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Theme :

Influence of additives on the rheology of drilling muds

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Abstract

The objective of this study is to examine the rheological properties of bentonite suspensions with additives. We worked on conducting a literature review and provide an example of a study on the influence of the addition of polymers (carboxymethyl cellulose and xanthan), with the aim of highlighting the influence of these polymers on the rheological behavior of bentonite suspensions that are considered as a crucial component of water-based drilling mud.

Résumé

L'objectif de cette étude est d'examiner les propriétés rhéologiques des suspensions de bentonite avec des additifs. Nous avons travaillé sur la réalisation d'une étude bibliographique et fourni un exemple d'étude sur l'influence de l'ajout de polymères (carboxyméthylcellulose et xanthane), dans le but de mettre en évidence l'influence de ces polymères sur le comportement rhéologique des suspensions de bentonite, considérées comme un composant crucial des boues de forage à base d'eau.

ملخص

هدف هذه الدراسة هو فحص الخواص الريولوجية لتعليقات البنتونيت مع المضافات. لقد عملنا على إجراء مراجعة للمصادر حول سوائل الحفر وتقديم مثال على دراسة حول تأثير إضافة البوليمرات (السليلوز كاربوكسي ميثيل والزانثان)، بهدف تسليط الضوء على تأثير هذه البوليمرات على السلوك الريولوجي لتعليقات البنتونيت التي تعتبر مكونًا حاسمًا في طين الحفر القائم على الماء.

Acknowledgments

I would like to express my sincere gratitude and appreciation to all those who have contributed to the successful completion of this project.

First and foremost, we are deeply thankful to our superviser, Mr BERKACHE Kamel for his invaluable guidance, support, and mentorship throughout the entire duration of this project. Their expertise and insights have been instrumental in shaping the direction and quality of our work.

We immensely grateful to our co-supervisor, Mr DEGHMOUM Mohamed for agreeing to co-supervise our work, as well as for their availability, valuable guidance, their constant encouragement and insightful discussions.

We would also like to extend our heartfelt appreciation to the president of Jury and examiner, Mrs SMAIL Fatima and Mr BOUTRA Abdelkader, for their valuable feedback and constructive criticism, which have greatly enhanced the overall quality of this project as well as the time they dedicated to studying this work.

BEN ABDI Soumia

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General Introduction

Rheological measurements are commonly used in a wide range of industries, including materials science, chemical engineering, food science, pharmaceuticals, cosmetics, and petroleum engineering. These measurements are used to design and optimize the processing and handling of materials, as well as to ensure that materials meet specific quality and performance standards. In summary, rheology is the study of how materials deform and flow under stress and is an essential tool for understanding and optimizing the behavior of complex fluids and soft solids [1].

In the petroleum sector, Rheology is used to design and optimize drilling fluids that are used to drill oil and gas wells. The viscosity and fluid behavior of the drilling fluids are critical to ensuring the efficient and safe drilling of the well [2].

Moreover, the addition of polymers to bentonite suspensions, which are the main component for WBM, causes a significant modification of its rheological properties. In general, the behavior laws of these materials turn out to be complex due to their shear-thinning character with yield stress and their viscoelastic behavior.

In this context, the work will be focusing on the following:
In the first literature review chapter, it was necessary to introduce some definitions used by petroleum engineers regarding drilling fluids.
In second chapter, we focused on a study that investigated the influence of additives (polymers) on the behavior of bentonite dispersions in aqueous solutions of xanthan gum and CMC at various concentrations.

Chapter 1

Generalities of Drilling Fluids

1.1 Introduction

The good choice of drilling fluid contributes to the success of a drilling operation while these fluids, commonly referred to as drilling mud, are considered complex due to their composition, which may include emulsions or suspensions of different elements, and their multiple functions. The rheological properties of these fluids, which include non-Newtonian behavior, Shear-thinning, thixotropic, and sensitive to temperature changing, are playing important role in the success of the drilling operation and may vary depending on the specific type of mud and operating conditions [3].

1.2 Definition of Drilling Fluids

The drilling fluid is known as the fluid that assists the equipment in drilling wells and has been used for this purpose for a long time, even before the discovery of the oil industry [4].

Drilling fluids are key to the success of water, oil, and gas drilling wells, so the quality and properties of the drilling fluid must match the drilling conditions to achieve the best performance. Therefore, the progress and efficiency of drilling operations largely depend on the use of the appropriate drilling fluid for the soil and layers being excavated.

The drilling fluid is referred to as any liquid used in rotary drilling and is pumped by its own pumps, flowing through the drill pipes to the bottom of the well. Drilling fluids can include gases, oil, and liquids. It is sometimes referred to as drilling mud.

1.3 Principal Functions of Drilling Muds:

- Ensuring the removal of cuttings from the bottom of the well to the surface is achieved by circulating a viscous fluid in the annular space. These cuttings provide geological information about the formations encountered during drilling.

