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Physico-chemical and rheological characterization of water-based mud in the presence of polymers

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Abstract Under the geological conditions of wells and during the drilling operation, some of the water-based mud compositions are sometimes not effective for the drilling success of the oil wells (case of the oil wells in the south Algeria). For this, the aim of this study is to examine the influence of polymer types [carboxymethylcellulose (CMC) and polyanionic cellulose (PAC)] on the physico-chemical and rheological properties of water-based drilling muds. A mud samples were prepared with a polymers (PAC or CMC) according to mud formulations currently used in the wells drilling. The properties are controlled at such values that the mud provides optimum performance. For this purpose, the physico-chemical (pH, Pb: mud alkalinity) and rheological (apparent viscosity, yield point, and behavior rheological) were measured out on the studied muds. According to the obtained results, the rheological characteristics of studied muds (yield point and plastic viscosity) were clearly improved in the polymers presence. However, it should be noted that the PAC has given the better results compared to the CMC at a concentration of 8 g/l. By against in the temperature presence (hot rolling), the CMC is a good controller agent of mud filtrate compared to those containing the PAC for the same concentration.

Keywords Water-based mud · Polymer · CMC · PAC · Rheology · Yield point · Viscosity · API filtrate

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Introduction

The polymer-based muds are considered as biodegradable mud that has significant properties in a biological attack or micro-organisms (American Petroleum Institute 1969). The polymers commonly used in the industrial oil are classified as biodegradable polymers such as starch, xanthan, gum xanthan, cellulose, and PAC (American Petroleum Institute 1969; Garcia and Parigo 1968; Baba Hamed and Belhadri 2009). Generally, the drilling muds are used to clean the well, maintain whole integrity, transport the rock cuttings, lubricate the drill bit, and control formation pressures. In contrast, the drilling success of oil or gas depends mainly on the right choice of drilling fluids used. The formulation optimizing of the mud can be to reduce significantly the overall cost of drilling a well (American Petroleum Institute 1969; Garcia and Parigo 1968). For this purpose, the drilling mud is chosen according to the nature of training, the architecture of the well, the economic objectives and the environmental constraints. In the composition of a water-based drilling mud (WBM), the bentonite is not the only element used as viscosifiant. For example the xanthan gum (XG) is a natural biopolymers (Amanullah and Long 2004; Alderman et al. 1988), most common used as a viscosifier in the drilling fluids due to its interesting rheological properties such as viscosity improvement (Ching et al. 1993; Baba Hamed and Belhadri 2009; American Petroleum Institute 1969). However, polymers are often added in the drilling fluid in order to get adequate properties and permitting to ensure numerous functions and facilitate a good drilling operation process (American Petroleum Institute 1969; Garcia and Parigo 1968).

Furthermore, the polymers addition to drilling fluids provokes an important rheological properties modification. In general, the suspension behavior laws seem complex because of their limited thixotropy, rheofluidifying character, and their rigidity which makes them viscoelastic. Several studies were established on the rheological properties of drilling fluids biopolymers. The studies carried have shown that only the type of polymer is different considering its molecular configuration, its rheological behavior in aqueous medium, as well as the viscosifier properties which it confers on drilling mud (Baba Hamed and Belhadri 2009). The good knowledge of the fluid rheological properties as well as the comprehension of physico-chemical interactions in these charged colloidal systems is precious elements to adapt the fluid composition to the drilling conditions. Today's literature (API 1996; Gray et al. 1980; Baba Hamed and Belhadri 2009) is rich in contributions treating, from one hand, rheological and colloidal properties of clay suspensions (with and without additives) and, on the other hand, the nature of the interactions between their components (Khodja et al. 2010; Simpson et al. 1994; Durand et al. 1995; Schlemmer et al. 2002). Nevertheless, the relationship between the rheological and the physico-chemical properties of these suspensions has been well established, mainly for the clay–anionic polymers mixtures often used the drilling fluids formulation (Khodja et al. 2010; Amorina et al. 2004; Kok and Alikaya 2003; Kok and Alikaya 2005). Many previous research studies have shown the effectiveness of some biopolymers as filtration control agent for drilling mud (Baba Hamed and Belhadri 2009; Pérez et al. 2004; Mahto and Sharma 2004). Moreover, in other studies initiated on drilling muds containing water-based bentonite, the results show that the presence of bentonite can modify the physico-chemical and rheological properties (Caenn and Chillingar 1996; Zhang et al. 1999a, b). It results in that the action and the nature of some biopolymers deserve study. Also, it was suggested by some authors, to study the stability of the suspensions containing the complicated system (clay-water-polymer). However, it is difficult to graft two groups using this process, especially, when one is hydrophilic and the other is hydrophobic in one reaction because they need different solvents.

