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Choosing the composition of a drilling fluid containing partially hydrolyzed polyacrylamides (PHPA) for core drillings

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Research Article

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ABSTRACT

In core (diamond) drilling operations, the controlling of drilling fluid's rheological and filtration properties within specific value ranges is essential to ensure effective well cleaning and the maintenance of both mechanical and chemical equilibrium within the well. Furthermore, the additives in the fluid contribute significantly to improving core recovery efficiency. Partially hydrolyzed polyacrylamides (PHPA), known for their ability to encapsulate formations and drill cuttings to prevent the interaction of active clays with water, are also recognized for their effectiveness in improving core recovery efficiency. In core drilling operations, the high-speed rotation of the drill string can lead to challenges such as cake formation when the drilling fluid contains excessive solid particles (e.g., bentonite, calcite, barite, or drill cuttings). Drilling fluid engineers typically prefer polymer-based fluids with low solids content to reduce these issues. In this study, the rheological and filtration properties of various low-solids fluid compositions containing PHPA were investigated under laboratory conditions to identify the most suitable formulations for core drilling. The results of tests revealed that fluid compositions incorporating calcite + xanthan gum + modified starch + PHPA and bentonite + xanthan gum + modified starch + PHPA exhibited superior rheological and filtration properties compared to other fluid formulations. Additionally, the composition of PAC L + PHPA + calcium carbonate exhibited rheological and filtration values suitable for core drilling applications.

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1. Introduction

The rheology of drilling fluids during drilling operations is designed to carry out a wide range of functions, including the transportation of drill cuttings through the annulus to the surface, suspension of cuttings, minimization of formation damage, cooling of drilling equipment, lubrication of the drill bit, maintenance of wellbore stability, control of formation pressure, transmission of hydraulic horsepower, and the reduction of fluid loss and circulation losses (Ahmad et al., 2018; Muhammed et al., 2021; Ali et al.,

2022; Singh et al., 2022). The rheological properties of drilling mud, such as yield point, plastic viscosity, and gel strength, are tried to be kept within specific value ranges depending on factors including the drilling method, annular velocity, formation characteristics, and mud type. These parameters are critical for transporting cuttings effectively to the surface and ensuring their suspension during circulation stops. Field experience indicates that maintaining the yield point, which reflects the dynamic carrying capacity, within the range of 10–20 lb/100 ft², and the 1-minute

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and 10-minute gel strengths, representing the suspension capacity, within the ranges of 2–4 lb/100 ft², 3–6 lb/100 ft², and 8–16 lb/100 ft², respectively, is adequate for core drilling operations.

One of the most important issues in drilling fluid engineering is maintaining control over the filtration rate of the fluid during the drilling of active (swelling) clays to ensure chemical equilibrium within the well. The structure and chemistry of the formation cut, along with the cuttings produced, continuously alter the properties of the drilling mud, in adverse way. The drilling fluid engineers responsibility is to restore the deteriorating mud with appropriate additives, ensuring that its properties remain within the predefined threshold values. Maintaining the filtration rate below 5 ml/30 minutes for drilling through active formations such as clays and shales, and keeping the filtration rate between 4- 12 ml/30 minutes for drilling conducted under normal conditions, preserves the desired properties of the drilling mud. When the filtration rate is kept below 12 ml/30 minutes during operations, a thin, robust, and impermeable filtrate cake with a thickness of less than 1 mm typically forms. However, if the filtration rate exceeds 12 ml/30 minutes, the quality of the filtrate cake deteriorates, and its thickness increases depending on the filtration rate. An increase in cake thickness not only heightens the risk of drill string sticking due to differential pressure within the well, but also complicates retrieving operation of the stuck drill string.

Determining the composition of the drilling fluid is essential to maintain mechanical and chemical stability within the well, especially in formations characterized by brittleness, effluent tendencies, swelling, or water-induced dissolution. As the rheological properties and filtration rate of the selected fluid composition provide effective well cleaning and stability, the mud additives used should enhance chemical equilibrium and optimize core recovery efficiency. Polymer-based drilling fluids are typically preferred in problematic formations, whereas water or bentonite-based fluid is commonly utilized for drilling in more stable and durable formations. Generally, HV CMC (high molecular weight carboxymethyl cellulose), PAC R (high molecular weight polyanionic cellulose), HEC

