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Rheological characterization of the systems clay-polymer-electrolyte. Application to water based drilling fluids

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Abstract

Clay-polymer - electrolyte systems are commonly used as basic constituents of water-based drilling fluids to meet the many requirements that such a fluid must meet for the smooth running of operations. In this paper we presented results on the rheological behavior of bentonite-polymer-electrolytes. We have clearly shown that increasing the dose $CaCl_2$ and $Bacl_2$ in the bentonite-Poly-Salt mixture causes an increase in the yield stres, the consistency index and a decrease in the flow index of the mixture up to a critical dose of 0.4g of $CaCl_2$ and $Bacl_2$. From this dose, the yield stress, the consistency index decreases and the flow index increases. The rheological study also shows that the presence of KCl in the bentonite – Poly-Salt mixture causes an increase in viscoelasticity and a decrease in the fluidity, Newtonian viscosity and delayed viscosity of mixture.

Keywords: Clay; polymer; electrolyte; drilling mud; rheological

1. Introduction

The fluid of drilling is chosen based on several factors: nature of the rock, the objective of the survey, economic constraints. The clay-polymer-electrolytes systems are commonly used as basic constituents of drilling fluids to meet the many demands that such a fluid must fill for the smooth running of operations [1-4]. The drilling fluid must first create a hydrostatic pressure to ensure stability bored walls and to prevent the arrival of fluids from groundwater crossed [5, 6]. The knowledge and improvement of the rheological properties of drilling muds is essential in order to ensure the smooth running of drilling process. For this, several works have been carried out on the rheological properties of drilling mud and additive drilling mud in order to find a formulation which meets the requirements of drilling techniques [7-10]. Recently the effect of ZnO nanoparticles on rheological properties of water- based drilling mud has been was studied by Salehnezhad et al [11]. It was shown the increasing the percentage of ZnO nanoparticles in the water- based drilling mud caused an amelioration of theirs plastic viscosity. The effect of pH and electrolyte concentration on the rheological properties of Wyoming bentonite dispersions has been studied by Kelessidis et al [12]. It was observed a maximum of the yield stress, flow consistency index and apparent viscosity at the natural pH of the dispersions, while there is monotonous decrease of these parameters with increasing of salt concentration. Ben Azouz et al [13] studied the effect of the temperature on the rheological properties of a complex bentonite-sodium carboxymethylcellulose. They observed that in the liquid like regime, the viscosity of the fluids decreased as the temperature increased and in the solid-like regime have been observed at low shear stresses. According to these authors the increase of temperature generates an increase of the Brownian motion.

Although many researchers have investigated the rheological behavior of drilling mud and additive drilling mud, the results of this article is quite different since we are proposing a new formulation of drilling mud with a new polymer that is not currently studied.

2. Materials and methods

2.1. Materials and sample preparation

The polymer used in this work is Poly-Sal T is designed to reduce to fluid loss and increase the viscosity of all water-based mud. It is especially applicable and economical in saturated salt and brine systems where others products are not effective. The Poly-Sal T as function in $Nacl$, Kcl, $MgCl_2$, $CaCl_2$ and complex brines. The Poly-Sal T used in this work was supplied from Sonatrach society Algeria. The table 1 presented the physical properties of the Poly-Sal T used in this study.

Table 1: Typical physical properties of the Poly-Sal T

Physical appearance	Tan granular powder
Specific gravity	1.5
pH	7.0
Solubility in water	Soluble
Bulk density	561 kg/m^3

The clay used in this study is bentonite of Maghnia (west of Algeria) is commercially by Bental Company. The main components of this sample are: SiO_2 (61.78%) , Al_2O_3(17.15%), Fl_2O_3 (3.82%), MgO (3.56%), CaO (0.26%).The X-ray diffractogram of the bentonite (Figure 1) indicates that our clay is mainly composed of Montmorillonite, with some impurities that consist of dolomite, calcite, hematite and quartz. The ray of distance 15.61 Å located at 2Θ = 5.77 is indexed as the line (001) characteristic of Montmorillonite.

