

Effects of Ageing and Temperature on the Rheological Properties of Water-Based Mud Formulated With Non-Synthetic Polymers and Additives

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ABSTRACT

Rheological behaviour of drilling fluids plays a critical role in effective hole cleaning, wellbore stability, and overall drilling performance during natural oil and gas exploration. As drilling depth increases, downhole temperature rises, which directly alters the properties of the drilling fluid and consequently reduces its performance efficiency. This issue becomes particularly significant when the drilling fluid is formulated with non-synthetic additives, as these materials are more susceptible to thermal degradation. This study therefore investigates the combined effects of temperature and ageing time on the rheological properties of a water based drilling fluid formulated with non-synthetic additives. Rheological parameters including plastic viscosity, yield point, apparent viscosity, and gel strength were measured using a rotational viscometer over at 30 50, 80 and 110°C respectively to mimic the surface and downhole conditions. Ageing tests were conducted under static conditions for 24, 48 and 72 hours to simulate prolonged circulation and downhole residence time. Results indicate that increasing temperature leads to a significant reduction in viscosity and yield point due to thermal thinning and weakened interparticle interactions. Conversely, ageing was observed to promote structural buildup in the fluid, resulting in increased gel strength and, in some cases, partial recovery of viscosity. The combined influence of temperature and ageing reveals competing mechanisms that govern drilling fluid performance under realistic operating conditions. These findings provide valuable insight for optimizing drilling fluid formulation and managing rheological stability in high temperature and extended drilling operations.

1. INTRODUCTION

The rheological behaviour of drilling fluids is a critical determinant of drilling efficiency, wellbore stability, and cuttings transport, particularly in modern oil and gas operations that increasingly target deep and ultra-deep formations characterized by harsh downhole environments. Water-based drilling fluids are widely preferred due to their cost-effectiveness and environmental acceptability; however, their performance is highly sensitive to variations in temperature, pressure, and ageing conditions encountered during drilling operations. Elevated temperatures and extended ageing periods can significantly alter key rheological parameters such as plastic viscosity, yield point, and gel strength through thermal degradation of additives, physicochemical alteration of clay particles, and changes in intermolecular interactions between additives

(Quitian-Ardila *et al.*, 2024). Experimental studies have demonstrated that increasing temperature and ageing time generally lead to reductions in viscosity and yield point, while producing complex and sometimes non-linear effects on gel strength, which subsequently decrease hole cleaning efficiency and suspension capacity of the drilling fluids (Abdullah *et al.*, 2024; Yang *et al.*, 2024).

Several studies have investigated strategies to enhance the thermal and ageing stability of water-based drilling fluid (Zhu & Zheng, 2021) systems especially using synthetic and non-synthetic polymer additives. Quitian-Ardila *et al.* (2024) reported that increasing xanthan gum concentration improves both rheological performance and thermal stability due to enhanced network structuring and resistance to degradation. Similarly, Abdullah *et al.* (2024) demonstrated that nanocomposite additives such as polyethyleneimine-grafted graphene oxide significantly improve plastic viscosity and yield point even at elevated temperatures up to 160 °C, highlighting the importance of additive interaction with clay particles in maintaining rheological integrity. Furthermore, Sun *et al.* (2025) emphasized that temperature has a strong and continuous influence on rheological parameters across a wide range of pressure–temperature conditions, necessitating accurate modelling and characterization for reliable fluid performance prediction (Abdullah *et al.*, 2024).

In recent years, there has been increasing interest in the development of environmental friendly, non-synthetic additives particularly biopolymers to improve drilling fluid performance under thermal and ageing stresses (Zhu & Zheng, 2021; Ali *et al.*, 2022; Yang *et al.*, 2024). Hadadi *et al.* (2024) investigated biopolymers such as pectin and Astragalus gum and found that these materials significantly enhance viscosity, yield point, and thermal stability while reducing filtration loss, with improved resistance to high-temperature degradation compared to conventional systems. In a related study, Ghazali *et al.* (2025) introduced a tannin-based biopolymer deflocculant that maintained desirable rheological properties at temperatures up to 150 °C, demonstrating the effectiveness of bio-derived additives in high-temperature environments. These findings align with earlier experimental observations that the incorporation of natural polymers enhances the viscoelastic structure of drilling fluids and improves their resistance to thermal thinning and ageing effects.