(hydroxyethyl cellulose), PHPA (partially hydrolyzed polyacrylamide) and xanthan gum are used as viscosity-forming polymers, whereas polysaccharide derivatives (modified starch), LV CMC (low molecular weight carboxymethyl cellulose) and PAC L (low molecular weight polyanionic cellulose) are used for filtration control. CMC, xanthan gum and modified starch are natural polymers, whereas PAC is semi-synthetic and PHPA is a synthetic polymer. Xanthan gum and modified starch are non-ionic polymers characterized by high salt resistance and crosslinking capabilities (Zhao et al., 2016; Magzoub et al., 2020; Bazyar and Monfared, 2021), in contrast to other polymers, which are anionic and linear in structure. However, both xanthan gum and modified starch are sensible to bacterial degradation. Polymer-based muds containing partially hydrolyzed polyacrylamide (PHPA) are commonly used for shale stabilization through encapsulation, as the long-chain acrylamide-acrylate structure allows the negatively charged sites of PHPA to bond with the positively charged sites on clay particles (Jain et al., 2015; Gueciouer et al., 2017). High molecular weight PHPA is especially preferred in mineral exploration drilling to promote fluid viscosity, thereby maintaining the suspension and transport of fine cuttings to the surface (Grabsch et al., 2024). PHPA polymers, which have the ability to coat formation surfaces, are preferred as mud additives in core drilling because of their effectiveness in increasing core recovery efficiency. Since PHPA is chemically consumed while adsorbing onto the formation surface and physically consumed while passing through bit nozzles or desilters, its concentration in the system must be continuously monitored. Carboxymethyl cellulose (CMC) and polyanionic cellulose (PAC) perform effectively in a wide pH range, but are sensitive to high concentrations of divalent ions such as Ca²⁺ and Mg²⁺. In contrast, modified starch and xanthan gum, being non-ionic, exhibit high tolerance to polyvalent cations and salts, while also performing effectively over a broad pH range. At pH values exceeding 10.5, PHPA is converted into acrylate by hydrolysis, and ammonia (NH₃) gas is released. The interaction between polymers and clay particles in bentonite-polymer fluid compositions can occur through various mechanisms. The primary chemical bond is the electrostatic attraction between

the anionic polymer and the positively charged surface sites of the clay particles. Additionally, interactions between the anionic polymer and the negatively charged clay surfaces can occur through three ways: (1) displacement of hydroxyl groups on the clay surface by the anionic groups of the polymer, (2) hydrogen bonding between hydroxyl groups on the clay surface and the polymer chain, and (3) formation of a bridging structure between the clay surface and the polymer by divalent cations (Güngör and Karaoğlu, 2001; Yalçın et al., 2002; Benchabane and Bekkour, 2006; Toka et al., 2009). The reduction for the decrease in water loss is that, theoretically, the polymers bound to the clays form an impermeable mud cake and the free polymers remaining in the liquid fill the voids within the mud cake. (Plank and Hamberger, 1988; Audibert et al., 1999).

Because of the drill rotation speeds being very high in core drillings, the centrifugal force formed in the drill string and the particles in the fluid cause cake in the pipe (Toka, 2022). Therefore, the use of mud solid additives, including bentonite, calcite, barite is avoided and polymer-rich mud systems are preferred.

Calcite (calcium carbonate), generally used to make the drilling fluid heavier, contribute to form a filtrate cake by establishing a bond (bridge) between polymers, and thus reducing filtration loss (Toka and Toka, 2015).

The drilling fluid compositions containing PHPA for enhancing core efficiency are preferred, therefore, laboratory tests of different compositions containing PHPA were performed in this study, and the best fluid compositions for core drilling were selected.

2. Material and Methodology

In this study, a commercially available sodium bentonite was sourced from Reşadiye. The mineralogical analysis of the bentonite was conducted using X-ray diffraction (XRD) with a Rigaku-Geigerflex X-ray diffractometer equipped with a Ni-filter and Cu-K α radiation. The mineralogical composition of the bentonite sample primarily consisted of sodium montmorillonite, with minor amounts of quartz and calcite (Toka et al., 2013).

HV CMC, LV CMC, PAC R, PAC L, xanthan gum, modified starch, and PHPA were obtained from İlbe Mineral. The particle sizes of the tested calcium carbonate and bentonite were below 200 mesh. The pH of the fluid compositions was adjusted to a range of 9.5–10.0 using caustic soda.

The rheological and filtration properties of the prepared compositions were measured using a Fann 35A viscometer and an API filter press at a controlled temperature of 20.0 ± 0.1 °C. The rheological parameters of the fluids TS EN ISO 13500 (2010) were calculated according to the formulas given below.

$$AV = \frac{\theta_{600}}{2} \quad \text{Equation 1}$$

$$PV = \theta_{600} - \theta_{300} \quad \text{Equation 2}$$

$$YP = \theta_{300} - PV \quad \text{Equation 3}$$

AV = Apparent viscosity (cP)

θ_{600} = Viscometer reading at 600 RPM

θ_{300} = Viscometer reading at 300 RPM

PV = Plastic viscosity (cP)

YP = Yield strength (point) (lb/100 ft²)

The mud compositions used in this study were based on the laboratory test results aimed at determining the rheological and filtration properties of drilling fluids (Toka et al., 2016). These tests were conducted as part of the Drilling Department's research and development project under the General Directorate of Mineral Research and Exploration.

The ratio of additives used in the mud compositions were optimized to achieve minimal water loss, a minimum yield point ($YP > 8$ lb/100 ft²) to ensure adequate dynamic carrying capacity, and minimal gel strengths ($0-10'$ gel strengths $> 1-2$ lb/100 ft²) to provide sufficient static carrying capacity.