- To maintain the cuttings in suspension during a circulation stop in order to prevent settling and restart drilling without blockage, it is possible due to the thixotropic nature of the fluid.

- To cool and lubricate the tool in order to prevent rapid wear of the moving metal parts.

- Filtration in permeable formations of a portion of the liquid phase of the mud creates a film on the walls of the wellbore, and this film is called cake. The deposition of the cake helps consolidate and reduce the permeability of the wellbore walls. [5]

- The mud allows for continuous information about the evolution of encountered formations and fluids. This information is obtained through:

    - The cuttings brought up during fluid circulation,
    - The monitoring of physical and/or chemical characteristics of the mud,
    - The detection of gases or other fluids mixed with the mud.

1.4 Circulation of Drilling muds:

The drilling mud is in continuous circulation throughout the drilling process, both downhole and at the surface. The fluid is prepared in mud tanks, then injected into the drill string down to the tool. It then returns to the surface through the annular space, carrying the cuttings formed at the drilling face.

Upon exiting the well, the mud undergoes various treatments such as screening, dilution, and addition of additives. These treatments aim to remove transported cuttings and readjust the mud's physicochemical and rheological properties to their desired values before the injection.

The following figure illustrates the drilling fluid cycle during the drilling process and the basic equipment to treat it for subsequent use.

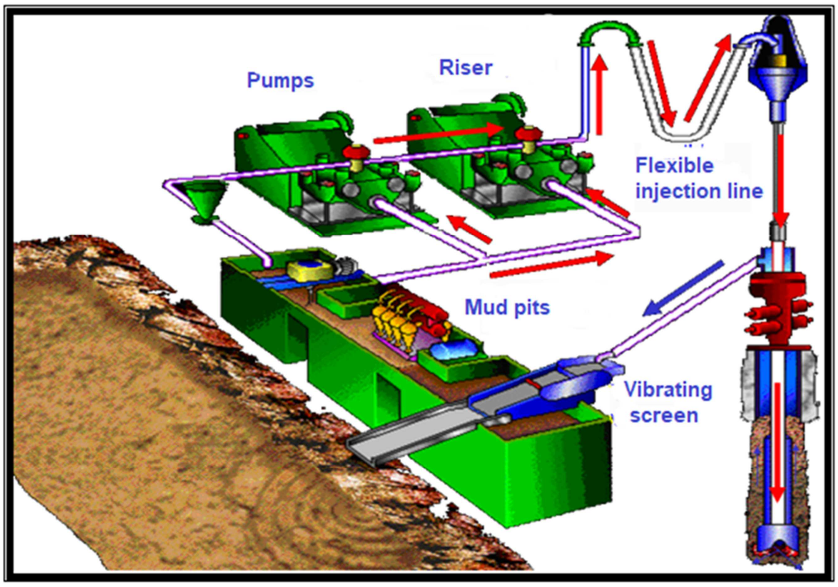

Figure 1-1 Diagram of mud circulation on the drilling site

1.5 Selection criteria for drilling fluids:

Drilling fluids are selected based on one or more of the following criteria:

- **Cost**:

Traditionally, cost has been a primary factor in the selection of drilling fluids. However, other equally important factors include the total well cost and the impact of the fluid on well productivity.

- **Application and performance:**

Drilling fluid systems should be selected to provide the best overall performance for each specific well. Factors such as drilling efficiency, wellbore stability, and formation damage prevention should be considered.

- **Logistics**:

Logistics is a major consideration in well planning and developing mud programs, especially when operating in remote regions. Product efficiency, shelf life, packaging, transportation costs, storage, and inventory volumes should also be taken into consideration.

- **Environmental impact and safety:**

Minimizing the environmental impact of a drilling operation and ensuring safety considerations directly influence the choice of drilling fluid additives and drilling fluid systems.

1.6 Classification of drilling fluids:

There is no specific standard for classifying drilling fluids, but the most commonly used classification, based on the continuous phase (base), is as follows [6]:

Water-based drilling fluids: These are drilling fluids where the continuous phase is water, often containing electrolytes and other additives, including polymers. Water-based drilling fluids are the most widely used type of mud in the drilling industry [6].

Gas-based drilling fluids: These are drilling fluids where the continuous phase is gas, mixed with varying proportions of water from the formation being drilled. The gas can be air, natural gas, foam, or mist.

Oil-based drilling fluids: There are two types of oil-based muds: oil-based muds containing a maximum of 5 to 15% water and inverse emulsion muds that can contain up to 60% water. In both types of mud, the formed emulsion is always oil-in-water [7].

1.7 Properties of Drilling fluids

The physical and chemical properties of drilling fluid play a crucial role in the success of a drilling operation. The properties of the drilling fluid may be the only variables in the entire drilling process that can be quickly modified to enhance drilling efficiency. These properties generally receive the highest level of attention.