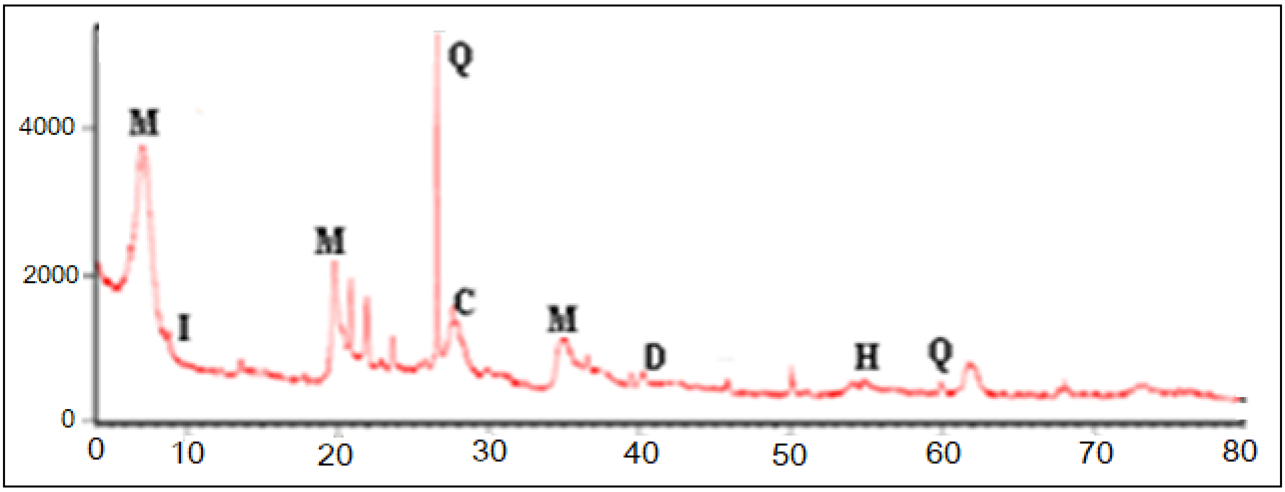

Figure 1. X-ray diffractogram of bentonite (**M**: Montmorillonite, **Q**: Quartz, **C**: Calcite, **H**: Hematite, **D**: Dolomite).

Given that the way of preparation has a great influence on the final state of suspensions, and thus on the rheological behavior, all tests were carefully carried out under equal conditions to allow for comparison of the results. The preparation consists in mixing 4g of bentonite and 2 g of Poly-Salt in 96 g of distilled water. This mixture is subsequently stirred for 24 hours with magnetic agitation in order to obtain the homogenization of the suspension. After 24 hours, different concentration of electrolytes (0 to 0.8 g) was dispersed in the water-bentonite-Poly-Salt mixture with magnetic agitation for 2 hours. Experimental methods: The rheological measurements were performed by using a torque controlled rheometer (Discovery Hybrid Rheometer DHR2 from TA instrument), equipped with a cone-plate geometry (diameter: 60mm; angle: 2°; gap: 54 µm). It has a Peltier temperature control system that allows having a very quick response to any change in temperature range to -40 at 200°C. In order to prevent changes in composition during measurements due to water evaporation, a solvent trap was placed around the measuring device.

For the steady state measurements the sample was pre-sheared at a frequency of $500s^{-1}$ for 60 s in the measuring device in order to avoid any memory effect. After pre-shearing the sample has kept at rest for 600 s prior to measurements in order to permit the material recovering its initial structure partially at least. After kept rest a continuous ramp of shear rate which is ranging from 0.5 to 500 s^{-1} and has been applied on each sample during 600 s.