For this, the main objective of this work is to study the polymer action (type CMC and PAC) on the physico-chemical and rheological properties of water-based mud, in order to see the nature effect of the polymer used and theirs physico-chemical and rheological behavior in the geological conditions of a well.

Experimental program

Materials used

In this work, two polymer types were used in water-based mud (WBM) formulation to compare their effect on the drilling mud properties. These additives are provided by MI-Swaco Algeria, which are as follows:

CMC polymer is a high-viscosity sodium carboxymethylcellulose designed to control fluid loss and provide viscosity in water-based drilling fluids ranging from fresh water to saturated salt water. CMC HV is used in high viscous sweeps for surface hole drilling. CMC HV also helps prevent clays from swelling. It coats the cuttings and protects them from hydration. CMC HV is resistant to bacterial attack and is temperature stable up to 135 °C (275 °F).

Cellulose polyanionic (*PAC*) The polyanionic cellulose (PAC) is a high-quality, water-soluble polymer designed to control fluid loss, and because it is an "Ultra-Low" (UL) additive, it causes a minimal increase in viscosity in water-base muds. POLYPAC UL resists bacterial attack and does not require a biocide or preservative. It is effective in low concentrations, with the normal concentration to control fluid loss ranging from 0.71 to 2.85 kg/m^3 (0.25–1 lb/bbl).

WBM composition and test methods

The composition of the studied muds in this work is that currently used for drilling of oil wells in Algeria. In 350 cc of mud samples containing, 3.5 % of Bentonite, 0.16 ml of soda ash, 0.16 ml of caustic soda, 5.50 ml of potassium chloride and 24.26 ml of barite (as weighting agent of mud). All these components are fixed and the studied polymers (PAC_UL and CMC) were added at different content (4, 8 and 16 g/l).

Different mud systems were prepared using API equipments (API RP 13B-1, 2003). The physico-chemical (pH, Pb: mud alkalinity) and rheological parameters were determined. The rheological tests were conducted using a rheometer fann 35 at variable speed (3–600 rpm). With a viscometer which gives the viscosity values in cP or in mPa.s, and using the formulas (1 and 2) from API recommended practice for field testing drilling fluids. The physico-chemical measurements of studied muds were carried according the API chemical tests. API filtrate and gel 0/10 (3 rpm dial reading after mixing and after 10 min) are determined with using API recommendations (API RP 13B-1, 2003). The rheological properties such as apparent and plastic viscosities, gel strengths (Gel 0/10), and yield points were measured for each mud samples.

The *Plastic viscosity* (V_p) is calculated by the following formula:

$$V_p = \theta_{600} - \theta_{300};\ (\text{in cp}). \qquad (1)$$

The *Apparent Viscosity* (V_A) is calculated by

$$V_A = \frac{\theta_{600}}{2};\ (\text{in cp}). \qquad (2)$$

The *Yield Point* (Y_p) is calculated by

$$Y_p = \theta_{300} - V_p;\ (\text{in lb}/100\text{ft}^2). \quad (3)$$

θ_{600} is the reading at 600 rpm and θ_{300} is the reading at 300 rpm.

