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Performance Analysis of Kuçovë Clay in Drilling Mud Formulation: A Rheological Perspective

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ABSTRACT: This study examines the rheological performance of water-based drilling muds using Kuçovë clay, a locally sourced material from Albania, as an alternative to imported clays. Experiments evaluated the effects of clay concentration, weighting agents (barite), chemical additives (CMC and FCLS), and temperature on key parameters: effective viscosity (η_{ef}), plastic viscosity (η_p) and yield stress (τ_0). Results indicate that increasing clay concentration (1.09–1.30 g/cm³) elevates shear stress and rheological parameters, with a sharp rise beyond 1.20 g/cm³. Barite addition marginally increased viscosity but stabilized yield stress, highlighting its role in density enhancement rather than rheological modification. CMC additives slightly improved viscosity and yield stress, while FCLS reduced flow resistance, suggesting its utility as a thinner. Temperature increases (20–95°C) consistently reduced all rheological parameters, with FCLS accelerating this decline compared to CMC. The findings demonstrate Kuçovë clay's potential to formulate cost-effective, high-performance drilling muds tailored to Albanian oil fields, reducing reliance on imported materials. This study provides a foundation for optimizing local clay-based fluids, enhancing operational efficiency, and promoting sustainable drilling practices.

KEYWORDS: Drilling mud, Rheology, Kuçovë clay, Viscosity, Yield stress, Additives.

I. INTRODUCTION

Drilling fluids, including drilling muds, are dispersed systems (suspensions) where interfacial surface phenomena between phases significantly influence their behavior. This behavior determines key aspects such as the execution of technological functions, stability, the mechanism of reagent interactions, and the effectiveness of their chemical treatment (Riza Aleti, 2018). In most cases, when referring to the drilling fluid, we mean a mixture of water as the dispersing medium and clay as the dispersed phase.

In the pursuit of improving drilling operations, the performance of drilling fluids plays a pivotal role. Drilling mud ensures efficient wellbore operations by stabilizing the wellbore through filter cake formation, controlling formation pressure, and maintaining physicochemical balance with the formations (Riza Aleti B. C., 2005). It facilitates rock destruction at the bit, cleans the wellbore face, and transports cuttings to the surface. Additionally, it cools and lubricates the drill bit and pipes, transmits hydraulic power, suspends cuttings and weighting materials when circulation stops, supports part of the drill string's weight, and serves as a source of geological information on drilled formations and their fluids (Williamson, Spring 2013).

The physical and chemical properties of these fluids are highly influenced by their composition, with clay minerals being one of the most significant contributors. Among the various types of clays used in drilling fluids, Kuçovë clay presents a unique set of characteristics that may hold the key to advancing drilling fluid formulations in the region.

The Kuçovë oil field, located in central Albania, is known for its considerable but challenging oil reserves. While the region has a history of oil production, its specific geotechnical and fluid management challenges require innovative solutions. The use of locally sourced clays in drilling fluid formulations offers an untapped potential to enhance the efficiency and reduce the cost of drilling operations in Albanian oil fields (Fatmir Shehu, 1991). Kuçovë clay, particularly noted for its blend of illite (37.4%), kaolinite (36.4%), chlorite (21.1%) and montmorillonite (10.8%), offers a unique mineralogical profile that may enable the development of drilling fluids with tailored rheological properties to better suit the specific conditions of Albanian oil fields (Riza Aleti F. S., 1987).

In recent years, the focus has shifted toward optimizing the use of native materials to create cost-effective, high-performance drilling fluids. While clays such as bentonite have dominated the industry, local alternatives like Kuçovë clay provide an opportunity to reduce reliance on imported materials and mitigate associated costs. Furthermore, given the increasing demand for sustainable drilling practices, utilizing local resources contributes to both environmental and economic sustainability.