3. Polymer Based Drilling Fluid Composition

In this experimental study, the rheological and filtration properties of a composition consisting of 5 ppb LV CMC, 0.5 ppb HV CMC, and 0.5 ppb PHPA, prepared by incorporating PHPA into a CMC polymer system without the use of particulate mud additives

such as bentonite and calcite were examined. The results, given in Figure 1, indicate that the yield point (YP) value, which reflects the dynamic cutting carrying capacity of the composition, is notably low, whereas the water loss is significantly high. These characteristics -low YP and high-water loss- limit the application of polymer-only fluid compositions in core drilling. According to these findings, it is evident that the addition of bridging agents such as bentonite and/or calcite, which possess viscosity-enhancing and water-loss-reducing properties, is necessary to improve the YP value and reduce the filtration rate of the system.

4. Calcite Additive Drilling Fluid Composition

The compositions prepared using only polymers do not provide the desired rheological and filtration

properties, calcium carbonate, commonly utilized as a bridging agent to reduce water loss, is added into the polymeric mixtures at a concentration of 14.25 kg/m^3 (5 ppb). The compositions of the various polymeric fluids prepared with the addition of calcium carbonate are presented in Table 1.

In the initial composition, calcium carbonate was introduced at a concentration of 14.25 kg/m^3 into a composition containing CMC and PHPA. This addition does not result in any increase in yield point (YP) or gel strength values, but it significantly reduced the fluid loss, attributed to the bridging effect of calcium carbonate (Figure 2). The quite low YP and gel strength values of this composition suggest that the fluid, in its dynamic state, possesses limited capacity for carrying drilling cuttings, as well as low static

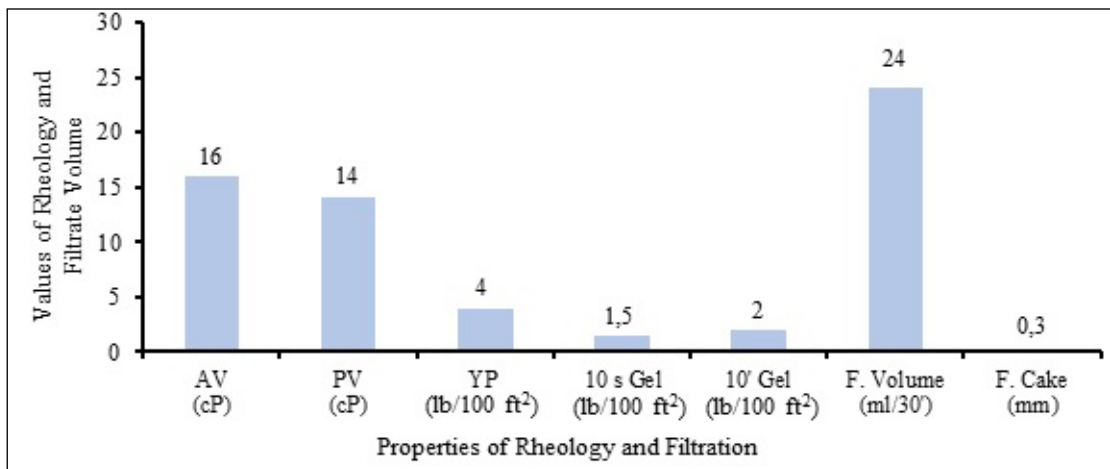


Figure 1- Rheological and filtration properties of the drilling fluid composition containing CMC + PHPA.

Table 1- Drilling fluid composition containing calcium-polymer.

First Composition	5 ppb (14.25 kg/m^3) Calcium carbonate + 5 ppb (14.25 kg/m^3) LV CMC+ 0.5 ppb (1.43 kg/m^3) HV CMC+ 0.5 ppb (1.43 kg/m^3) PHPA
Second Composition	5 ppb (14.25 kg/m^3) Calcium Carbonate + 2.5 ppb (7.13 kg/m^3) PAC L+ 0.5 ppb (1.43 kg/m^3) PHPA
Third Composition	5 ppb (14.25 kg/m^3) Calcium Carbonate + 5 ppb (14.25 kg/m^3) Modified Starch + 0.8 ppb (2.28 kg/m^3) Xanthan Gum + 0.5 ppb (1.43 kg/m^3) PHPA

