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RHEOLOGICAL BEHAVIOR OF POLYMER-BASED DRILLING FLUIDS: EXPERIMENTAL STUDY OF TEMPERATURE EFFECTS

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Drilling fluids most commonly used are generally based on polymers. Polymers such as methylcellulose carboxylate (CMC), polyanionic cellulose (PAC) and xanthan (Xn) have a very important role in the success of drilling operations. Indeed, they are also used to improve certain properties, in particular rheological. However, these polymers can lose their characteristics under the influence of increasing temperature at the bottom of oil wells, thus affecting the ability of the mud to perform its useful role in the drilling operation, namely to raise the cuttings from the bottom of the well to the surface. The present work aims to study the effect of temperature on the main rheological properties (shear stress and plastic viscosity) as well as on the rheological behavior of water-based drilling muds (WBM). WBM_CMC and WBM_PAC (at Xn content fixed) were selected to evaluate the temperature effect (20°C; 40°C; 60°C and 80°C) on the rheological parameters and the rheological behavior. The results revealed that the shear stress and the plastic viscosity of the studied muds were considerably affected by an increase in temperature. A significant decrease in these drilling mud parameters as a function of temperature up to 80°C. A reduction of 58.8% in shear stress and 78.5% in plastic viscosity was observed. The results show that regardless of the test temperature, the shear thinning behavior of the WBM_CMC and WBM_PAC drilling muds is the same as the Herschel-Bulkley model.

Key words: polymers, methylcellulose carboxylate, drilling fluid, shear stress, viscosity, rheological behavior.

1. Introduction

Over a century, oil and natural gas have taken an important place in our civilization, given the abundant use of these natural resources in various fields (chemical industry, energy, etc.) [1-2]. The countries producing of these natural resources have more and more difficulty to meet the demand of the consuming countries, because these natural resources are extracted in very deep places and the new deposits are at *4000* meters or even deeper and their exploitation requires complex drilling techniques and the use of high performance fluids, namely drilling muds.

Polymer mud systems are classified as biodegradable muds having rheological properties which are important for the success of drilling oil wells [3-4]. Generally, polymers commonly used are starch, xanthan, xanthan gum, cellulose, CAP [4-7]. A well-optimized drilling mud formulation can significantly reduce the overall cost of drilling a well [6-8]. The deeper the borehole, the mud is found under conditions with high or pressure and high or temperature (HPHT), which makes the drilling operation very difficult with additional costs under these conditions [9]. A drilling mud is chosen according to the nature of geological formations, the economic objectives and the environmental constraints. The water based drilling muds (WBM) have bentonite

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which is not the only element used as a viscosifier [7-8, 10]. Xanthan gum (XG) is most commonly used as a viscosifier in drilling fluids due to its valuable rheological properties such as improved viscosity [3, 6, 11-12]. Temperature effects on the good progress of the drilling operations have been studied in several research works. Among the most recent and significant works are the studies carried out by Beg *et al.* [13], who found that rheological properties of high temperature drilling muds are imponderable due to several variables involved, namely: the physical, chemical and electrochemical interaction of the mud components during circulation at high temperature [13-15]. In these works, drilling fluids based on nanoparticles were subjected to high temperature rolling conditions at *110°C* and *30 rpm* for *16* hours and after the API filtrate of these muds were studied. It was found that nanoparticles imparted resistance to thermal degradation in rheological and filtration characteristics of drilling fluids. Using an additive along with a conventional fluid loss reducer not only enhances the efficacy of that additive but also improves the thermal stability and rheological properties of a drilling mud.