Despite these advancements, gaps remain in understanding the combined influence of ageing and temperature on water-based drilling fluids formulated exclusively with non-synthetic additives and Nigerian clays particularly under prolonged static and dynamic downhole conditions. Previous investigations ((Anthony *et al.*, 2020; Arinkoola *et al.*, 2021; Arinkoola *et al.*, 2022) on Nigerian clays for drilling fluids applications have primarily focused on rheological behaviour and viscosity changes under limited conditions. There is a notable lack of studies that evaluated rheological properties as they respond to elevated temperature and ageing under realistic downhole conditions. This absence of integrated thermal and rheological analysis under prolonged static and dynamic environments limits the understanding of their practical applicability in high-temperature drilling operations. Therefore, a systematic investigation into the effects of ageing and temperature on the rheological properties of water-based drilling fluids formulated with Nigerian clay and non-synthetic additives is essential to optimize fluid design, improve operational reliability, and support the transition toward more sustainable drilling practices.

2. METHODOLOGY

2.1 Materials

Clay samples were obtained from Ubakala (7° 36′ N/5° 86′ E) and Uturu (5° 78′ N / 7° 43′ E), both towns located in Umuahia South Local Government Area and Isuikwuato Local Government Area, of Abia State Nigeria. Ubakala and Uturu experience tropical wet and dry climate which promotes intense chemical weathering, hydrolysis and clay mineral formation. The clay deposits of Ubakala are primarily associated with tertiary coastal plain sands of the Niger Delta Basin, while those in Uturu are linked to cretaceous shale-rich formations of the Anambra Basin (Allison *et al.*, 2019). Despite differences in geological origin,

both deposits are economically significant and suitable for various industrial applications, including drilling fluid formulation, ceramics, adsorbent and construction materials.

Non-synthetic additives including cassava starch, breadfruit starch, corn fibre, bush mango seed, and Nigerian barite were sourced locally. The natural polymers were initially cleaned to remove adhering impurities. Thereafter, they were processed following established procedures reported in the literature (Jimoh *et al.*, 2021; Arinkoola *et al.*, 2022). The processing involved thorough washing with distilled water, followed by drying at controlled temperatures to prevent thermal degradation of the polymeric constituents. The dried materials were subsequently subjected to mechanical size reduction using a high energy ball milling apparatus and sieved to obtain fine powders of uniform particle size suitable for drilling fluid formulation.

For the starch-based materials (cassava and breadfruit starch), a pre-gelatinization step was incorporated to enhance their functional performance in the drilling fluid system. The process involved dispersing the starch in water and heating the suspension to temperatures above the gelatinization point. At this stage, the starch granules swell, rupture, and undergo molecular reorganization, resulting in improved solubility, hydration capacity, and viscosifying properties. Gelatinized starch was then dried at 80°C and further milled to produce a free-flowing pre-gelatinized starch powder. This modification is known to improve the interaction between the biopolymer and the aqueous phase of the drilling fluid, thereby enhancing rheological and filtration properties.

Although no specific standard exists for the extraction, modification, and preparation of these natural polymers, the adopted methodology is consistent with widely reported scientific practices for biopolymer processing and utilization in drilling fluid applications. Nigerian barite was processed and characterized in accordance with American Petroleum Institute recommended practice (API Spec 13A) to ensure compliance with standard requirements for drilling fluid weighting materials and to confirm its suitability for use in the formulated systems. Uturu clay sample was used without modification while Ubakala clay was modified 3.3 M Na₂CO₃. This decision was informed based on a previous research by Jimoh *et al.* (2021) where modification of Uturu clay with NaOH, KOH, Na₂CO₃ and NaHCO₃ did not enhance the rheology of the spud mud.

2.2 Clay and Additive Characterization

Thermogravimetric Analysis (TGA) was performed using a PerkinElmer TGA 4000 instrument to investigate thermal stability and compositional changes of clay samples and additives. Samples were analyzed under a nitrogen atmosphere at a controlled heating rate of 5°C/min, with mass loss continuously recorded as a function of temperature. This allowed identification of distinct thermal events such as moisture release, starch decomposition, fibre degradation, dehydroxylation of clay minerals, and the inert thermal behaviour of barite. Complementarily, Differential Scanning Calorimetry (DSC) was conducted using the same equipment under the same heating conditions to measure heat flow associated with these transitions, providing insight into endothermic processes such as dehydration and exothermic reactions such as organic additive decomposition. Both techniques offered a comprehensive understanding of the thermal behaviour of each material, linking observed mass changes to corresponding heat flow events and thereby clarifying their distinct physicochemical characteristics.