Creep and recovery tests are carried out as follows: After a rest time of 60s prior to the measurements, a constant shear stress $\tau = 0.5$ Pa was applied to the samples and the compliance (J) was recorded as a function of creep time; at t = 60 s the stress τ was set to zero and the recoverable part of compliance was measured as a function of the recovery time equal to 60s. Results: Particles size distribution: Figure 2 shows the particle size distribution of bentonite and poly-slat polymer measured by the light scattering technique with a Malvern Instruments Mastersizer 2000 system technique with a Malvern Instruments Mastersizer 2000 system. In order to avoid the formation of aggregates during the measurements, the sample was submitted to ultrasound excitation. We observed in figure 1 the particle sizes of bentonite ranging between 0.12 and 138 µm were found with a symmetric distribution centered at about 46 µm and particle sizes of poly-Salt polymer ranging between 17 and 830 µm were found with a symmetric distribution centered at about 455 µm. We also observed the maximum volume of poly-salt is greater than of maximum volume of bentonite what does poly-salt mean more swelling compared to bentonite [14-16].

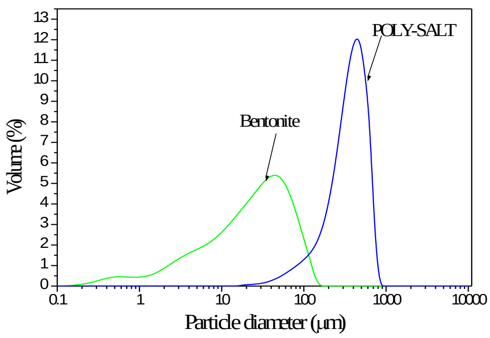

Figure 2. Particle size distribution of bentonite and Poly-Salt

2.2. Flow curve of drilling muds

Figures 3 shows the flow curve of drilling mud at different dose of $CaCl_2$ and $Bacl_2$. It shows clearly Non-Newtonian behavior after a yield stress. Therefore experimental data were fitted to the classical model of Herschel–Bulkley:

$$\tau = \tau_0 + K\dot{\gamma}^n \quad (1)$$

where τ is shear stress in Pa, $\dot{\gamma}$ is shear rate in s^{-1}, τ_0 is the yield stress in Pa, $K$the consistency index in $Pa.s^n$ and n is the flow index.