In the literature, there are few studies that address the effect of oil well temperature on the efficiency of used polymers in drilling muds and its influence on the properties of the fluid. The objective of this work was to study the effect of temperature on the rheological properties and the rheological behavior of drilling muds based on polymers (carboxymethyl cellulose and polyanionic cellulose). Although the combined effect of polymers on the properties of mud is very beneficial for the success of the drilling operation, but the effect of temperature during the drilling process can have a negative effect on the characteristics of mud. This work presents a study of the rheological properties of polymer-based muds (CMC and PAC) under temperature effects. Model drilling muds were formulated based on two polymers (CMC and PAC) with Xn content fixed at *0.2%*, in order to evaluate the effect of temperature (*20°C*; *40°C*; *60°C* and *80°C*) on the rheological parameters (shear stress and viscosity plastic) as well as on the rheological behavior of these muds.

2. Experimental study

2.1. Materials and methods

In this study, two polymer types were used in water-based-mud (WBM) formulation to compare their effect on the drilling mud properties. CMC is a high viscosity sodium carboxyméthylcellulose designed to control fluid loss and provide viscosity in water based drilling fluids. CMC is currently used in high viscous sweeps for surface holes drilling and also helps prevent clays from swelling. It is resistant to bacterial attack and is temperature stable up to *275°F* (*135°C*). The other polymer used is polyanionic cellulose (PAC). PAC is a high-quality, water-soluble polymer used to control fluid loss, and it causes a minimal increase in viscosity in water-base muds. Also, it resists bacterial attack and it is effective in low concentrations. CMC and PAC are used at fixed content of the xanthan gum (Xn). Xn is commonly used in drilling fluids to provide viscosity, solid suspension, and fluid-loss control but it is sensitive to high temperatures. Some of the properties of xanthan gum include high viscosity at low concentrations, pseudo plasticity and insensitivity to a wide range of *pH* and electrolyte concentrations [16-17].

2.2. Experiment procedure and drilling fluids formulation

The studied water-based muds (WBM) were prepared by stirring for *30* minutes using the standard mixer used for drilling fluids. All components were gradually added to *350 ml* of water and stirred at ambient temperature. The mud samples were aged to hydrate thoroughly at room temperature before testing their rheological properties at *20°C* and at different temperatures (*40*, *60* and *80°C*) by using a Thermo-Haake viscometer.

Mud samples series were prepared based on CMC (WBM_CMC) and another series based on PAC (WBM_CMC) at fixed content of Xn (*0.2%*). The base muds were prepared by adding each of the biopolymers to pre-hydrated bentonite-water system. The concentrations of components in the tested muds were similar to those commonly used in oil well drilling sites and also similar to previous research works [18-21]. The details of the mud mixtures are given in Tab. 1.

Table 1. Drilling mud formulations in volume *500 mL*.

Drilling fluid ID	Bentonite	Water	Caustic Soda (NaOH)	Xanthane (Xn)	Polyanionic Cellulose (PAC)	Carboxylate MethylCellulose (CMC)
WBM_PAC	*3*	*96,3*	*0,2*	*0,2*	*0,4*	-
WBM_CMC	*3*	*96,3*	*0,2*	*0,2*	-	*0,4*

2.3. Rheological test methods

Different mud systems were developed to evaluate the temperature effect (*20°C*; *40°C*; *60°C* and *80°C*) on the rheological parameters (shear stress and plastic viscosity) as well as on the rheological behavior of theses muds. All rheological measurements were carried out using a *VT500* viscometer (Thermo-Haake viscometer) with coaxial cylinder geometry (Fig. 1).