This study aims to demonstrate how the rheological behavior of drilling muds formulated with Kuçovë clay varies under specific laboratory conditions, considering the effects of temperature, clay concentration, weighting agents, and chemical additives. By analyzing these parameters, the research takes the first step toward assessing whether the incorporation of Kuçovë clay can enhance drilling fluid efficiency, reduce operational costs, and provide a viable alternative for drilling operations in Albania.

The paper is organized as follows: Section II provides a detailed description of the materials and equipment, including the properties of Kuçovë clay, the chemical additives used, and the apparatus employed for the preparation and characterization of the drilling mud formulations. Section III outlines the methodology, presenting the experimental procedures and conditions under which the drilling mud samples were prepared and tested. Section IV presents the experimental results, analyzing the influence of temperature, clay concentration, weighting agents, and chemical additives on the rheological behavior of the drilling muds. Finally, Section V concludes the paper by summarizing the main findings, discussing their implications for drilling operations, and suggesting potential avenues for future research.

II. MATERIALS AND EQUIPMENT

In this study, the following materials and reagents were utilized to formulate the drilling mud:

- A. Kuçovë clay (density 2g/cm^3 , powdered form): This clay will serve as the primary component in the preparation of the drilling mud, contributing to the suspension properties and rheological behavior of the fluid.
- B. Fresh water (density 1g/cm^3): Serves as the dispersing medium for the mud formulation, providing the necessary base for the clay and other additives to interact.
- C. Barite (BaSO_4 , density 4.5g/cm^3 , powdered form): Used as a weighting agent to increase the density of the drilling mud, ensuring proper hydrostatic pressure to control wellbore pressure during drilling.
- D. FCLS reagent (Ferrochrome-Lignosulfonate, powdered form): Added as a chemical additive to modify the mud's rheological properties, improving its performance in transporting cuttings and maintaining wellbore stability.
- E. CMC reagent (Carboxymethyl Cellulose, powdered form): Used as a viscosifier and stabilizer to enhance the flow properties of the drilling fluid, preventing sedimentation and promoting wellbore wall stability.

In this study, the following equipment was utilized to prepare and test the drilling mud formulations:

- A. Laboratory scale (minimum measurement of 1g) – used to measure the precise mass of materials, including clay and additives, for creating consistent drilling mud formulations.
- B. Densimeter (Mud Balancer) – used to measure the density of the drilling fluid, ensuring the appropriate balance of solid and liquid phases to meet operational requirements.
- C. FANN viscometer with 6 RPM levels (3, 5, 100, 200, 300, 600) – utilized to assess the rheological properties of the drilling mud by measuring its viscosity at different shear rates, critical for evaluating fluid behavior during drilling.
- D. Thermometer – employed to monitor the temperature of the drilling fluid, as temperature fluctuations can influence its viscosity and other rheological parameters.
- E. Heating device for drilling mud – used to control and maintain the temperature of the mud during experiments, simulating the conditions under which the mud will be used in actual drilling operations.
- F. Laboratory metal glass – used to hold the water, clay, and other additives during the preparation of drilling mud and to facilitate mixing.
- G. Mixer (Stirrer) – employed to thoroughly mix the components of the drilling mud, ensuring that the clay and additives are uniformly distributed within the water phase to form a consistent suspension.
- H. Lab glass cylinders: Used to accurately measure the volume of water added to the mixture, ensuring consistency and precision in the preparation of the drilling fluid.

III. METHODOLOGY

Experiment 1: Influence of the solid phase on the rheological behavior of drilling fluid.

To observe this influence on the rheological behavior, five solutions, each with a volume of 500 ml, were prepared consisting of water and clay according to the following recipes:

Solution 1: 455 ml of water and 90 g of clay; Solution 2: 420 ml of water and 160 g of clay;

Solution 3: 400 ml of water and 200 g of clay; Solution 4: 370 ml of water and 260 g of clay;

Solution 5: 350 ml of water and 300 g of clay;

The ingredients for each solution were measured, added to the metal glass, and then mixed for 10 minutes to achieve homogeneity. Afterward, the densities of each solution were measured using a densimeter (mud balancer). For each of these solutions, shear stress measurements were performed at six shear rate levels: 5 sec^{-1} (3 RPM), 10 sec^{-1} (6 RPM), 170 sec^{-1} (100 RPM), 340 sec^{-1} (200 RPM), 510 sec^{-1} (300 RPM), and 1020 sec^{-1} (600 RPM) using the FANN viscometer. The rheological properties will be analyzed and compared to evaluate the effect of clay concentration on the drilling mud behavior.