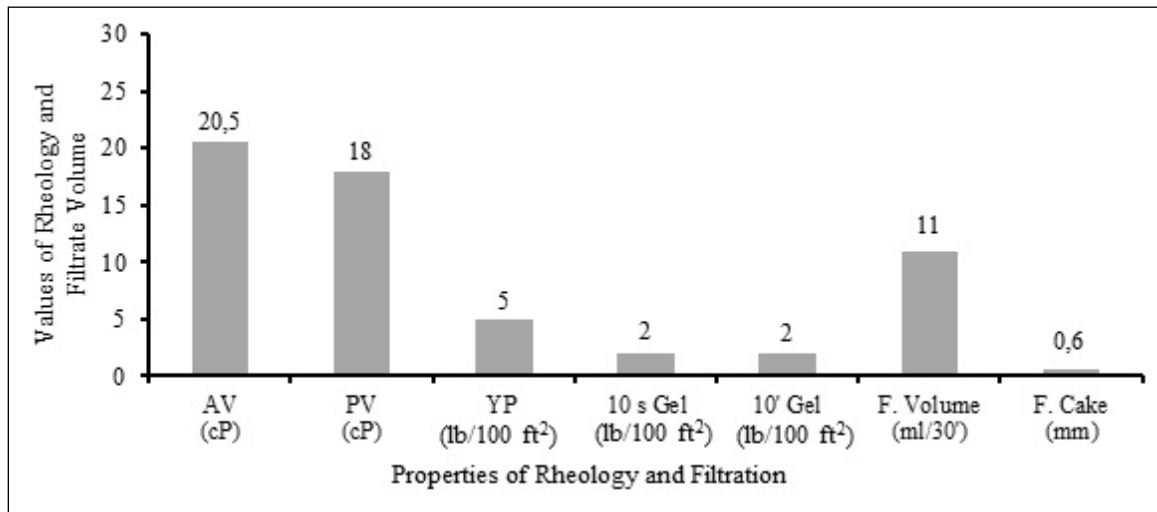


Figure 2- Rheological and filtration properties of the first composition containing CMC + PHPA + calcium carbonate.

suspension properties. Compared to Figure 3, the plastic viscosity (PV), representing friction between solids, increased with the inclusion of calcite alone in the composition. However, the absence of any increase in YP, which reflects chemical bonding, indicates that the polymers do not form chemical interactions with the inert (non-charged) materials.

In the second composition, semi-synthetic PAC L was used instead of CMC. The yield point (YP) of this formulation, comprising PAC L, PHPA, and calcium carbonate, was measured at 10 lb/100 ft², while the gel strength ranged between 1.5 and 2 lb/100 ft² (Figure 3). The fluid loss value was recorded as 13 cm³/30 minutes. Compared to the first composition, the PAC

polymer, even at a lower concentration, resulted in a higher YP value than CMC. This difference is attributed to the properties of the PAC polymer.

The third composition was prepared using the PHPA polymer in combination with xanthan gum and modified starch, both of which are non-ionic, branched polymers. The yield point (YP) of this fluid, consisting of modified starch, xanthan gum, PHPA, and calcium carbonate, was found to be higher than its plastic viscosity (PV). The 10-second and 10-minute gel strength values were recorded at 6–7 lb/100 ft² and were closely aligned (Figure 4). The fluid loss value was measured at 12 cm³/30 minutes, with a filtrate cake thickness of 0.4 mm. The higher YP compared

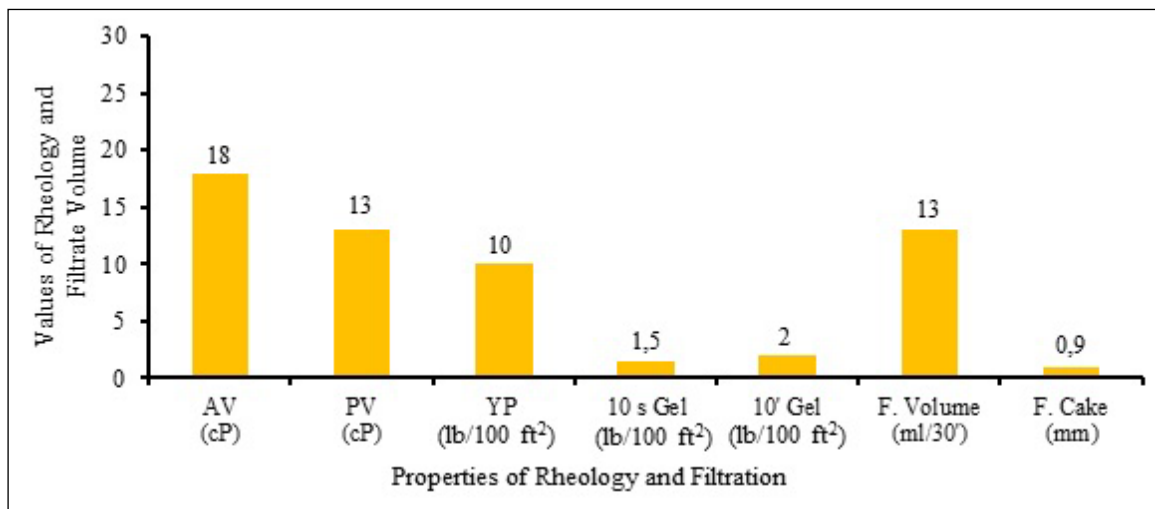


Figure 3- Rheological and filtration properties of the second composition containing PAC L + PHPA + calcium carbonate.