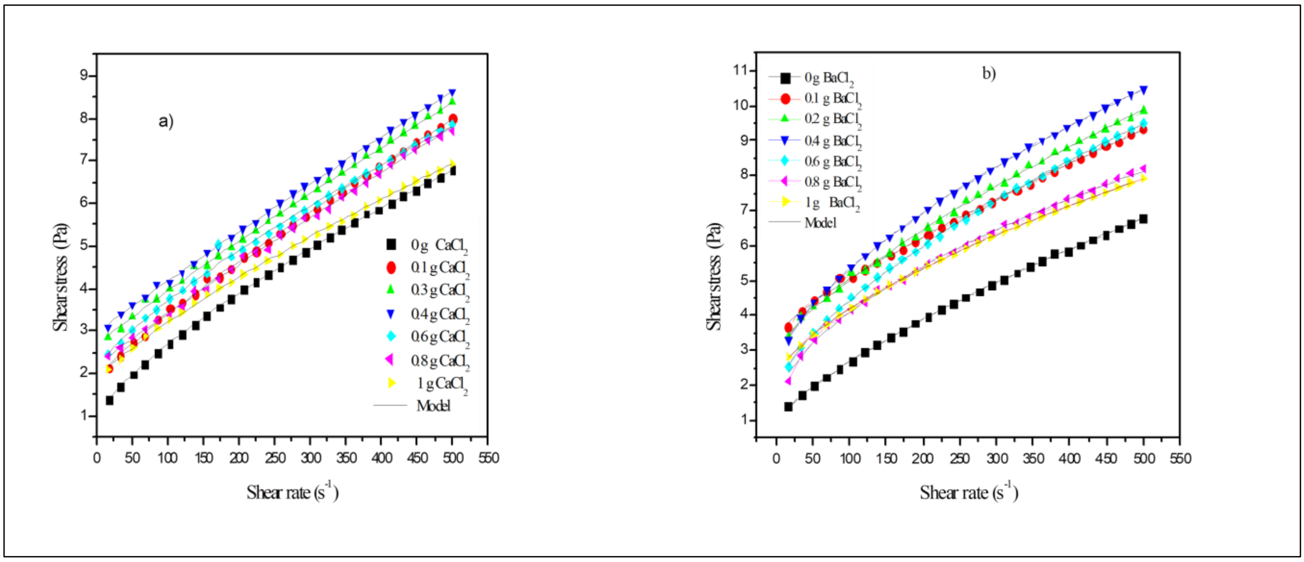

Figure 3. Flow curve of curve of drilling mud at different dose of a) $CaCl_2$, b) $Bacl_2$

Figures 4 shows that the evolution of yield stress and consistency index of mixture bentonite- polymer-electrolytes as a function of dose in electrolytes adds to the drilling mud. For the both electrolytes added to water-based drilling muds, we observe that for doses of electrolytes lower than a critical dose, an increase in the yield stress and consistency index, followed by a decrease in the yield stress and consistency index from the critical dose of electrolytes.

For the dosing of electrolytes lower than a critical the ions of Ca^{2+}bind with water and decrease the free water , this results in the formation of a dense network between the particles of clay and polymer and caused the increase of yield stress [17] . For doses higher than the citric dose in this case the aggregations disperse in the system this phenomenon due to the penetration of the cations Ba^{+} or Ca^{2+} which locating between the sheets of bentonite causing the dispersion under the effect of the repulsive forces which cause a decrease in the yield stress [18].

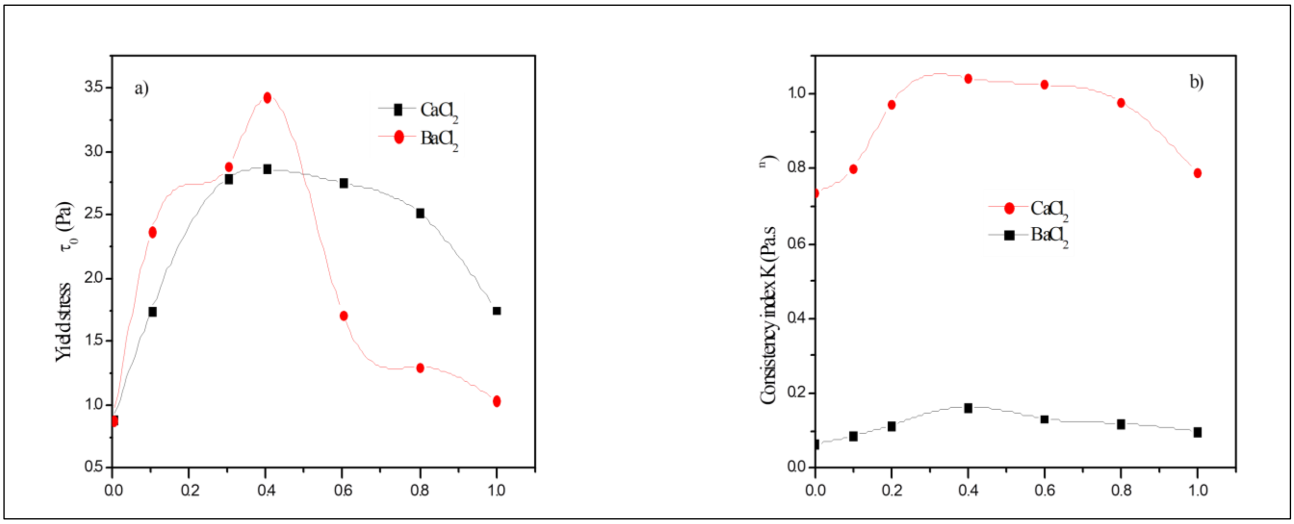

Figure 4. Evolution of yield stress and consistency index of drilling muds as a function of electrolytes a) τ_0, b) K