The gel strength *Gel* 0/10 (initial 0 s/10 min) is the shear stress of drilling mud that is measured at low shear rate after the drilling mud is static for a certain period of time. The gel strength is one of the important drilling fluid properties because it demonstrates the ability of the drilling mud to suspend drill solid and weighting material when circulation is ceased (in case of drilling stop).

Results and discussions

Effect of PAC_UL polymer

Rheological parameters

Figure 1 shows the evolution of the main rheological parameters of muds as a function of the PAC_UL concentration. It is noteworthy that the main rheological parameters (yield point *Yp* and plastic viscosity *Vp*) of mud increases with the concentration of PAC_UL. Indeed, beyond 8 g/l of PAC_UL, the yield point increased by 50 % (from de 4 to 6 lb/100ft^2) (see Fig. 1). However, a slight increase in the plastic viscosity was observed beyond 8 g/l of PAC_UL. Indeed, the viscosity of mud was doubled (12.5–25 of CP) (see Fig. 1). This can be explained by the fact that the carboxyl groups in the molecule of PAC provide good dispersion in water and leading to increased friction between the particles.

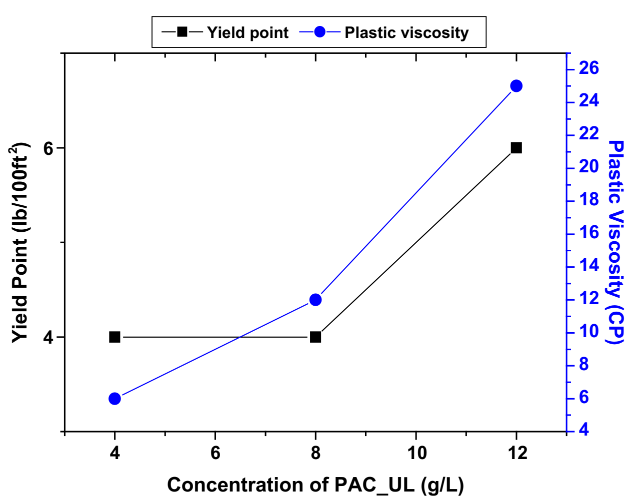

Fig. 1 Effect of the PAC_UL content on the rheological parameters of WBM

Figure 2 illustrates the PAC_UL concentration effect on the gel (0/10) of studied mud suspensions. According to this figure, it is clear that with the increase in the PAC_UL content in mud, gel 0 remains constant and the gel 10 has decreased then it is increased beyond 8 g/l of PAC_UL. Noted that, above this concentration (8 g/l), the plastic viscosity and the yield point have increased by 100 %, which causes the increase in the recess 10 gel.

Rheological behavior

Figure 3 shows the rheological behavior of the PAC_UL suspensions. According to rheograms, all suspensions show non-Newtonian flow. The behavior of these muds can be identified by the use of existing rheological models. Indeed, according to that, several researchers have found that the behavior of these types of mud follows the model of Herschel–Bulkely (Baba Hamed and Belhadri 2009).