Experiment 2: Influence of weighting agents on the rheological properties.

To measure this influence, nine different solutions were prepared, each with a volume of 500 ml, consisting of water, clay and barite according to the following recipe:

Solution 1: 445ml of water + 55g of clay + 30g of barite; Solution 2: 420ml of water + 80g of clay + 45g of barite;

Solution 3: 400ml of water + 100g of clay + 60g of barite; Solution 4: 375ml of water + 125g of clay + 70g of barite;

Solution 5: 345ml of water + 155g of clay + 75g of barite; Solution 6: 335ml of water + 165g of clay + 80g of barite;

Solution 7: 300ml of water + 200g of clay + 90g of barite; Solution 8: 280ml of water + 220g of clay + 95g of barite;

Solution 9: 255ml of water + 245g of clay + 100 g of barite;

The same procedure as for the clay solutions was applied to these mixtures.

Experiment 3: The influence of chemical processing on the rheological behavior of water-based clay solution.

To assess this influence, a base solution (1,000 ml) was prepared using 740 ml of water and 520 g of clay, achieving a density of 1.26 g/cm^3 . The density was confirmed using a mud balancer, and its rheological parameters were recorded. The base solution was then divided into two equal parts of 500 ml each, and modifications were made as follows:

A. Modification with CMC:

Solution 1: Base solution + 0.5% CMC (5.5 g);

Solution 2: Solution 1 + additional 0.5% CMC (5.5 g);

Solution 3: Solution 2 + another 0.5% CMC (5.5 g);

B. Modification with FCLS:

Solution 4: Base solution + 0.5% FCLS (5.5 g);

Solution 5: Solution 4 + additional 0.5% FCLS (5.5 g);

Solution 6: Solution 5 + another 0.5% FCLS (5.5 g);

For each of these solutions, we follow the same procedure as in Experiment 1, using the FANN viscometer to measure shear stress at six shear rate levels: 5 sec^{-1} (3 RPM), 10 sec^{-1} (6 RPM), 170 sec^{-1} (100 RPM), 340 sec^{-1} (200 RPM), 510 sec^{-1} (300 RPM), and 1020 sec^{-1} (600 RPM). The rheological properties of these solutions will be analyzed and compared to evaluate the effect of CMC and FCLS concentrations on the drilling fluid behavior.

Experiment 4: The influence of temperature on the rheological behavior of the drilling fluid.

In this experiment, the base solution from Experiment 3, as well as Solutions 2 (base solution + 1% CMC) and 5 (base solution + 1% FCLS), will have their rheological parameters measured at different temperatures. These solutions will be heated using a controlled heating device until they reach the respective temperatures of 20°C , 35°C , 50°C , 65°C , 80°C , and 95°C . At each temperature level, their rheological parameters will be recorded to analyze the impact of temperature on the drilling fluid properties.

IV. EXPERIMENTAL RESULTS

Results of Experiment 1: Each shear stress value measured using the FANN viscometer will be denoted by the symbol Φ , with the corresponding RPM at which the measurement was taken as its subscript (e.g., Φ_{300} for 300 RPM). Since drilling fluids behave as Bingham plastic fluids (Riza Aleti B. C., 2005), the following parameters can be calculated:

Effective viscosity $\eta_{ef} = \frac{1}{2} \Phi_{600}$ (Equation 1)

Plastic viscosity $\eta_p = \Phi_{600} - \Phi_{300}$ (Equation 2)

Yield stress $\tau_0 = 4.79 * (\Phi_{300} - \mu_p)$ (Equation 3)

All these results are summarized in Table 1.

