress - temperature rating, for an A type crude oil additivated with Petrosin

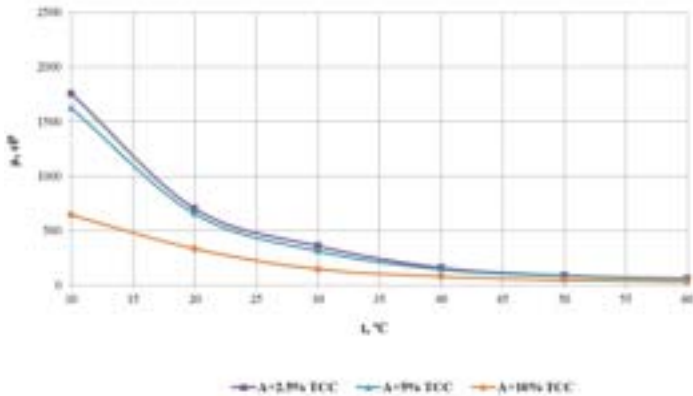


Fig. 8. Dynamic viscosity - temperature rating, for an A type crude oil additivated with TCC

About shear stress, a random variation of this parameter can be observed, for different concentrations of Petrosin used in tests. Nevertheless, overall, we can notice an increasing trend of shear stress at low temperatures especially at small values of concentrations (fig. 7 - 2.5%), while there is a decreasing trend at high temperatures (> 30°C), also visible at small values of Petrosin concentrations. Peaks correspond to shearing rate modifications due to rotating speed growing.

A type Crude oil + TCC (carbon tetrachloride). TCC was used to additivate an A type crude oil at concentrations of 2.5, 5 and 10 %, i.e. similar to the above concentrations.

Figures 8 and 9 present viscosities and shear stresses determined after the performed tests.

Studying charts presented in figure 8, we can notice that viscosity decreases with TCC concentration increasing at temperatures up to 40 - 50°C, and then the additive process has almost no effect upon the crude oil viscosity. We can also notice that the influence of 0.05 concentration upon the crude oil viscosity is similar to influence of 0.025 concentration. About shear stress, at low temperatures (< 20°C), it increases at concentrations up to 0.05 TCC and decreases at higher concentrations (ex. 0.1 TCC), the trend reverses after that temperature and over 50°C the decreasing trend remains irrespective of the concentration value. We can notice peaks on the chart coincident with the moment of shearing rate modification (growing).

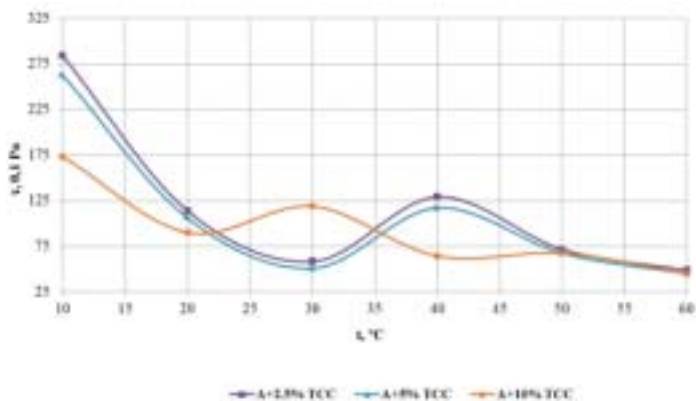


Fig. 9. Shear stress - temperature rating, for an A type crude oil additivated with TCC

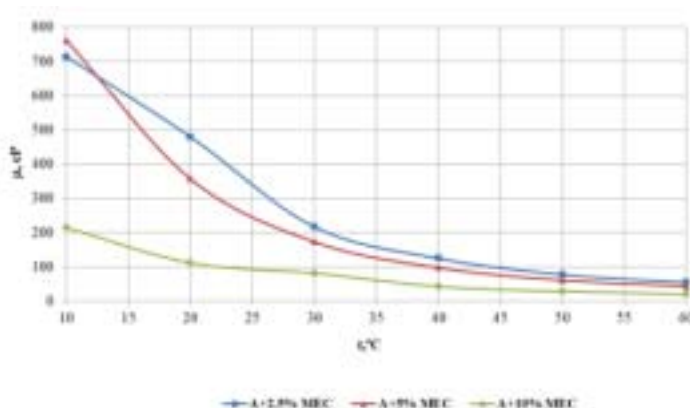


Fig. 10. Dynamic viscosity - temperature rating, for an A type crude oil additivated with MEC

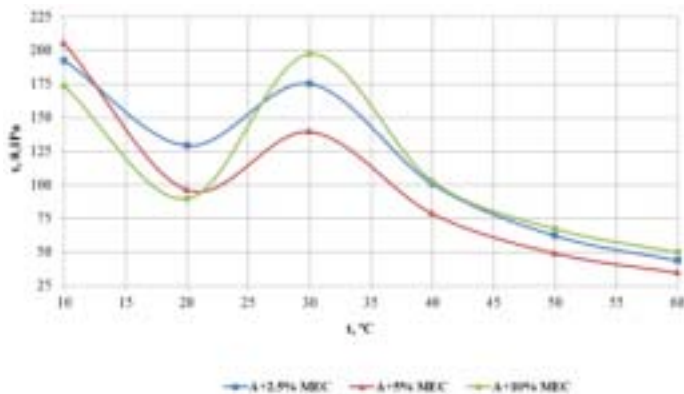


Fig. 11. Shear stress - temperature rating, for an A type crude oil additivated with MEC