2.3. Creep and recovery of drilling muds

Figure 6 shows the variation of the elastic compliance of the drilling muds as a function of time at different dose of Kcl and $CaCl_2$. The analysis of the results obtained shows that a generalized Kelvin-Voigt model constituted by the assembly of a Maxwell liquid (damper in series with a spring) and a certain number of Kelvin-Voigt solids (damper in parallel with a spring) can satisfactorily represent this viscoelastic behaviour [19, 20].
The function of creep of this model is than written :

$$J_F = J_0 + \frac{t}{\mu_0} + \sum_{i=1}^{N} J_i \left[1 - \exp\left(-\frac{t}{\theta_i}\right)\right] \quad (2)$$

$$\theta_i = \frac{J_i}{\eta_i} \quad (3)$$

Whereas the recovery strain is given by:

$$J_R = \frac{t_1}{\mu_1} + \sum_{i=1}^{n} J_i \left[\exp\left(\frac{t_1}{\theta_i}\right) - 1\right] \exp\left(-\frac{t}{\theta_i}\right) \quad (4)$$

where J_0 is the purely elastic contribution (or the instantaneous elastic compliance), μ_1 is the purely viscous contribution (internal viscosity) , represented by the dashpot of the Maxwell model, i.e., the uncoupled or residual steady-state viscosity obtained from the creep curve at long times when the compliance curve is linear, J_i is the contribution to retarded elastic compliance, θ_i is the retarded time, is the μ_i retarded viscosity and t_1 is the time where the stress is applied for $t \leq t_1$ and removed at $t = t_1$

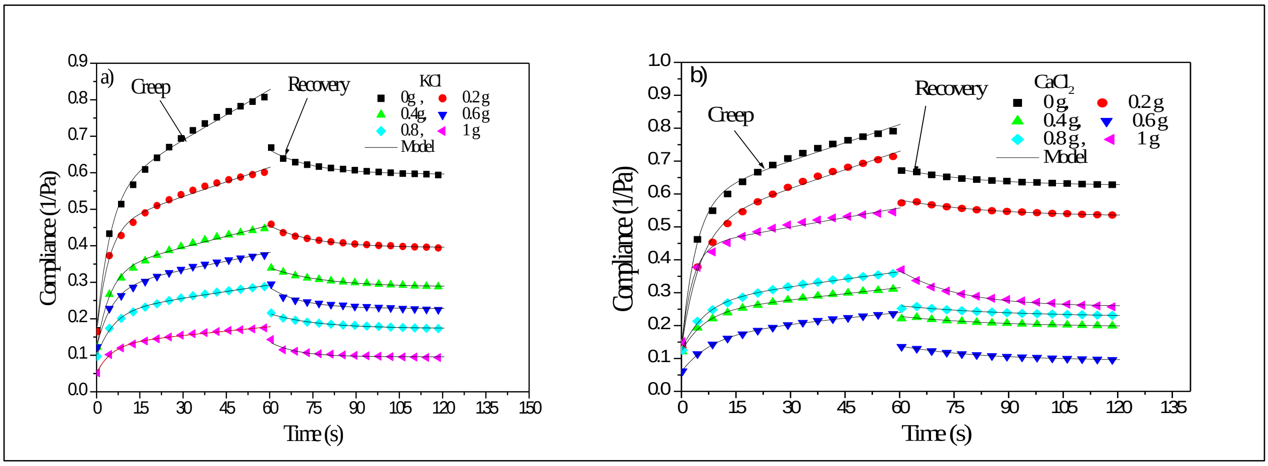

Figure 5. Effect of electrolytes in creep and recovery (viscoelasticity) of drilling muds a) Effect of , b) Effect of $CaCl_2$

Figure 6 shows the variation instantaneous modulus $(G_0 = \frac{1}{J_0})$ of Maxwell unit at $t = 0$ and retarded elastic modulus $G_1 = \frac{1}{J_1}$ as a function of electrolytes in drilling mud. It is clearly in Figure 6 the increase of KCl between 0 and 1g an drilling mud caused the increase of G_0 and G_1 . So the increase of dose of KCl in drilling mud cussed increase of their viscoelastic behaviour. Concerning the effect of $CaCl_2$, the figure 6 shows for the dose of $CaCl_2$ lower than a 0.6 g, an increase in the G_0 and G_1 followed by a decrease in G_0 and G_1 after the critical dose of $CaCl_2$ added in drilling mud.