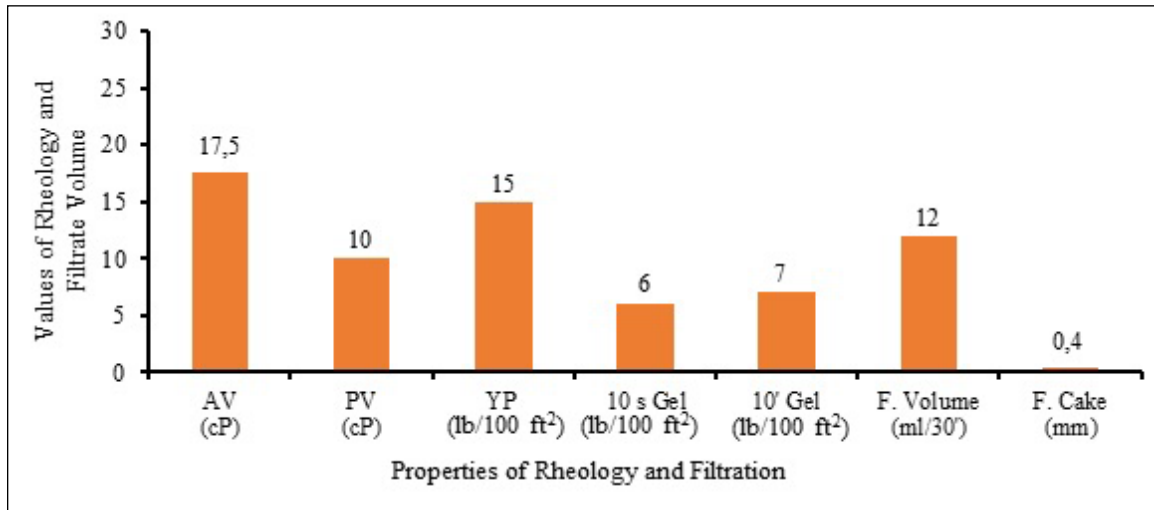


Figure 4- Rheological and filtration properties of the third composition containing modified starch + xanthan gum + PHPA + calcium carbonate.

to PV suggests that the branched polymers establish stronger chemical bonds. The elevated YP, consistent gel strength values, low fluid loss, and thin filtrate cake thickness enhance the suitability of this fluid system for use in core drilling applications. However, the potential impact of calcium carbonate on in-pipe caking should be further investigated under field conditions.

5. Bentonite Additive Drilling Fluid Composition

In order to determine the effects of polymer-bentonite mixtures on the rheological and filtration properties of drilling fluids, various polymers were added in different proportions to untreated bentonite

(Reşadiye bentonite) at a concentration of 9.3 kg/m³ (3.25 ppb). Due to the encapsulation properties of the PHPA polymer, a bentonite-water mixture was initially prepared and allowed sufficient time for the bentonite to swell. The contents of four different compositions, prepared by incorporating various types of polymers into the hydrated untreated bentonite, are presented in Table 2.

Figures 5, 6, 7, and 8 illustrate the changes in the rheological properties of the compositions with the addition of bentonite, especially in terms of plastic viscosity (PV), yield point (YP), and filtration rate values. In the initial composition, consisting of an LV CMC, PHPA, and bentonite mixture, the PV value is

Table 2- Bentonite-polymer-containing drilling fluid composition.

First Composition	3.25 ppb (9.3 kg/m ³) Untreated Bentonite+ 4.5 ppb (12.8 kg/m ³) LV CMC+ 0.6 ppb (1.7 kg/m ³) PHPA
Second Composition	3.25 ppb (9.3 kg/m ³) Untreated Bentonite+ 4.5 ppb (12.8 kg/m ³) LV CMC+ 0.2 ppb (0.6 kg/m ³) Xanthan Gum+ 0.3 ppb (0.9 kg/m ³) PHPA
Third Composition	3.25 ppb (9.3 kg/m ³) Untreated Bentonite+ 1.5 ppb (3.8 kg/m ³) PAC L+ 0.3 ppb (0.9 kg/m ³) Xanthan Gum + 0.3 ppb (0.9 kg/m ³) PHPA
Fourth Composition	3.25 ppb (9.3 kg/m ³) Untreated Bentonite+ 4 ppb (11.4 kg/m ³) Modified Starch+ 0.5 ppb (1.4 kg/m ³) Xanthan Gum+ 0.5 ppb (1.4 kg/m ³) PHPA