Table 1. Shear stress measurements and rheological parameters derived from Experiment 1.

Sol. Nr.	Content	RPM	3	5	100	200	300	600	Rheological parameters		
		dv/dr (sek ⁻¹)	5	10	170	340	510	1020	η_{ef} (cp)	η_p (cp)	τ_0 (din/cm ²)
		Density (g/cm ³)	Φ_3	Φ_6	Φ_{100}	Φ_{200}	Φ_{300}	Φ_{600}			
1	Water + Clay	1.09	0.8	1	1.6	2.2	2.8	5	2.5	2.2	2.874
2	Water + Clay	1.16	1	1.3	2.4	3.6	5	9	4.5	4	4.79
3	Water + Clay	1.2	1	1.4	3.8	4.8	6.8	11.5	5.75	4.7	10.059
4	Water + Clay	1.26	5.2	5.5	8.8	11.2	14.5	18.5	9.25	4	50.295
5	Water + Clay	1.3	7.5	8	11.5	16	18.5	23.5	11.75	5	64.665

The data show that as the solid phase concentration increases in the solution, shear stresses also increase, as illustrated in Table 1. Up to a density of 1.20 g/cm³, the shear stress rises gradually. Beyond this point, there is a sudden increase in shear stress. The rheological parameters of the solutions are shown in Figure 1, where it is evident that as the solid phase (solution density) increases, the clay-based solution's plastic viscosity, effective viscosity, and yield stress also rise.

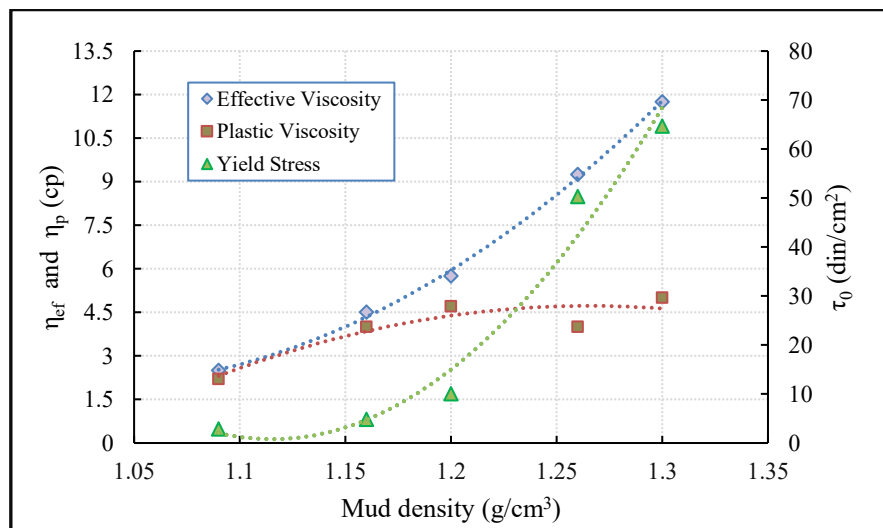


Figure 1. Relationship between solid phase concentration and rheological parameters in clay-based solution.

Results of Experiment 2: As seen from the Table 2, the addition of weighting material causes only a slight and gradual increase in the rheological parameters of the drilling mud. This indicates that the weighting agent has a minimal impact on the rheological behavior of the water-based clay mud. Compared to the influence of the solid phase on the overall behavior of the drilling mud, the effect of the weighting agent is significantly smaller. Additionally, the effective

viscosity of the weighted mud is lower than that of the unweighted mud, and the rate of change in effective viscosity is more pronounced in the unweighted mud than in the weighted one.

The shear stress values across different RPMs follow a similar trend, increasing with density but showing a more stable progression compared to yield stress, indicating that barite primarily enhances viscosity rather than gel strength (Figure 2).

Table 2. Shear stress measurements and rheological parameters derived from Experiment 2.