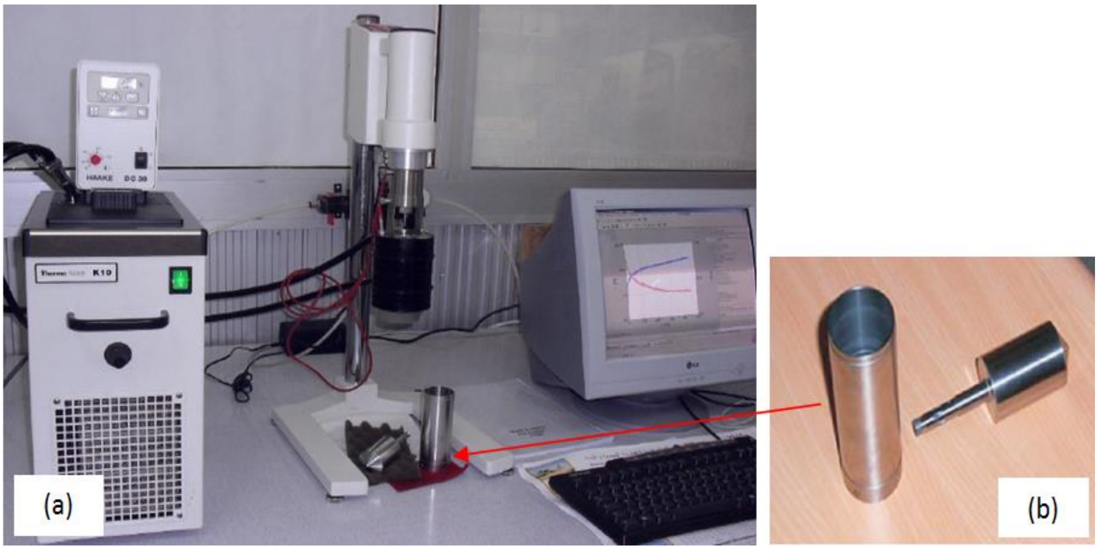

Fig.1. Rheological test: (a) *VT500* viscometer (b) coaxial cylinder geometry.

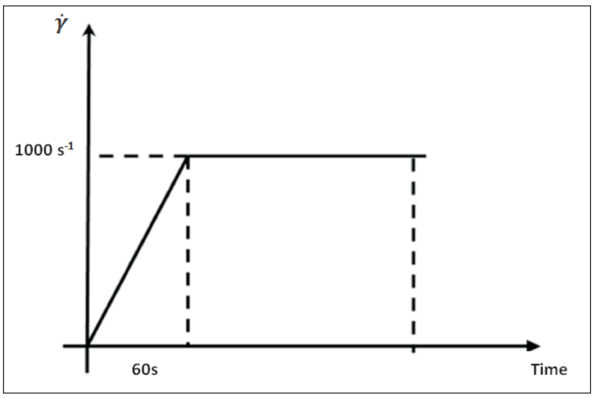

Fig. 2 Rheological procedure.

A thermal control system of viscometer is used to keep the temperature constant. All the measurements are carried out according to protocol testing (pre-shear for all sample muds, during *60 sec* after mixing according to Fig. 2). Rheological tests were carried at different temperatures (*20°C*; *40°C*; *60°C* and *80°C*). These temperatures correspond to the geothermal conditions of the drilling fluid circulation in the well. The test is performed at the imposed shear rate (the imposed shear rate is approximately $1000\ s^{-1}$). The TA Data Analysis Thermo-Haake viscometer software allowed us to identify the rheological behavior of all studied muds.

3. Results and discussions

3.1. Effect of temperature on the main rheological parameters

Case of WBM_PAC muds: Figure 3 shows the evolution of the main rheological parameters of all studied muds as a function of shear rate, measured at different temperatures. It is noteworthy that the main rheological parameters (shear stress and viscosity) of mud decrease with increasing temperature. A decrease of more than *30%* in shear stress and *46%* in viscosity of WBM_PAC muds was noted. The effect of increasing temperature on rheological properties of water-based muds was different depending on the polymer used. However, the effect of temperature on viscosity was significant where the temperature effect decreased the viscosity of the fluids due to thermal stability of polymers.