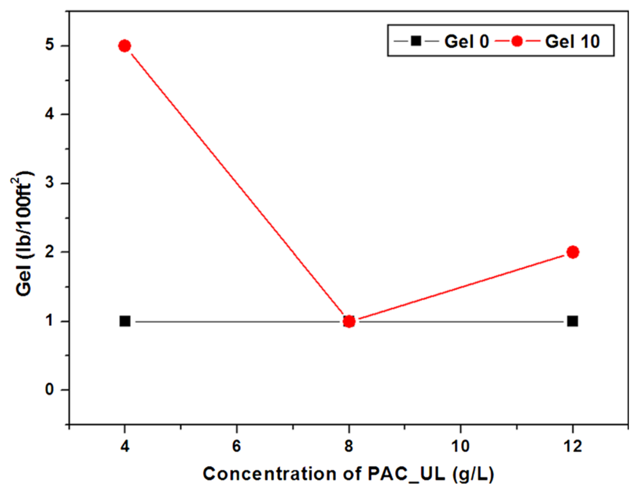

Fig. 2 Effect of the PAC_UL content on the Gel 0/10

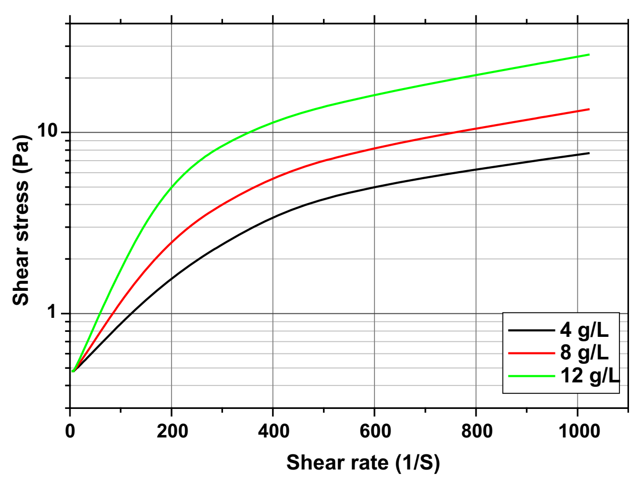

Fig. 3 Rheogram of PAC_UL suspensions

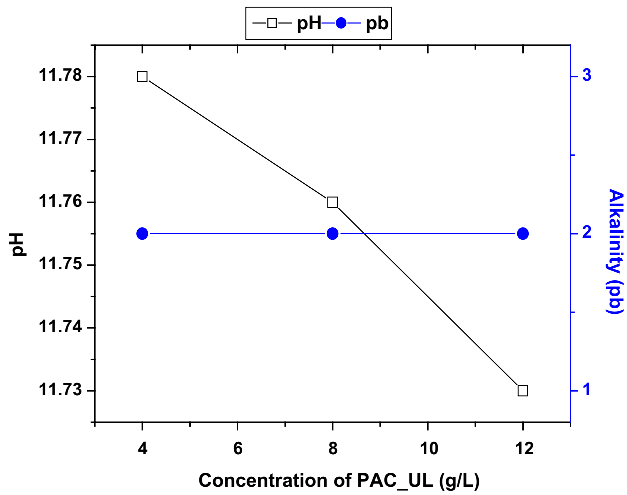

Fig. 4 Effect of concentration of PAC UL on the physico-chemical parameters (pH, Pb) mud suspensions studied

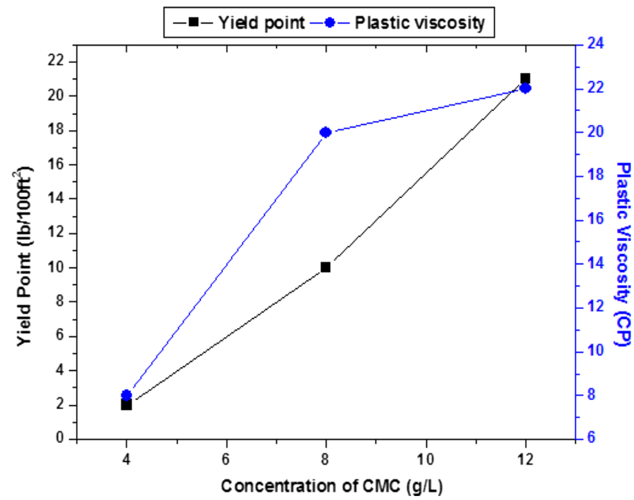

Fig. 5 Effect of the CMC content on the rheological parameters of WBM

Physico-chemical parameters

The evolution of physico-chemical parameters of suspensions (pH and Pb) in dependence on the concentration of polymer PAC_UL is shown in Fig. 4. The latter shows that whatever the concentration of PAC_UL, the alkalinity of the mud does not change, i.e., it remains constant (see Fig. 4). While the pH of the mud decreased slightly from 11.78 to 11.73 for a concentration of 12 g/l of PAC_UL (see Fig. 4), i.e., the middle of the suspension remains basic. It should be noted that the basic medium of the solution is better suited for polymers as PAC_UL.