1.7.1 Density

Density is an important parameter of drilling mud. It must be sufficiently high so that the hydrostatic pressure exerted by the mud on the formation prevents the influx of water, oil, and gas, and consequently, blowouts. However, it should not exceed the strength limit of the formations to avoid fracturing them and causing losses during circulation.

The mud exerts a pressure on the wellbore walls given by the following expression:

$$P = 0.981\,\frac{h.d}{10}$$

With:

P: hydrostatic pressure in bar (bar).

h: depth in meters (m).

d: density in (kgf/dm^3).

- **Control Equipment**

The following figure represents the device used to measure density along with its basic components.

Figure 1-2 : Fann Density Meter

1.7.2 Rheology

Rheology is the science of deformation and flow of matter. When applied to drilling fluids, rheology deals with the relationship between flow rate and flow pressure and their combined effects on the flow characteristics of the fluid.

The following figure represents the device used to measure viscosity:

Figure 1.3: Speed Fann Viscosimeter

The characteristics to be determined are plastic viscosity and the value of the yield point.

These determinations are carried out using the Fann viscometer according to the A.P.I standard, which considers the readings at 600 and 300 rpm. [8]

- **Plastic Viscosity**

$$Vp = \theta600 - \theta300$$

- Vp: Plastic Viscosity in (cP)
- θ600: Fann reading at 600 rpm
- θ300: Fann reading at 300 rpm

- **Yield Point**

$$Yp = \theta600 - 2(\theta600 - \theta300)$$

- Yp: Yield Point in Pa or lb/100 ft²
- θ600: Fann reading at 600 rpm
- θ300: Fann reading at 300 rpm

- **Gels and Thixotropy**

A drilling mud left undisturbed gradually develops a structure that increases its rigidity, which can be reduced by agitation. This phenomenon, characterized by its non-instantaneous and reversible nature, is known as thixotropy.

The thixotropic nature of a drilling mud is evaluated by measuring the "gel 0" and "gel 10". The gel 0 represents the gel strength immediately after agitating the mud. These measurements are performed using the Fann viscometer at a speed of 3 rpm and expressed in lb/100ft². On the other hand, the gel 10 represents the gel strength after the mud has been allowed to rest for 10 minutes.

1.7.3 pH

An aqueous solution can contain various ions; it always contains, to a greater or lesser extent, dissociated H+ and OH- ions. Practically, the pH of commonly used Muds varies between approximately 6 and 13.5. Muds with a pH below 10.5 are referred to as low pH, while those with a pH above 10.5 are referred to as high pH.

pH is measured by:

- Either a colorimetric method (PH paper or colored indicators).
- Or an electrometric method (PH meter) using glass electrodes. [9]

Chapter 2

Rheology of bentonite-additive mixtures

2.1 Introduction

The purpose of this chapter is to share previous results obtained from a study on the influence of the addition of polymers (carboxymethyl cellulose and xanthan)and comparing those results and observations to our study and its results , with the aim of highlighting the influence of these polymers on the rheological behavior of bentonite suspensions. Water-based drilling fluids containing a high concentration of bentonite can have negative effects on the drilling operation, such as excessive friction. Therefore, the chosen concentration of bentonite in most water-based drilling fluid formulations is 3%.

2.2 State of the art

K.Benyounes (2010) : He conducted a study to investigate the effect of two polymers, carboxymethyl cellulose and xanthan (commonly used as an additive in drilling fluids), on the rheological properties of a bentonite suspension.

2.2.1 Preparatory mode of mixtures

He separately prepared the reference bentonite suspension (3%) and polymer solutions. Initially, a predetermined amount of demineralized water was agitated. The desired concentration of the base bentonite (or polymer) was then slowly added to the water to prevent the formation of aggregates. To ensure proper homogenization and swelling of the materials, they were continuously agitated for 24 hours. The polymer solution was added to the base bentonite suspension. The resulting mixture was agitated for 24 hours before proceeding to the testing phase.

2.2.2 Rheological characterization of bentonite-xanthan mixtures

2.2.2.1 Flow test of the bentonite-xanthan mixture

He applied a precise strain rate of 100 s^{-1} to the sample for 1 minute, followed by a rest period of 2 minutes. Secondly, he applied an increasing stress ramp of 0.033 Pa.s^{-1}. During the rheological tests, the temperature was maintained at 20°C.

Figure 2.1 presents the rheograms of bentonite at 3% concentration and xanthan at various concentrations.

It was observed that the shape of the bentonite-xanthan mixture curve is similar to that of xanthan solutions, with an increase in apparent viscosity and yield stress. This suggests that the rheological behavior of the bentonite-xanthan mixture is governed by xanthan.