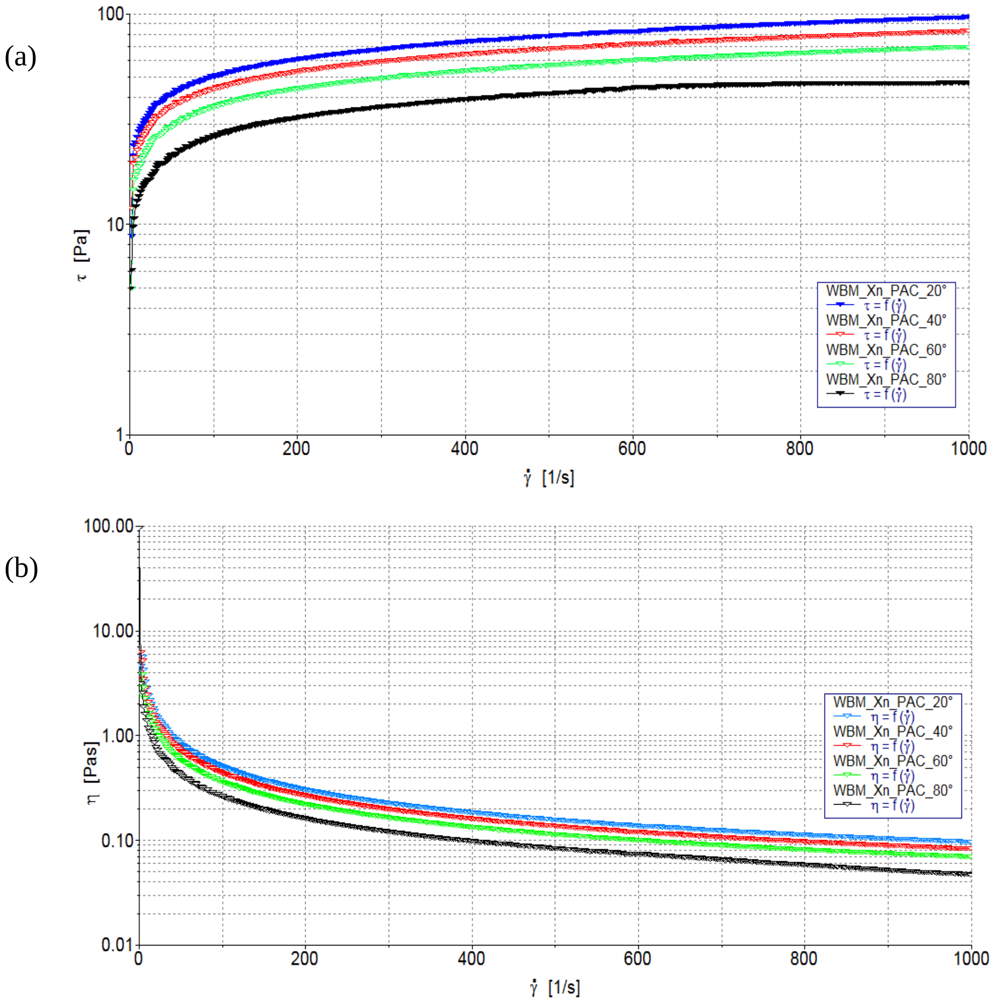

Fig.3. Evolution of the main rheological parameters of WBM_Xn_PAC at different temperatures: (a) Shear stress, (b) Viscosity.

The viscosity variation of all studied muds (WBM_PAC and WBM_CMC) at different testing temperatures has been examined as a function of the shear rate. It is clear that viscosity decreases with the shear rate (decreasing shear) [9]. This behavior can be explained by the fact that the carboxyl group in the PAC or CMC molecule does not promote a good dispersion in water, leading to an increase in friction particles, but the temperature increase causes the solvency [22-24]. With increasing temperature, the side chains tended to dissociate leading to stronger repulsive interactions between flocs causing the formation of a low physical network structure with the expected thinning behavior.

Case of WBM_CMC muds: Figure 4 shows the evolution of the main rheological parameters of WBM_CMC muds as a function of shear rate, measured at different temperatures. It is noteworthy that the main rheological parameters (shear stress and viscosity) of mud decreases with increasing temperature [21-25]. In the case of WBM_CMC muds, it should be noted that the main rheological parameters (shear stress and viscosity) of mud decreases with increasing temperature up to *60°C*. A significant increase in rheological parameters was recorded at *80°C*.