Figure 7 shows the effect the electrolytes on residual viscosity μ_1 and internal viscosity μ_0 of drilling mud. For all electrolytes, it is clear that the residual viscosity μ_1 are greater than internal viscosity μ_0. Moreover the increase of KCl on the drilling mud caused an increase on residual viscosity and internal viscosity.

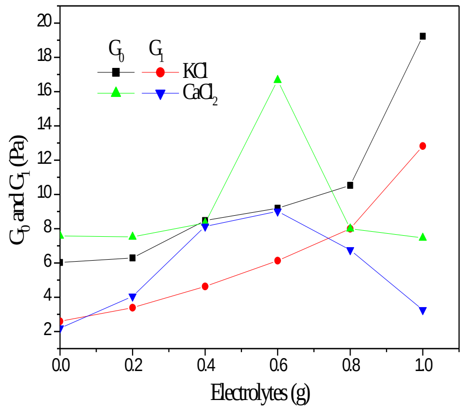

Figure 6. Instantaneous modulus and retarded elastic modulus as a function of electrolytes

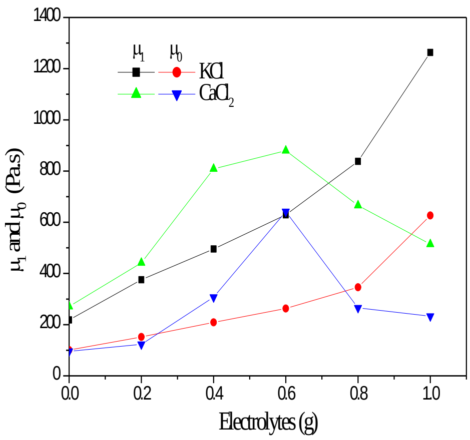

Figure 7. Instantaneous modulus and retarded elastic modulus as a function of electrolytes

According to Mao et al [5] the increase of the viscosity due formation of aggregates caused by Potassium chloride. Concerning the effect of $CaCl_2$ the figure 7 shows for the dose lower than of 0.6 g an increase in the viscosity's of drilling mud. This increase of viscosity, due to the increasing degree of crosslinking between calcium and bentonite [21]. For the dose of $CaCl_2$ greater than 0.6 g added in drilling mud the viscosity is decrease. The decrease of viscosity can explain by degradation of poly-salt by high quants of $CaCl_2$ [22].

3. Conclusion

The effect the electrolytes on the stationary and viscoelastic behaviour of Polymer -water based drilling were studied. The non-Newtonian stationary flow behavior of Polymer -water based drilling was successfully modeled by using the Herschel–Bulkley model over the studied range electrolytes. The addition $Bacl_2$ and $CaCl_2$ in a concentration ranging between 0 and 0.4 g in Polymer -water based drilling caused the increase in the yield stress , consistency index and decrease in flow index. The study also shows that for the dose of $Bacl_2$ and $CaCl_2$ greater than 0.4 g an decrease of the yield stress, consistency index and increase of flow indie of drilling mud.

The increase of quantity of KCl in drilling mud causes an increase on viscoelastic behavior of Polymer -water based drilling mud and structure of particle-to-particle bonds. The structure of particle-to-particle bonds of water based drilling caused a problem during the process of pumping the drilling mud. So, in order to facilitate the process of pumping the mixture Polymer -water based drilling we propose to adding the $Bacl_2$ and $CaCl_2$ as a third additive.

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