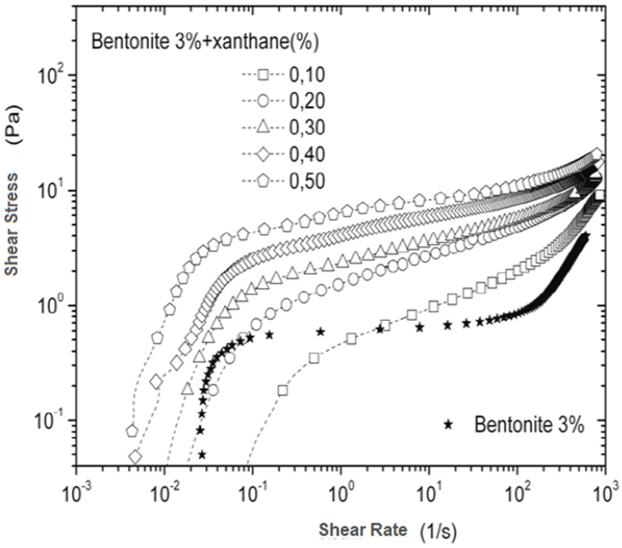

Figure 2-1 Rheogram of the 3% bentonite - xanthan mixture at different concentrations [10]

2.2.2.2 Viscosity-shear rate relationship of the bentonite-xanthan mixture

The variation of apparent viscosity as a function of shear rate gradient is illustrated in Figure 2.2. A decrease in viscosity is observed with an increase in shear rate gradient for all xanthan concentrations, indicating that xanthan leads to the rheofluidification of the water-bentonite-xanthan system.

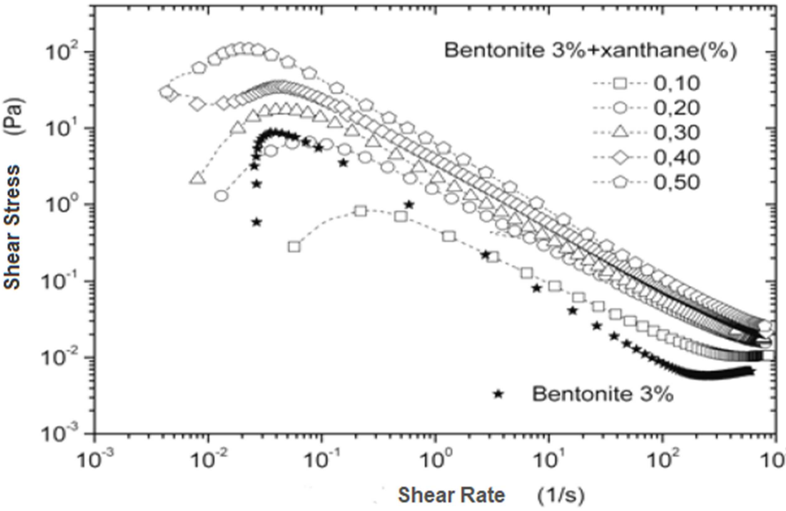

Figure 2-2 Variation of viscosity of the 3% bentonite - xanthan mixture at different concentrations as a function of shear rate. [10]

2.2.2.3 Dynamic test of the bentonite-xanthan mixture

The dynamic tests are performed by varying the frequency from 10^{-2} to 10 Hz, while keeping the applied stress constant for all mixtures at a value of 0.02 Pa.

Figure 2.3 shows the variations of the elastic modulus G' and the viscous modulus G'' as a function of frequency for the 3% bentonite suspension and the bentonite-xanthan mixtures at different concentrations. For all mixtures, the elastic modulus G' is higher than the viscous modulus G'', indicating a prevalence of elastic behavior over viscous behavior in the mixtures.

The modulus curves (G' and G") are slightly dependent on frequency and they are almost parallel for polymer concentrations ≥ 0.2%

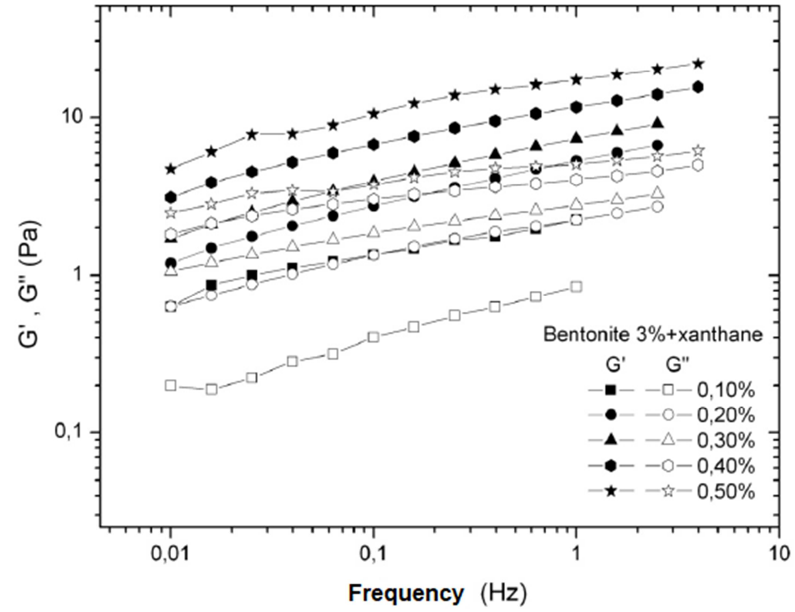

Figure 2-3 Variation of G' and G" of the bentonite-xanthan mixture as a function of frequency [10].