(a)

(b)

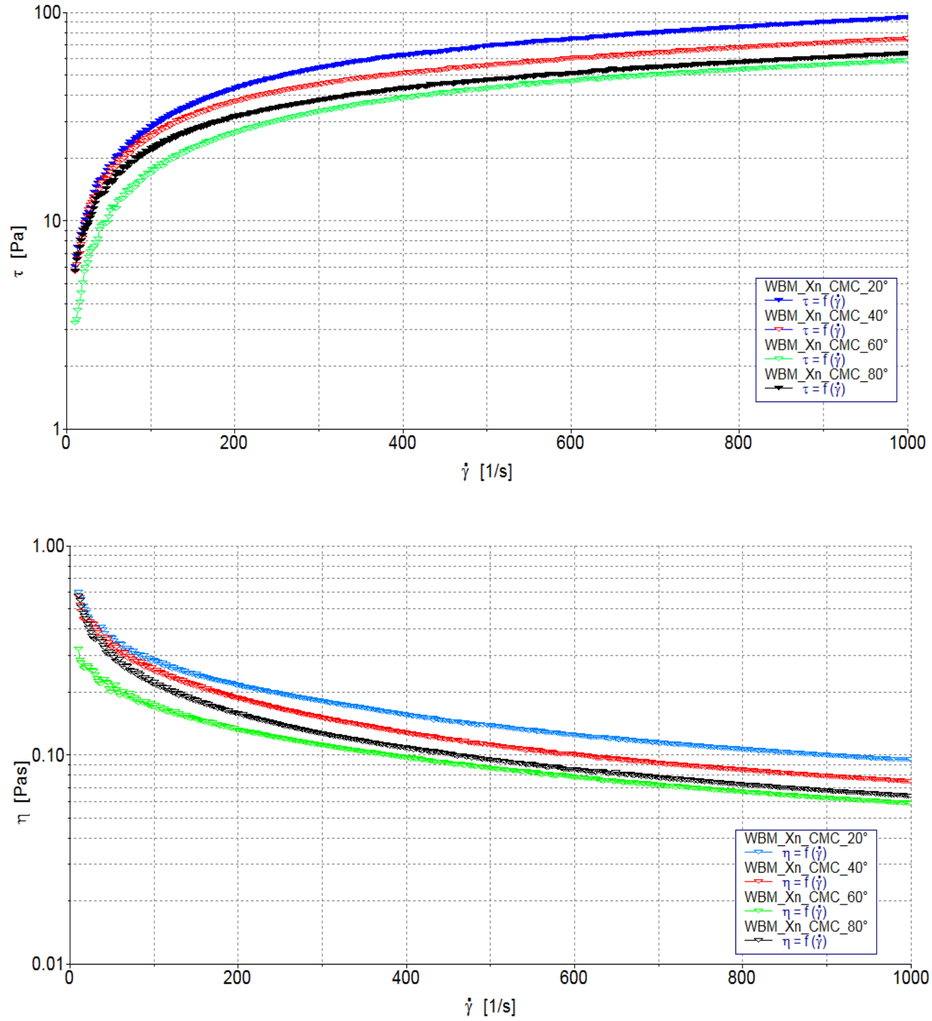

Fig. 4 Evolution of the main rheological parameters of WBM _CMC at different temperatures: (a) Shear stress (b) Viscosity.

It should be noted that a decrease of more than *36%* in viscosity of WBM_CMC muds at temperature *60°C*. In this case, the effect of increasing temperature on rheological properties of WBM_PAC muds was

different compared to CMC polymer. However, the effect of temperature on viscosity of the drilling mud was very significant. At *80°C* the viscosity has increased more than *70%*.
In order to clearly visualize the effect of temperature on the viscosity of the sludge, sludge viscosity values were obtained at a fixed shear rate of $400\ s^{-1}$ (Table 2). The figure below clearly shows the effect of temperature on the plastic viscosity of muds.