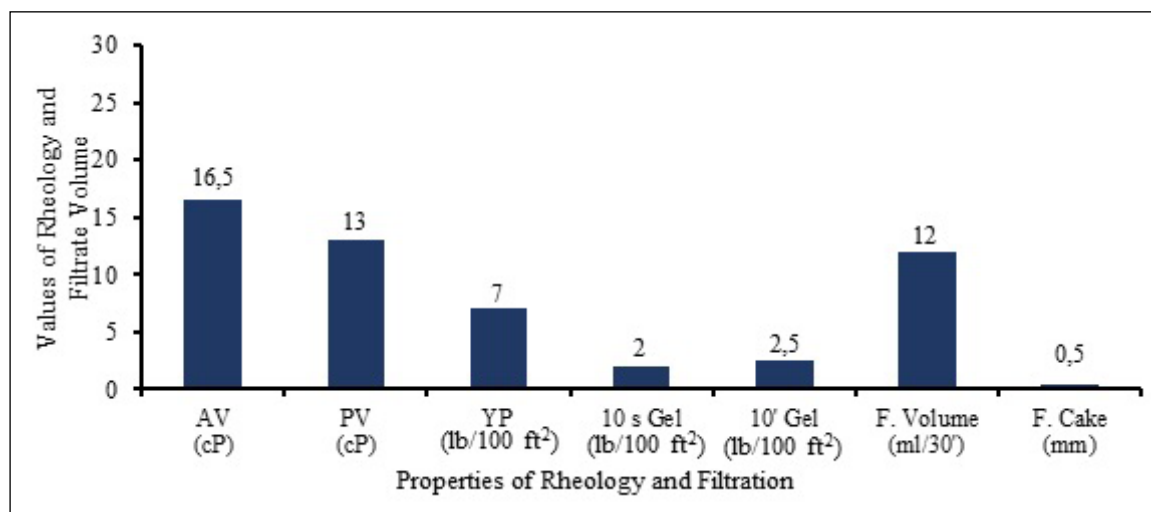


Figure 5- Rheological and filtration properties of the first composition containing bentonite + LV CMC + PHPA.

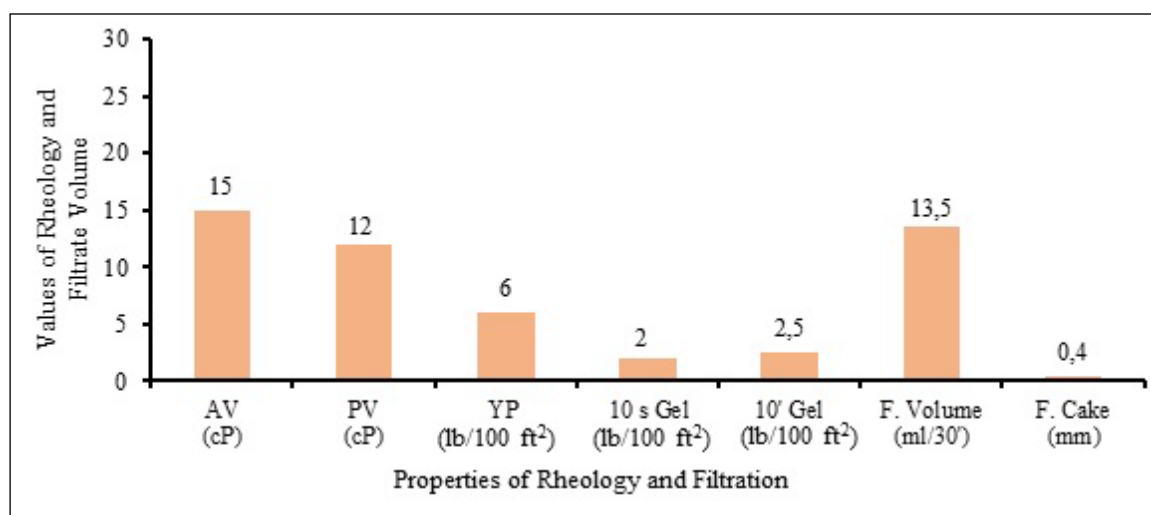


Figure 6- Rheological and filtration properties of the second composition containing bentonite + LV CMC + xanthan gum + PHPA.

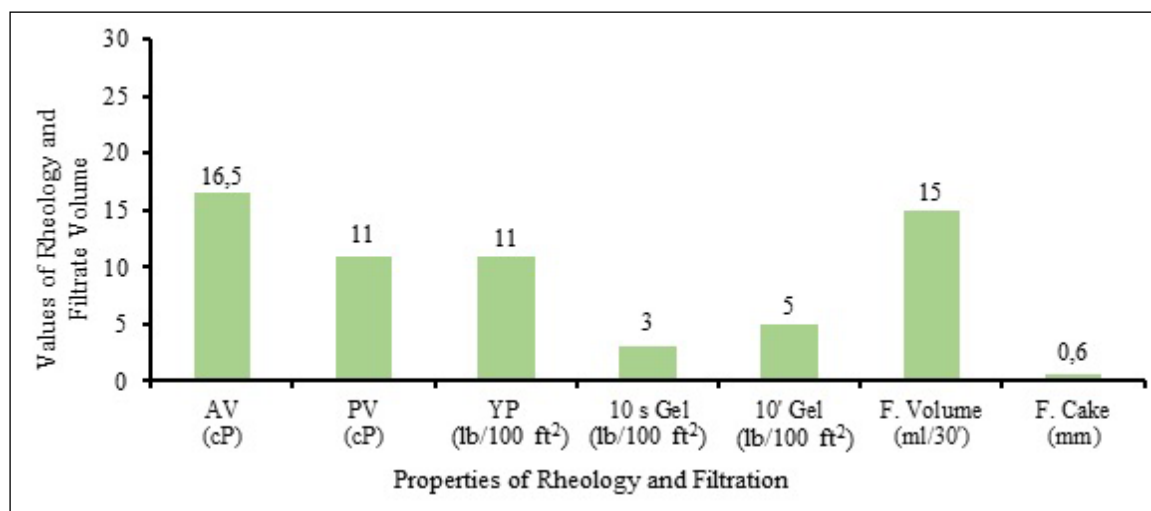


Figure 7- Rheological and filtration properties of the third composition containing bentonite + PAC L + xanthan gum + PHPA.