Sol. Nr.	Content	RPM	3	5	100	200	300	600	Rheological parameters		
		dv/dr (sek ⁻¹)	5	10	170	340	510	1020	η_{ef} (cp)	η_p (cp)	τ_0 (din/cm ²)
		Density (g/cm ³)	Φ_3	Φ_6	Φ_{100}	Φ_{200}	Φ_{300}	Φ_{600}			
1	Water + Clay + Barite	1.11	0.9	1	1.8	2.4	3	5.2	2.6	2.2	1.916
2	Water + Clay + Barite	1.16	1	1.2	2.2	3.4	4.8	8.2	4.1	3.4	3.353
3	Water + Clay + Barite	1.2	1	1.3	3.6	4.6	6.6	10.5	5.25	3.9	6.466
4	Water + Clay + Barite	1.25	1.1	1.5	5	6	9.4	14	7	4.6	11.496
5	Water + Clay + Barite	1.31	1.2	1.7	5.2	6.5	10.4	15	7.5	4.6	13.891
6	Water + Clay + Barite	1.33	1.5	1.9	5.5	6.8	10.5	15.9	7.95	5.4	12.214
7	Water + Clay + Barite	1.4	1.5	1.9	6	7.5	10.8	17.9	8.95	7.1	8.861
8	Water + Clay + Barite	1.44	1.9	3	6.5	8	11	19.5	9.75	8.5	5.987
9	Water + Clay + Barite	1.49	2.1	3	7.5	9	12	21	10.5	9	7.185

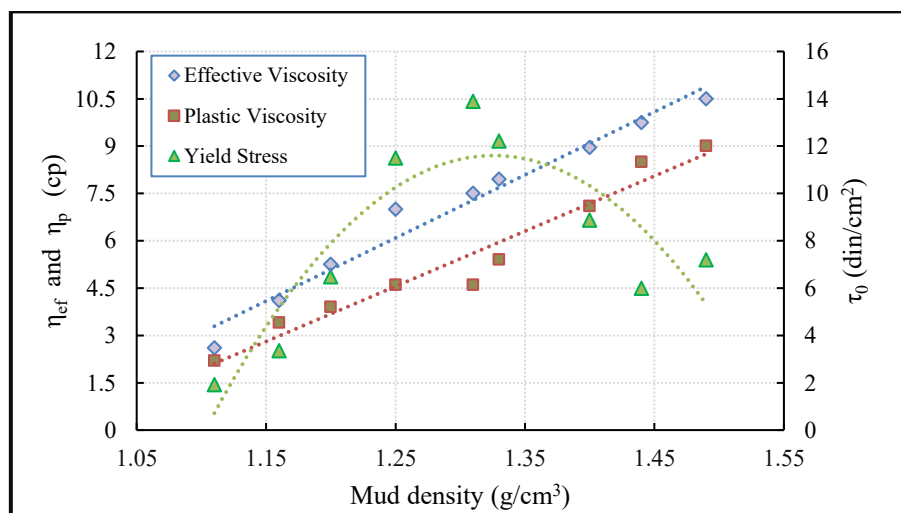


Figure 2. Relationship between weighting agent concentration and rheological parameters in drilling mud.

Results of Experiment 3: As seen from Table 3 and Figure 3(a), the addition of CMC to the drilling mud results in a slight and gradual increase in its rheological parameters. This means that CMC slightly increases the plastic viscosity,

effective viscosity, and dynamic yield stress. On the other hand, the chemical treatment with FCLS leads to a reduction in the rheological parameters of the water-based clay mud. Figure 3(b) shows that the addition of FCLS decreases the plastic viscosity, effective viscosity, and yield stress, making the mud less resistant to flow.

Table 3. Shear stress measurements and rheological parameters derived from Experiment 3.