Table 2. Plastic viscosity of drilling muds measured at $400\ s^{-1}$.

Testing temperature [*C°*]	Plastic viscosity [$Pas.S^{-1}$] measured at $400\ s^{-1}$	
	WBM_CMC	WBM_PAC
20	*0,154*	*0,183*
40	*0,127*	*0,160*
60	*0,098*	*0,133*
80	*0,170*	*0,098*

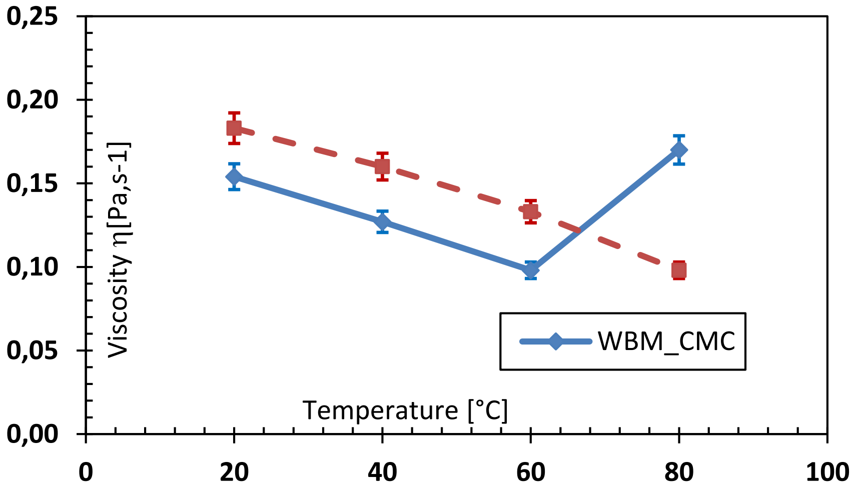

Fig.5. Effect of temperature on plastic viscosity of studied WBMs.

Previous studies showed that elevated temperatures caused flocculation of water based muds in the presence of polymers.

3.2. Rheological behavior of studied WBMs

Using rheometer software, we can identify the rheological behavior of all studied muds of existing models as shown in Figs 6 and 7. The results showed that whatever the testing temperature, the shear thinning behavior of the WBM_CMC and WBM_PAC drilling mud is same. All the muds show a behavior similar to the Herschel-Bulkley model described by Eq. (3.1), which is proven by several authors [8, 19, 22-25]

$$\tau = \tau_0 + K \cdot \dot{\gamma}^n \tag{3.1}$$

where τ is the stress, τ_0 is the yield stress; $\dot{\gamma}$: is the shear rate; K is the consistency index and n is the flow index.