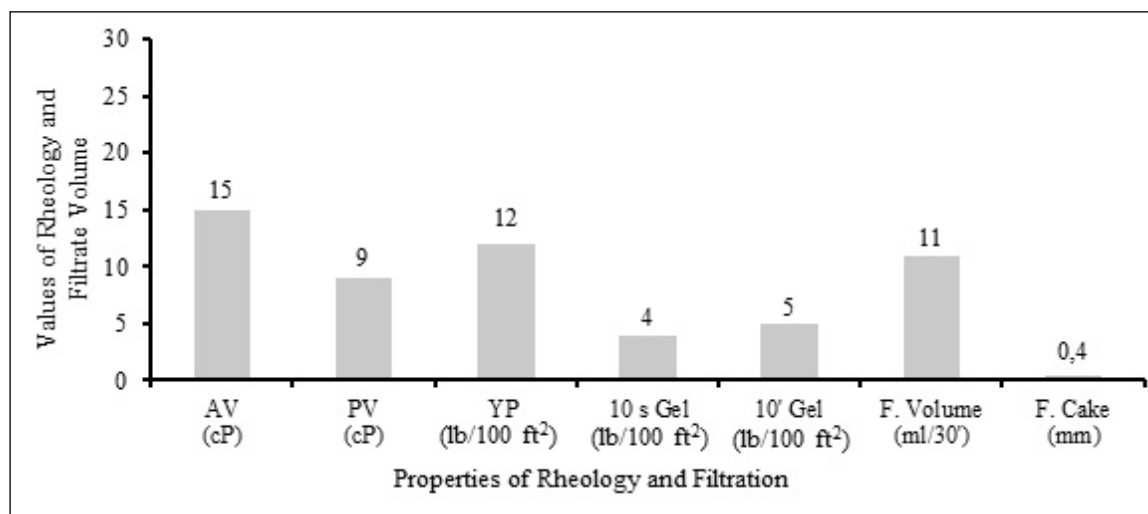


Figure 8- Rheological and filtration properties of the fourth composition containing bentonite + modified starch + xanthan gum + PHPA.

approximately twice that of the YP value (Figure 5). As PV expresses the interaction between solids within the fluid, lower PV values are generally preferred. Consequently, the relatively higher PV compared to the YP in this composition reduces its desirability for certain applications. The 10-second and 10-minute gel strength values are recorded at 2–2.5 lb/100 ft², while the fluid loss is measured at 12 cm³/30 minutes, with a filtrate cake thickness of 0.5 mm. This composition, consisting of straight polymers, is suitable for use in inactive formations.

In the second composition, consisting of LV CMC, xanthan gum, PHPA, and bentonite, the addition of xanthan gum to the system did not result in an increase in yield point (YP) or gel strength values. The plastic viscosity (PV) was observed to be twice the YP, with a fluid loss value of 13.5 cm³/30 minutes (Figure 6). The combination of straight polymers (CMC and PHPA) and the branched polymer (xanthan gum) produced results approximately the same with those of the first composition. However, due to xanthan gum's susceptibility to bacterial degradation, the first composition is considered more favourable.

In the third composition, consisting of PAC L, xanthan gum, PHPA, and bentonite, the plastic viscosity (PV) and yield point (YP) values were observed to be equal. The 10-second and 10-minute gel strength values were recorded as 3 lb/100 ft² and 5 lb/100 ft², respectively (Figure 7). The fluid loss

value was 15 cm³/30 minutes, with a filtrate cake thickness of 0.6 mm. The data obtained for this PAC-based composition indicate better rheological properties compared to the previous two compositions. Additionally, the encapsulation capability of the semi-synthetic PAC enhances the preservation of cuttings' integrity, making this formulation a potentially preferable choice over the other composition.

In the fourth composition, consisting of modified starch, xanthan gum, PHPA, and bentonite, the yield point (YP) value exceeded the plastic viscosity (PV) value. The 10-second and 10-minute gel strength values were similar, recorded at 4 lb/100 ft² and 5 lb/100 ft², respectively (Figure 8). The fluid loss value is 11 cm³/30 minutes, with a filtrate cake thickness of 0.4 mm. The higher YP value and gel strength compared to the other compositions enhance the suitability of this composition for core drilling applications. However, as modified starch and xanthan gum are susceptible to bacterial degradation, it is recommended to use this composition in alkaline environments (pH 10–10.5) and in conjunction with biocides to ensure stability.

6. Conclusions

Laboratory tests were conducted to determine the fluid compositions that provide optimal rheological and filtration properties for core drilling by varying the ratios of polymers, bentonite, or calcium carbonate. According to the results acquired for drilling.

The results indicate that incorporating bentonite or calcite for rheological improvement and water loss control is preferable to compositions consisting solely of polymers.

For bentonite-based fluids, the most effective compositions in terms of rheological and water loss properties were determined to be as bentonite + modified starch + xanthan gum + PHPA, and bentonite + PAC L + xanthan gum + PHPA.