Effect of CMC polymer

Rheological parameters

As regards the main rheological parameters of mud as function of the CMC concentration (Fig. 5), It is clear that these parameters (*Yp*; yield points and *Vp*; plastic viscosity) were increased with the concentration of CMC. Indeed, up to 8 g/l of CMC, the viscosity increased from 6 to 20 CP; then beyond this concentration, there was a slight increase in viscosity (see Fig. 5). For the yield point, it has increased from 0.2 to 20 lb/100ft^2) (see Fig. 5). CMC is known for its ability to viscosity, and it greatly increases the rheological parameters of the mud.

According to the obtained results given in Fig. 6, it is remarkable that with the increase of the concentration of CMC in the mud, freezing 0 also remains constant up to a concentration of 8 g/l CMC and then it increased beyond this concentration. While the gel 10 is increased, it remains constant beyond 8 g/l of CMC. It should be noted that

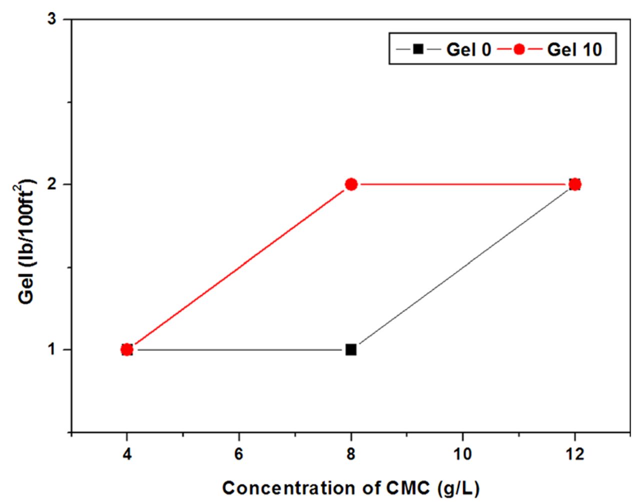

Fig. 6 Effect of the CMC content on the Gel 0/10

beyond this concentration (8 g/l), the viscosity and yield point have increased significantly over 100 %, which causes the increase in the recess 10 gel.

Rheological behavior

Concerning the identification of rheological behavior of CMC-based mud (see Fig. 7), all suspensions show a non-Newtonian flow. Indeed, according to the results obtained, it is clear that the suspension represent a flow threshold that means they have a non-Newtonian behavior. According to several researchers (Khodja et al. 2010; Jasim and Ramaswamy, 2004; Maallem et al, 2013; Kayacier and Dogan, 2006), it has found that the behavior of these types of mud follows the model of Herschel Bulkely.