2.2.3 Rheological characterization of bentonite-carboxymethyl cellulose mixtures

2.2.3.1 Flow test of the bentonite-CMC mixture

All flow curves were obtained by applying an increasing stress ramp. Prior to conducting the flow tests, the samples were subjected to a pre-shearing for 2 minutes, followed by a resting time of 10 minutes. The rheological tests were carried out using a stress-controlled rheometer (AR2000, TA Instruments) with a cone-plate geometry.

The high molecular weight carboxymethyl cellulose (CMC-HV) at different concentrations, in the presence of 3% bentonite in an aqueous medium, was subjected to a flow test. The representative rheogram corresponding to this test is shown in Figure 2-4Figure 2-4 : Rheogram of the bentonite (3%)/CMCHV mixture [10].. It is evident that the shape of the flow curves for the mixture is similar to the rheograms for CMC-HV solutions. Studies conducted by [11, 12] who have also observed similar flow curve patterns for bentonite-CMC-HV mixtures.

Despite the high molecular weight of CMC-HV, it is noticeable that there is no yield stress present in the various flow curves for all CMC-HV concentrations. The absence of yield stress is attributed to the flexible and structural nature of CMC and its high anionic charge. Due to these characteristics, CMC effectively deflocculates the clay particles [13].

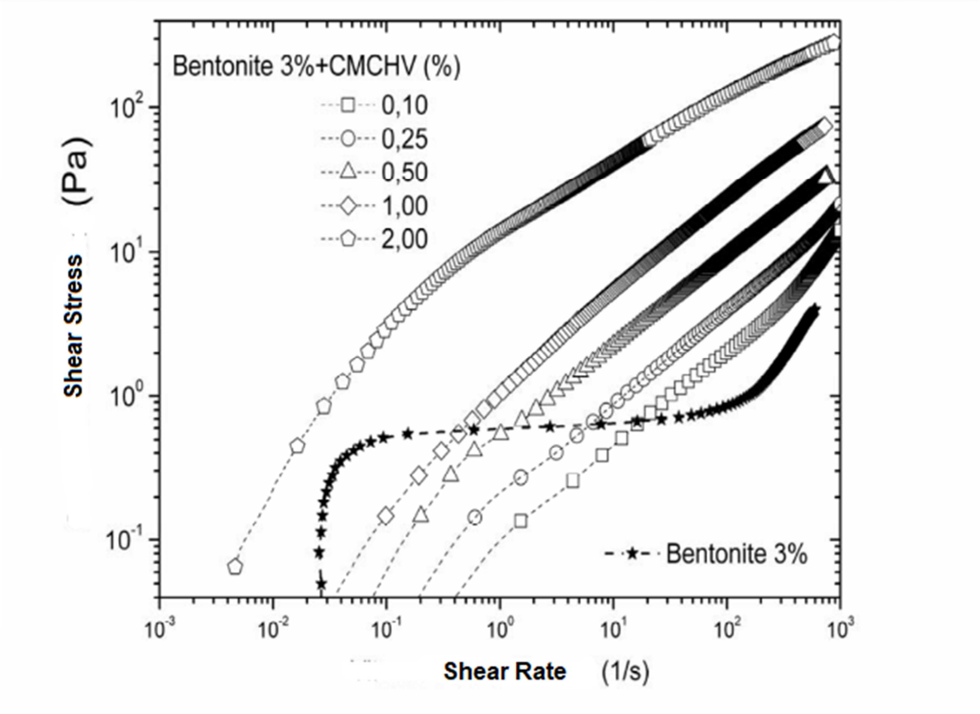

Figure 2-4 : Rheogram of the bentonite (3%)/CMCHV mixture [10].

2.2.3.2 Dynamic tests of the bentonite-CMCHV mixture

At a concentration of 1% CMCHV, the storage modulus (G') and the loss modulus (G") are almost equal. For polymer concentrations below 1%, the loss modulus is higher than the storage modulus, as shown in Figure 2-5. At these concentrations, the mixture is more viscous than elastic. However, when the concentration exceeds 1%, the storage modulus becomes higher than the loss modulus, indicating a predominance of the elastic nature of the mixture. This predominance can be explained by the entanglement regime of the water-bentonite-CMCHV system.