For calcite-based fluids, the composition of modified starch + xanthan gum + PHPA + calcium carbonate indicated optimum rheological and filtration properties. Additionally, the composition of PAC L + PHPA + calcium carbonate exhibited rheological and filtration values suitable for core drilling applications.

It is recommended that the performance of these optimized compositions should be further validated through field testing under operational conditions.

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References

- Ahmad, H. M., Kamal, M. S., Mamdouh, A., Al-Harthi, M. A. 2018. Rheological and filtration properties of clay-polymer systems: Impact of polymer structure, *Applied Clay Science*, 160 (2018) 226–237.
- Ali, I., Ahmad, M., Ganat, T. 2022. Biopolymeric formulations for filtrate control applications in water-based drilling muds: A review. *Journal of Petroleum Science and Engineering* 210 (2022) 110021.
- Audibert, A., Argillier, J. F., Ladva, H. KJ., Way, P. W. 1999. Role of polymers on formation damage, *Society of Petroleum Engineers* 54767.
- Bazyar, H., Monfared, M. S. 2021. Defining the optimum sequence in addition of shale inhibitor agents in WBDF considering inhibition of swelling of cuttings, *Upstream Oil and Gas Technology* 7 (2021) 100051.
- Benchabane, A., Bekkour, K. 2006. Effect of anionic additives on the rheological behaviour of aqueous calcium montmorillonite suspensions, *Rheologica Acta*, 45, 425-434.
- Grabsch, A. F., Fawell, P. D., Davies, M. G. 2024. Flocculating fine cuttings particles suspended within partially hydrolysed polyacrylamide (PHPA) solutions used as drilling fluids in mineral exploration, *Minerals Engineering* 206 (2024) 108510.
- Gueciouer, A., Benmounah, A., Sekkiou, H., Kheribet, R., Safi, B. 2017. Valorization of KCl/PHPA system of water-based drilling fluid in presence of reactive clay: Application on Algerian field, *Applied Clay Science*, 146 (2017) 291–296.
- Güngör, N., Karaoğlu, S. 2001. Interactions of polyacrylamide polymer with bentonite in aqueous systems, *Materials Letter*, 168-175.
- Jain, R., Mahto, V., Sharma, V. P. 2015. Evaluation of polyacrylamide - grafted - polyethylene glycol/silica nanocomposite as potential additive in water based drilling mud for reactive shale formation, *Journal of Natural Gas Science and Engineering* 26 (2015) 526e537.
- Magzoub, M. I., Salehi, S., Hussein, I. A., Nasser, M. S. 2020. Loss circulation in drilling and well construction: The significance of applications of crosslinked polymers in wellbore strengthening: A review, *Journal of Petroleum Science and Engineering* 185 (2020) 106653.
- Muhammed, N. S., Olayiwola T., Elkatatny, S. 2021. A review on clay chemistry, characterization and shale inhibitors for water-based drilling fluids, *Journal of Petroleum Science and Engineering* 206 (2021) 109043.
- Plank, J. P., Hamberger, J. V. 1988. Field experience with a novel calcium-tolerant fluid-loss additive for drilling muds, *Society of Petroleum Engineers* 18372, 351-359.
- Singh, D., Ruhil, D., Khandelwal, H., Rawat, H., Aggarwal, H., Ranjan, A., Thakur, N. K. 2022. Investigation of rheological and filtration properties of water-based drilling mud using commercially available additives, *Materials Today: Proceedings* 68 (2022) 1003–1010.
- Toka, B. 2022. Mud systems applied to problematic formations in core drilling rigs, *Bulletin of Mineral Research and Exploration* 168: 67-75, Ankara.
- Toka, B., Toka, N. 2015. Preparing drilling fluid compositions for geothermal reservoirs. *Proceedings World Geothermal Congress*. Melbourne, Australia.

- Toka, B., Toka, N., Arol, A. İ., Sivrikaya, O. 2009. Ca and Ca/Na bentonitlerinin sondaj çamuru olarak kullanımı, 4. Sondaj Sempozyumu, İzmir.
- Toka, B., Arol, A. İ., Özbayoğlu, M. E. 2013. Influence of borates as an activating agent on the rheological and filtrate properties of bentonites, XV Balkan Mineral Processing Congress, Sozopol-Bulgaria, 12-16 June 2013.
- Toka, N., Tan S., Çalışkan, O., Güngör, Y., Toka, B. 2016. Sondaj çamuru araştırma - geliştirme projesi laboratuvar çalışmaları, Maden Tetkik ve Arama Genel Müdürlüğü Sondaj Dairesi, Ankara (unpublished).
- TS EN ISO 13500. 2010. Petroleum and natural gas industries. Drilling fluid materials. Specification and tests.
- Yalçın, T., Alemdar, A., Ece, I., Güngör, N., Coban, F. 2002. By particle interactions and rheological properties of bentonites +ALS suspensions, Materials Letters 53, 211–215.
- Zhao, D., Liu, H., Guo, W., Qu, L., Li, C. 2016. Effect of inorganic cations on the rheological properties of polyacrylamide/xanthan gum solution, Journal of Natural Gas Science and Engineering 31 (2016) 283e292.