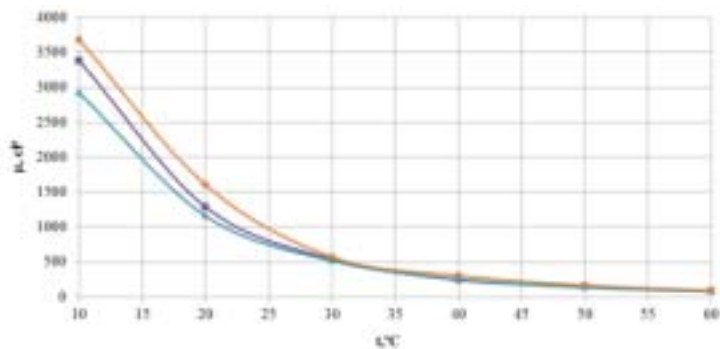


Fig. 12. Dynamic viscosity - temperature rating, for an A type crude oil additivated with CMC

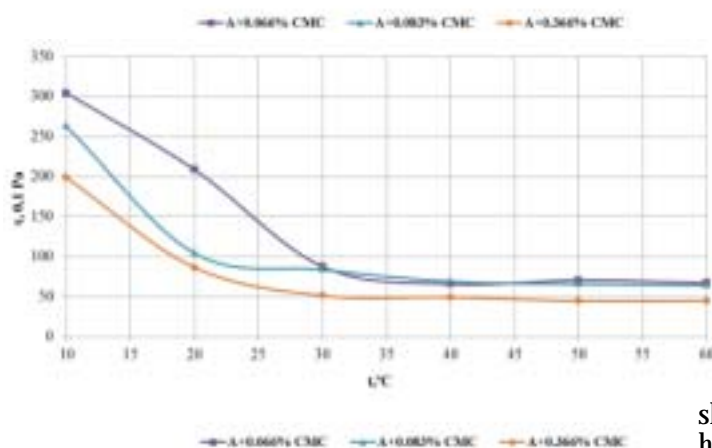


Fig. 13. Shear stress - temperature rating, for an A type crude oil additivated with CMC

A Type Crude Oil + MEC (methyl ethyl cellulose). Tests were performed using the same concentrations of MEC in A type crude oil as for Petrosin. Experimental results are presented in figures 10 and 11.

MEC influence is to decrease the oil viscosity by an additive process, this decreasing being even higher as the MEC concentration is higher. Viscosity variations for concentrations of 0.025 and 0.05 are very close (fig. 10). Shear stress has a variation specific to a trend of decreasing at low temperatures, increasing at medium temperatures and more obvious decreasing at higher temperatures. The highest decreasing is for a MEC concentration of 0.05 % (fig. 11).

A Type Crude Oil + CMC (carboxy methyl cellulose). The used CMC concentrations were 0.66 ‰, 0.83 ‰ and 3.66 ‰. The influence of CMC upon A type crude oil behaviour is presented in figures 12 and 13.

We can notice that viscosity increases using CMC as an additive, this increasing grows at higher concentrations. The least increasing of viscosity is for a concentration of 0.83 ‰.

This aspect is obviously noticed at low temperatures, but the viscosity increasing is very low over 30°C until it becomes almost negligible (fig. 12). Shear stress presents a decreasing trend accentuated by concentration increasing, remaining all the temperature rating; moreover,

shear stress becomes almost constant at temperatures higher than 30°C.

It is worthy of note that shear stress of the additivated crude oil does not present the picks due to shearing rate modification, as happened in the above situations (fig. 13).

Conclusions

Knowledge of the rheological behaviour of crude oils presents a great importance in all the processes involving them, starting with movement in porous medium (reservoir), tubing and pipelines, including storage and handling, processing and distribution to the consumers. Dynamic viscosity and shear stress decrease with temperature increasing both for viscous crude oil and crude oil with low viscosity.

- Study of rheological behaviour of viscous crude oil of A type indicates a linear behaviour but it presents a slight deviation at higher temperatures for viscosity; we can say that rheological behavior of a viscous A type crude oil is according to a Bingham model of fluid.

- By additivating A type crude oil using different substances as: C type crude oil, Petrosin, TCC and MEC, it was generally observed that dynamic viscosity decreases with increasing the concentration of the used substance. An opposite effect was noticed in case of using CMC as an additive, when dynamic viscosity grown, enhancing with concentration increasing. The influence of an additive upon

viscosity is significant for temperatures up to 40°C and then its effect is insignificant.

- Shear stress presents specific variations, depending on a case by case situation. A clearer variation trend (decreasing) is noticed for crude oil additivated with CMC, a trend that is also visible for the other additives at temperatures over 40...50 °C. On the shear stress variation curves we can notice the shearing rate modifications, unidentifiable on the dynamic viscosity variation curves.

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