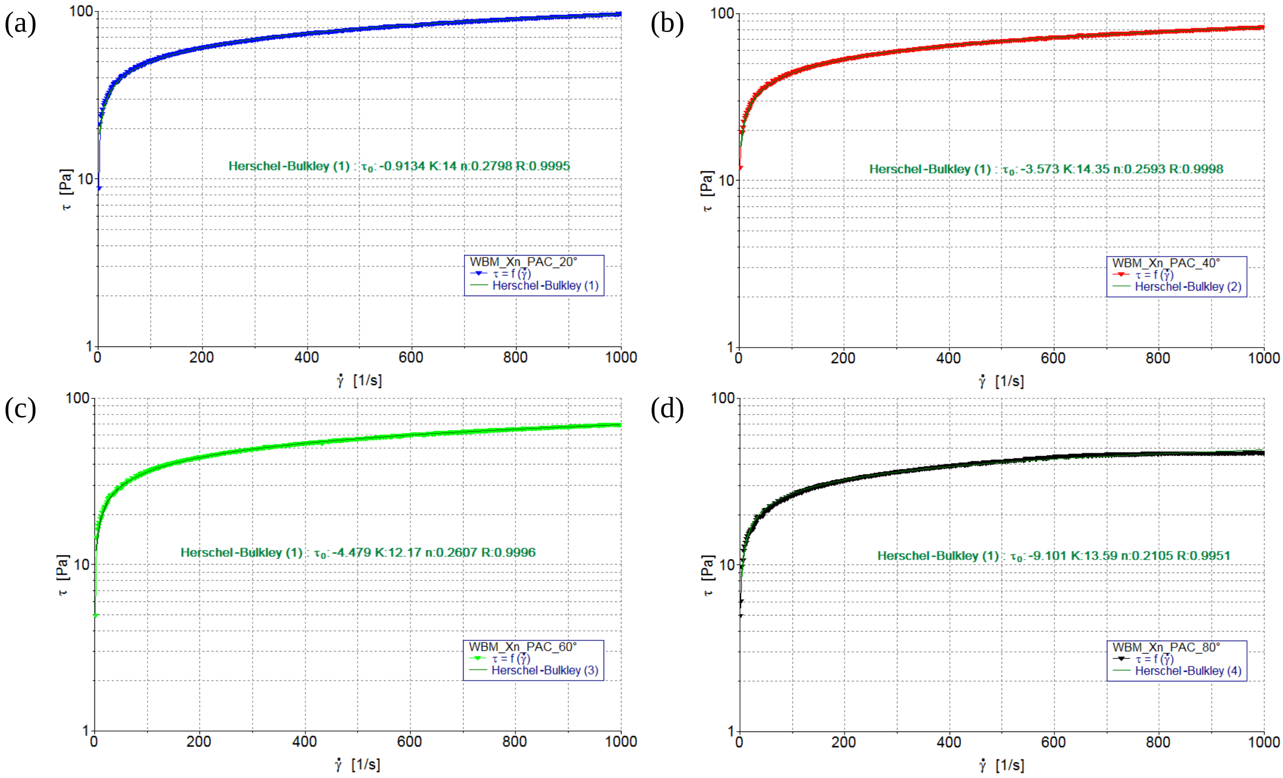

Fig.6. Rheological behavior of WBM_PAC muds at: (a) *20°C* (b) *40°C* (c) *60°C* (d) *80°C.*