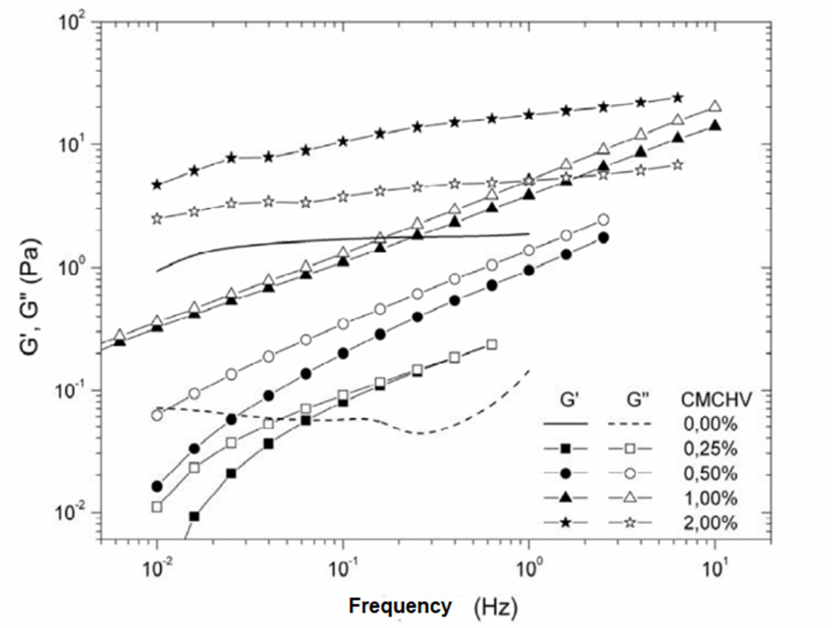

Figure 2-5 : Variation of G' and G" for the 3% bentonite suspension and the high viscosity bentonite-CMC mixture at different concentrations.[10]

The dynamic viscosity decreases with frequency for all the bentonite-CMCHV mixtures in Figure 2-6. However, the complex viscosity η* is significantly influenced by the increase in CMCHV concentration.

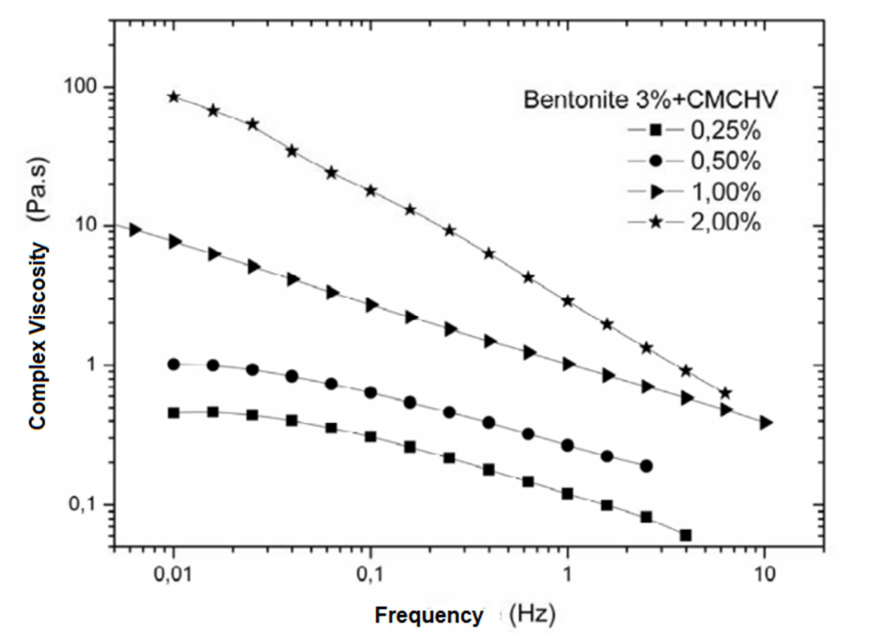

Figure 2-6 : Variation of complex viscosity as a function of frequency for the bentonite-CMCHV mixture [10]

2.3 Our Study – Experimental Part

2.3.1 Preparatory mode of mixtures

We initially prepared the reference bentonite suspension (3%) by having the desired concentration of the base bentonite that slowly was added to the water to prevent the formation of aggregates. To ensure proper homogenization and swelling of the bentonite, it was continuously agitated for 24 hours. We add the desired concentration (1%) of powdered used polymer (Xanthan and CMC) and continue stirring using a magnetic or mechanical stirrer until homogeneity is achieved.

2.3.2 Rheological characterization of bentonite-Xanthan mixtures

2.3.2.1 Flow test of the bentonite-Xanthan mixtures

The figure 2.7 down below shows the variation of shear stress and viscosity as function of shear rate where we can observe as the concentration of xanthan gum increases, so does the viscosity of the solution. Xanthan gum is known for its thickening properties, with a large increase in viscosity at higher concentrations.