Sol. Nr.	Content	RPM	3	5	100	200	300	600	Rheological parameters		
		dv/dr (sek ⁻¹)	5	10	170	340	510	1020	η_{ef} (cp)	η_p (cp)	τ_0 (din/cm ²)
		Density (g/cm ³)	Φ_3	Φ_6	Φ_{100}	Φ_{200}	Φ_{300}	Φ_{600}			
1	Water + Clay	1.26	5.2	5.5	5.8	11.2	14.5	18.5	9.25	4	25.147
2	Sol.1+0.5% CMC	1.26	5.3	5.8	9	11.5	15	19	9.5	4	26.345
3	Sol.2+0.5% CMC	1.26	5.5	6	9.5	12	15.5	19.8	9.9	4.3	26.824
4	Sol.3+0.5% CMC	1.26	5.6	6.2	9.8	12.8	16	20.6	10.3	4.6	27.303
5	Sol.1+0.5% FCLS	1.26	5.1	5.3	8	11	14	17.8	8.9	3.8	24.429
6	Sol.5+0.5% FCLS	1.26	5	5.1	7.5	10.6	13.4	17	8.5	3.6	23.471
7	Sol.6+0.5% FCLS	1.26	4.8	5	7	9.8	12.8	15.8	7.9	3	23.471

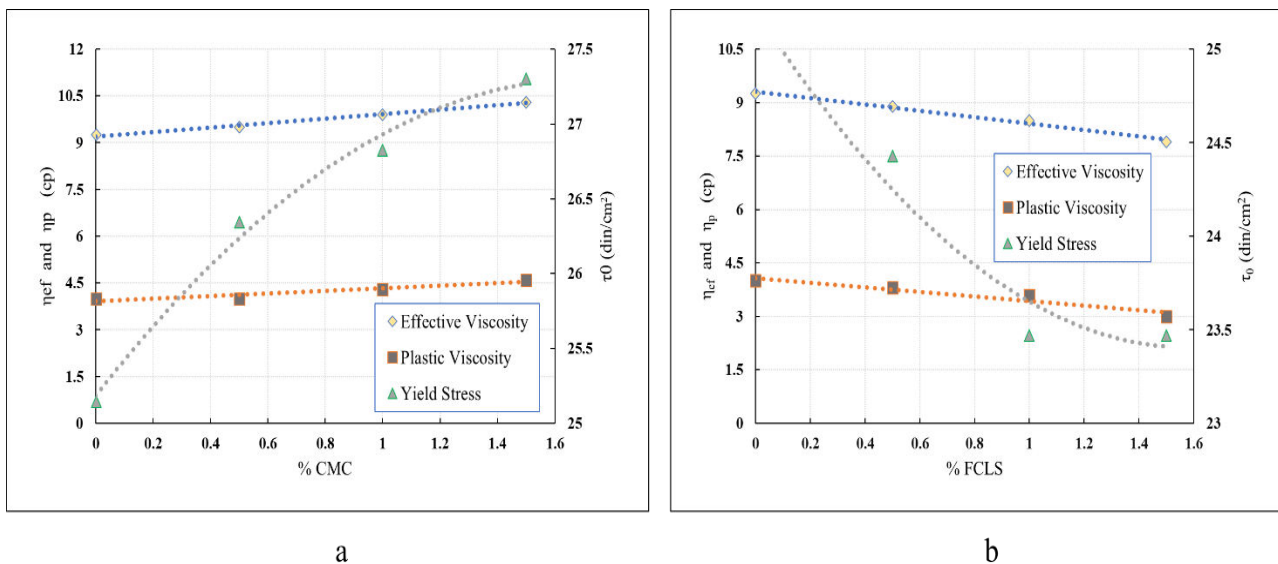


Figure 3. Relationship between (a): CMC / (b) FCLS concentration and rheological parameters in drilling mud.