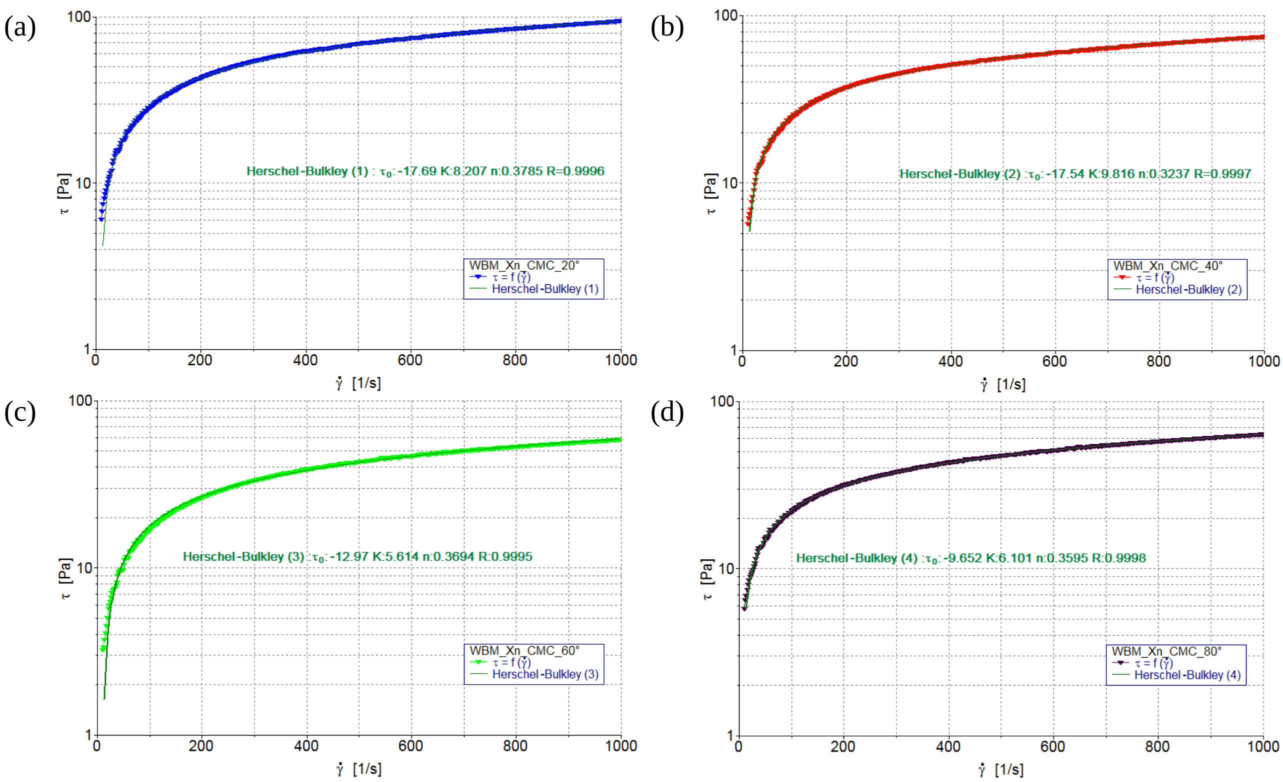

Fig.7. Rheological behavior of WBM_CMC muds at: (a) *20°C* (b) *40°C* (c) *60°C* (d) *80°C.*

It is known that several factors can influence the rheological behavior of drilling fluids. Drilling fluids, such as water-based muds with polymers, usually develop non-Newtonian characteristics as in the Herschel-Bulkley model [18, 20-24].

The effect of temperature may influence the rheological properties of drilling mud owing to the variations of the viscosity of the continuous phase and the changes induced in the solid fraction (in particular the particle-particle interactions [25-26].

The experimental results which are given in Figs 6 and 7 show that for all testing temperatures the shear thinning behavior of the WBM_CMC and WBM_PAC drilling mud has been quantified and compared with the Herschel-Bulkley model.

4. Conclusion

This work provides an experimental investigation of the effect of temperature on the properties and the rheological behavior of drilling muds in the presence of polymers (Carboxylate methyl cellulose CMC and polyanionic cellulose PAC). Although the combined effect of polymers on mud properties has a direct effect on mud properties, however the effect of temperature during the drilling process can have an adverse effect on mud characteristics. Drilling muds currently used in oil wells in Algeria based on two polymers in order to evaluate the effect of temperature (*20°C*; *40°C*; *60°C* and *80°C*) on the rheological parameters (shear stress and viscosity plastic) as well as on the rheological behavior of this sludge. Based on the experimental study the following conclusions can be drawn:

- The shear stress and plastic viscosity of mud have decreased with increasing temperature. In the case of WBM_CMC muds, it should be noted that the main rheological parameters of mud have decreased with increasing temperature up to *60°C*. A significant increase in rheological parameters was recorded at *80°C*;
- Also, the main rheological parameters of WBM_CMC muds have decreased with increasing temperature. Nevertheless, it should be noted that the shear stress and plastic viscosity have decreased with increasing temperature up to *60°C*. A significant increase in rheological parameters was recorded at *80°C*;
- The experimental study of rheological behavior of all studied muds showed us that whatever the testing temperature the shear thinning behavior of the WBM_CMC and WBM_PAC drilling mud has been quantified and compared with the Herschel-Bulkley model.

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Nomenclature

CMC – methylcellulose carboxylate
K – consistency index
n – flow index force
PAC – polyanionic cellulose
WBM – water-based drilling muds
$\dot{\gamma}$ – shear rate
τ – shear stress
τ_0 – yield stress

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