In other hand, Xanthan gum typically exhibits shear thinning behavior. And it is proved in the figure down below where we can observe that as the shear stress or shear rate increases, the viscosity of the solution decreases.

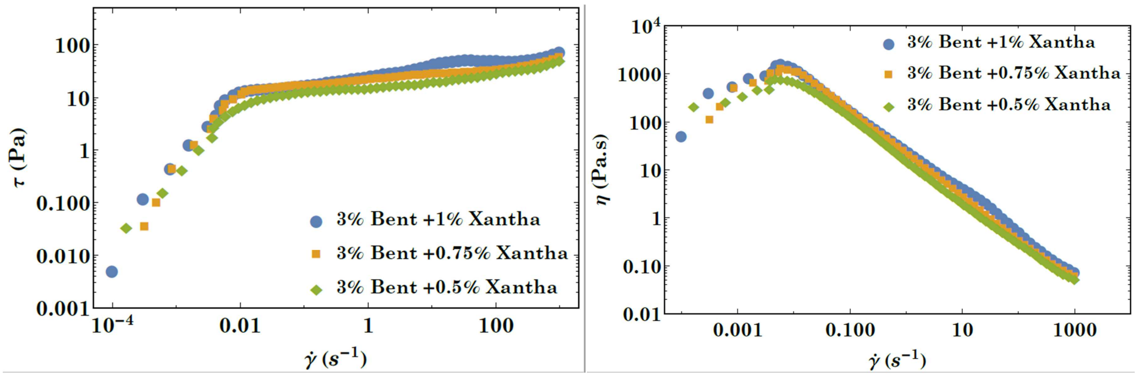

Figure 2-7: Rheogram of the 3% bentonite - xanthan mixture at different concentrations.

2.3.2.2 Dynamic tests of the bentonite-Xanthan mixture

Figure 2.8 shows the variation of the elastic modulus G' and the viscous modulus G'' as a function of frequency for the 3% bentonite suspension and the bentonite-xanthan mixture at concentration of 1%. We observe, the elastic modulus G' is higher than the viscous modulus

G'', indicating a prevalence of elastic behavior over viscous behavior in the mixtures while the modulus curves (G' and G'') are slightly dependent on frequency and they are almost parallel.

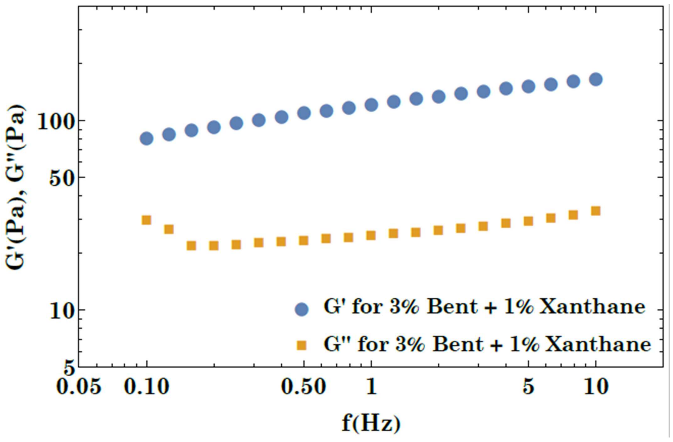

Figure 2-8 : Variation of G' and G" of the bentonite-Xanthan mixture as a function of frequency.

2.3.3 Rheological characterization of bentonite-CMC mixtures

2.3.3.1 Flow test of the bentonite-CMC mixtures

As show in the Figure 2-9, it represents the variation of shear stress and viscosity as function of shear rate for mixtures of 3% bentonite and different concentrations of CMC. We can tell that as the CMC concentration increases, so does the viscosity of the solution. CMC is known for its thickening properties, with large increases in viscosity at higher concentrations. Moreover, we are having a decrease in viscosity as shear rate or stress increases for the mixture therefore, we can indicate a shear-thinning behavior of this mixture.