Results of Experiment 4: As seen in Table 4, increasing the temperature generally leads to a reduction in the rheological parameters such as effective viscosity (η_{ef}), plastic viscosity (η_p), and yield stress (τ_0) for all three solutions. In the water + clay mixture (Sol. 1), this trend is consistent, with the rheological parameters decreasing as temperature increases, particularly at higher temperatures (e.g., 95°C), where the yield stress and viscosity values are notably lower than at 20°C. When 1% FCLS is added (Sol. 2), the reduction in rheological properties is more pronounced compared to the untreated mixture, suggesting that FCLS accelerates the decline in viscosity and yield stress as the temperature rises. This indicates that FCLS may have a thinning or stabilizing effect on the solution under heat. On the other hand,

the solution with 1% CMC (Sol. 3) also follows the trend of decreasing rheological parameters with increasing temperature but at a slower rate compared to the FCLS-treated solution. This suggests that CMC may offer some stabilization to the mixture, preventing a sharp decline in rheological properties despite the rising temperature. When comparing all three solutions, it is evident that both FCLS and CMC additives alter the rheological behavior of the water + clay mixture. At 20°C, the CMC-treated solution shows the highest rheological values, while the FCLS-treated solution demonstrates a more moderate viscosity and yield stress. As the temperature increases, the difference becomes more pronounced, with the FCLS-treated solution exhibiting the greatest reduction in rheological parameters (Figures 4 and 5).

Table 4. Shear stress measurements and rheological parameters derived from Experiment 4.

Sol. Nr.	Content	RPM	3	5	100	200	300	600	Rheological parameters		
		dv/dr (sek ⁻¹)	5	10	170	340	510	1020	η _{ef} (cp)	η _p (cp)	τ ₀ (din/cm ²)
		Temperature (°C)	Φ ₃	Φ ₆	Φ ₁₀₀	Φ ₂₀₀	Φ ₃₀₀	Φ ₆₀₀			
1	Water + Clay	20	5.2	5.5	8.8	11.2	14.5	18.5	9.25	4	25.148
		35	5.1	5.4	8.6	11	14.1	18	9	3.9	24.429
		50	5	5.2	8	10	13.6	17.4	8.7	3.8	23.471
		65	4.7	5.1	7.6	9	13.2	16.7	8.35	3.5	23.232
		80	4.5	5	7	8.8	12.8	16.2	8.1	3.4	22.513
		95	4	4.8	6.8	9	12.4	15.37	7.685	2.97	22.585
2	Sol.1+1% FCLS	20	5	5.1	7.5	10.6	13.4	17	8.5	3.6	23.471
		35	4.8	5	7	9.2	12.6	16	8	3.4	22.034
		50	4.6	4.8	6.8	8.6	11.5	14.8	7.4	3.3	19.639
		65	4	4.5	6.5	8	11	14.2	7.1	3.2	18.681
		80	3.6	4	6	7.6	10.8	14	7	3.2	18.202
		95	3	3.4	5.8	7	10	13	6.5	3	16.765
3	Sol.1+1% CMC	20	5.5	6	9.5	12	15.5	19.8	9.9	4.3	26.824
		35	5.2	5.8	9	9	15	19	9.5	4	26.345
		50	4.8	5.2	8.6	8.6	14.5	18.5	9.25	4	25.148
		65	4.2	5	8.2	8.2	14	17.9	8.95	3.9	24.190
		80	4	4.8	8	8	13.6	17.4	8.7	3.8	23.471
		95	3.8	4.2	7.6	7.6	13	16.6	8.3	3.6	22.513