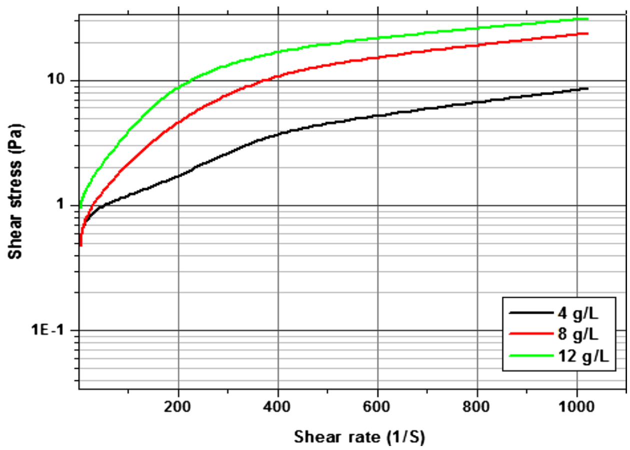

Fig. 7 Rheogram of CMC suspensions

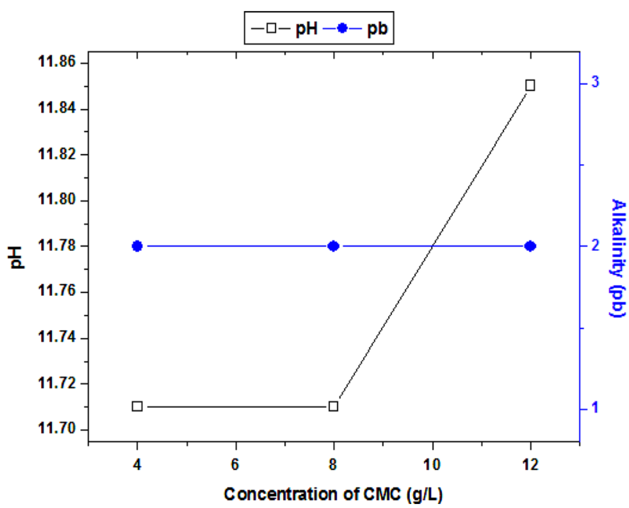

Fig. 8 Effect of CMC concentration on the physico-chemical parameters (pH, Pb) mud suspensions studied

Physico-chemical parameters

Figure 8 gives the variation of physico-chemical parameters (pH and Pb) as a function of the CMC concentration. This figure illustrates (as the case of PAC_UL) that whatever the concentration of CMC, the mud alkalinity does not change, i.e., remains constant (see Fig. 8). However, the pH remains constant up to a concentration of 8 g/l of CMC where it increased up to 11.84 at concentration of 12 g/l of CMC, this means the suspension is became a basic medium (see Fig. 8). It should be noted that the basic medium of the solution is better suited for polymers such as CMC.

Etude du filtrat

The mud filtrate is an important parameter for the proper conduct of the drilling operation. Figure 9 shows the variation of mud filtrate depending on the polymer

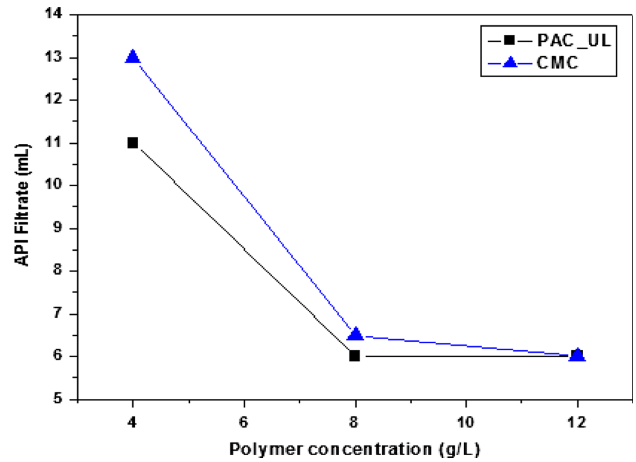

Fig. 9 Effect of PAC_UL concentration of the mud filtrate

concentration (PAC_UL, CMC). It was noted that the filtrate decreased significantly from 13.6 to 6 ml and then stabilizes at 6 ml at concentration of 8 g/l of PAC_UL. This value is acceptable for the filtrate of drilling muds. The PAC_UL, according to technical specifications, it is the best reducing filtrate of mud.

It was also found that the filtrate was significantly decreased of 13–6.5 ml then stabilizes at 6 ml at a concentration 12 g/l of CMC. This value is also acceptable for a recommended filtrate of drilling muds. According to several researchers, CMC is also the best filtrate reducer mud.

Conclusion

The aim of the present study was to compare the effect of two selected polymers on the properties of drilling muds in order to get the best mud compositions to properly conduct the drilling operation. From the results obtained, it can be concluded that the physico-chemical and rheological properties of mud significantly improved in the presence of polymers (PAC_UL and CMC). However, from the viewpoint of the mud filtrate, it was concluded that the PAC_UL has given better results compared to the CMC at the same concentration (8 g/l).

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