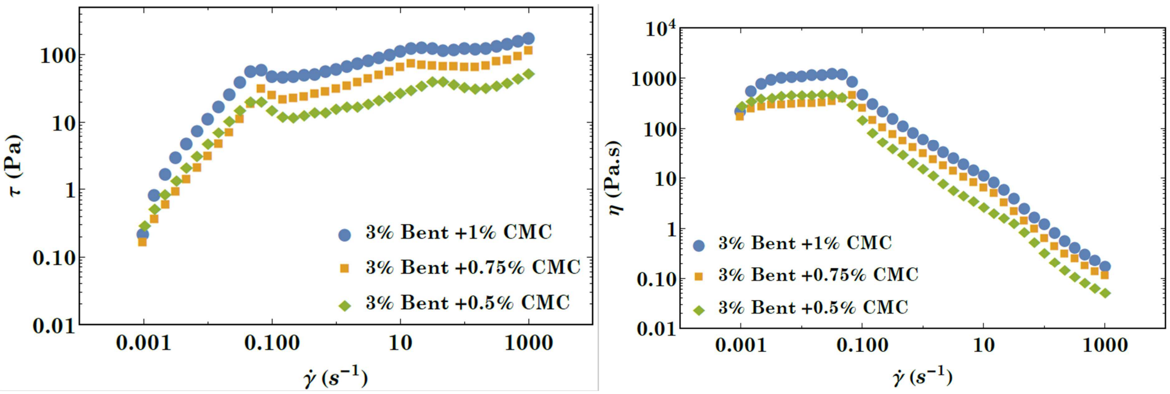

Figure 2-9: Left: Flow curves of Bentonite + CMC mixtures at different concentrations.

2.3.4 Rheological comparing of bentonite – polymers systems

2.3.4.1 Flow test of the bentonite-polymers mixtures

Flow curves mixtures containing 3% bentonite and a concentration of 1% (CMC & Xanthan) in addition to the evolution of the corresponding viscosities as a function of shear rates are presented in Figure 2-10. It is observed on that the flow curve of the bentonite suspension in water is located below the dispersion of mixtures bentonite – polymers and the same for mixtures where we can observe that B3CMC1 is being above the B3XAN1 and that could indicate at same time that CMC is exhibiting a higher viscosity or thicker consistency compared to xanthan gum in the same system as it shown in the figure down below. This behavior can be influenced by several factors, including the molecular structure. CMC is a high molecular weight linear polymer, while xanthan gum is a branched polysaccharide. Structural differences lead to changes in their rheological behavior.

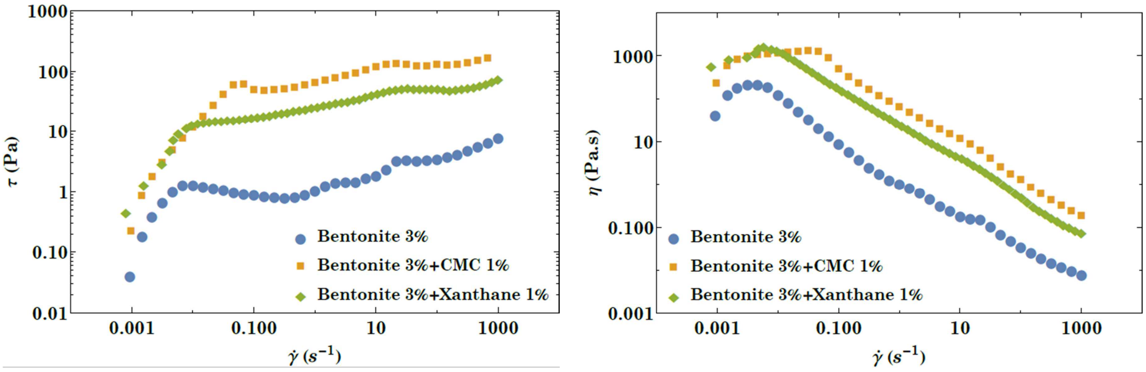

Figure 2-10 : Left: Flow curves of Bentonite + CMC and Bentonite + Xanthan mixtures at 1%

General Conclusion

The main objective of this work was to conduct a literature review and provide an example of characterizing the rheological properties of clay dispersions in aqueous polymer solutions, as well as to understand the relationship between these measured properties. The first chapter was dedicated to the literature review on drilling fluids, their functions, and properties. In the second chapter, we focused on a study that investigated the influence of additives (polymers) on the behavior of bentonite dispersions in aqueous solutions of xanthan gum and CMC at various concentrations.

Xanthan gum, being a natural biopolymer, exhibits excellent thickening and stabilizing properties. The viscoelastic tests conducted on the bentonite-xanthan gum mixtures reveal an enhancement of the viscoelastic nature of the mixtures, as evidenced by an increase in the dynamic moduli. It is noteworthy that the bentonite-xanthan gum mixtures exhibit a viscoelastic behavior with a predominant elastic component.

On the other hand, CMC, with its high molecular weight and anionic charge, also contributes to the viscosity enhancement and stability of the bentonite dispersion. The addition of CMCHV to the 3% bentonite suspension resulted in the disappearance of the yield stress in the mixtures. This disappearance of the yield stress is primarily caused by the adsorption of polymer chains onto the clay particles. As the adsorption phenomenon becomes widespread, the clay particles are masked by the polymer. Under these conditions, the rheological behavior of the water-bentonite-CMC system is dominated by the CMC polymer.

Overall, both xanthan gum and CMC play important roles in modifying the rheological properties of bentonite suspensions, enhancing their stability, and facilitating various applications in industries such as cosmetics, paints, drilling fluids, and ceramic processing.

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