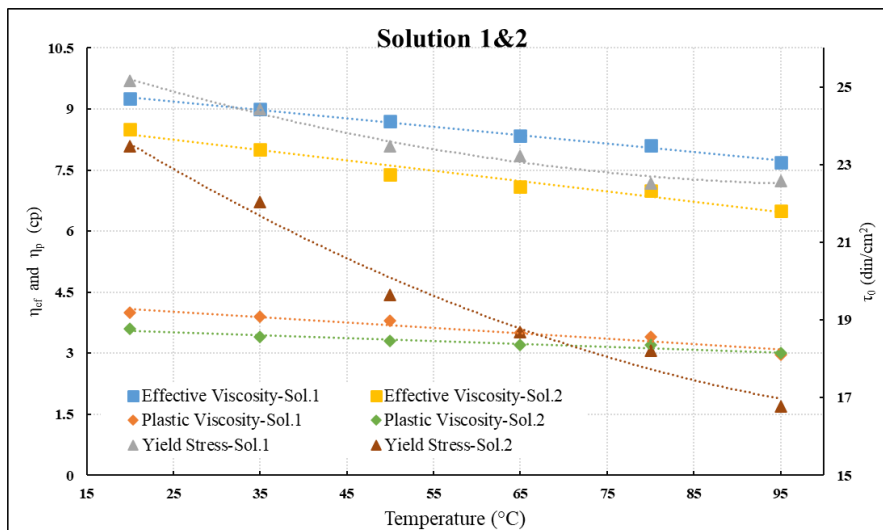


Figure 4. Relationship between temperature and rheological parameters Solutions 1 and 2.

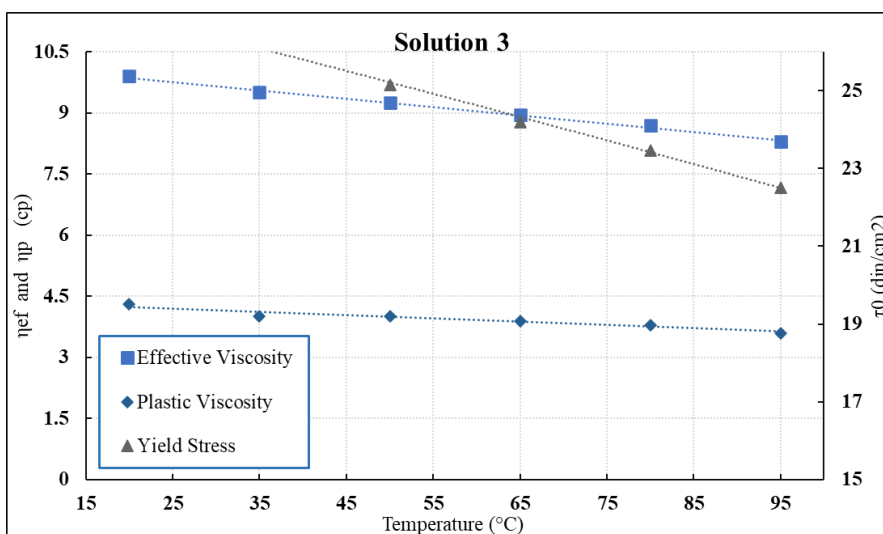


Figure 5. Relationship between temperature and rheological parameters Solution 3.

V. CONCLUSIONS

This study comprehensively analyzed the rheological behavior of water-based drilling muds formulated with Kuçovë clay, a locally abundant material in Albania. Key findings reveal that increasing clay concentration (up to 1.30 g/cm³) significantly enhances effective viscosity, plastic viscosity, and yield stress, with a pronounced threshold effect at 1.20 g/cm³. Barite, as a weighting agent, exhibited minimal impact on rheological properties, underscoring its primary role in density adjustment rather than flow behavior modification. Chemical additives demonstrated divergent effects: CMC moderately improved viscosity and stability, while FCLS reduced flow resistance, making it suitable for thinning overly viscous muds. Temperature elevation universally degraded rheological parameters, with FCLS exacerbating this trend compared to CMC.

These results highlight Kuçovë clay's suitability as a sustainable, cost-effective alternative to imported clays like bentonite in Albanian drilling operations. By tailoring clay concentration and additive ratios, operators can optimize mud performance for specific wellbore conditions, reducing costs and enhancing efficiency. Future research should

explore synergies between Kuçovë clay and other additives, long-term stability under high-pressure conditions, and field trials to validate laboratory findings. Additionally, investigating environmental impacts of local clay utilization could further align this approach with global sustainability goals. This work contributes to advancing regional energy independence and fostering environmentally conscious drilling practices.

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