2.3 Drilling Fluid Formulation and Characterization

Drilling fluids were formulated using processed additives and clay samples following the method of Arinkoola *et al.* (2021). Rheological properties, including viscosity and yield point, were measured at room temperature using an Anton Paar Rheolab QC rheometer according to the American Petroleum Institute Recommended Practice (API RP 13B). The formulated fluid was allowed to age for 24 hours to ensure proper hydration before viscosity measurements were taken. Rheological characteristics and flow behaviour were determined from experimental data using standard equations. The drilling fluid samples were further

aged for 24, 48, and 72 hours. Each ageing period was conducted at room temperature as well as at elevated temperatures of 50, 80, and 110 °C to simulate subsurface (downhole) conditions. Rheogram plots were constructed for drilling fluids at different temperatures.

Drilling fluids were prepared from processed additives and clay samples in accordance with the procedure described by Arinkoola *et al.* (2021). The rheological properties, including viscosity and yield point, were measured at room temperature using an Anton Paar Rheolab QC rheometer. Prior to measurement, the formulated fluids were aged for 24 hours to allow adequate hydration of the clay and full development of the fluid structure. Rheological parameters were subsequently derived from the experimental data using standard equations. To evaluate the influence of ageing and temperature on fluid performance, the samples were further aged for 48, and 72 hours at room temperature and at elevated temperatures of 50, 80, and 110°C, simulating downhole conditions. Rheograms (shear stress versus shear rate plots) were generated at each temperature to characterize the flow behaviour of the drilling fluids, determine their rheological model (Newtonian or non-Newtonian), and assess the effects of temperature and ageing on viscosity, yield stress, and structural stability.

3. RESULTS AND DISCUSSION

3.1 Thermogravimetric Analysis of Clay Samples

The TGA provides valuable information that can be used to select materials for certain end-use applications, predict product performance and improve product quality. It measures the amount and rate of change in the weight of a material as a function of temperature or time in a controlled atmosphere. Measurements are used primarily to determine the composition of materials and to predict their thermal stability at temperatures up to 1200°C. Results obtained for TGA and heat flow DSC for treated and untreated clay samples are shown in Figure 1 (a and b). Weight loss (%) and heat flow (mW) were plotted as a function of temperature. Major compositions of samples were categorized as moisture, volatiles and fixed carbon. DSC plots show three major endothermic peaks in all the clay samples. The first peak around 100 °C is due to evaporation of absorbed water, second peak at ≈ 530 °C (Figure 1b) and peak at ≈ 505 °C is due to dehydroxylation of structural OH unit of Kaoline and illite.

Similar results were reported by Derkowski & Kuligiewicz (2022) while studying the temperature phase evolution of Bolivian clay. The third endothermic at 700 °C can be attributed to hydroxylation of octahedral layer of the montmorillonite clay samples by Derkowski & Kuligiewicz (2022). The rate of dehydroxylation of montmorillonite and the temperature at the peaks depend on the nature of exchangeable cation and the presence of iron ions in the mineral structure (Adesina *et al.*, 2025). The final exothermic peak at 900°C indicated the final breakdown of the montmorillonite. This result is also in agreement with the studies of Grim and Rowland, (1942) and Early *et al.* (1953). DSC results confirmed the presence of mixed layered mineral containing kaolinite, illite, and montmorillonite as indicated by the XRD results.

The results of weight loss and temperature that correspond to specific weight losses are reported in Table 1. Before the onset of degradation (step 1), Uturu clay lost 0.928 % at 106.17°C, Ubakala clay loses 5.180% of its weight before treatment and 5.981% after treatment at 898.36°C. Weight loss at this step is attributed to desorption of absorbed water and dehydration of hydrated cation such as Na^+ and K^+ in the interlayer. A result similar to that of Ubalaka clay has been reported by Polcowñuk Iriarte *et al.* (2025) for montmorillonite with total weight loss for adsorption water clay of 5.435% at 135.5°C. Dhar & Bishnoi (2024) stated that water from clay minerals is liberated at different temperatures and in varying amounts, depending on the clay mineral, the exchangeable cations and the experimental conditions. Higher adsorption water weight loss for Ubakala clay may be attributed to the presence of high percentage of montmorillonite in the clay sample. Montmorillonite is known to have high water adsorption capacity as a result of water molecule entering the interlayer space of the mineral (Belhocine *et al.*, 2025).

The second weight loss step in the TGA is attributed to loss of structural hydroxyl group from within the clay. Weight loss for untreated Uturu clay was 13.223% at 706.20°C. The percentage weight loss obtained for untreated and treated Ubakala clay are 18.563 and 17.785% respectively at 712.11°C. Obviously, the weight loss due to dehydroxylation after clay treatment is smaller than the one obtained before treatment. This improved thermal stability observed can be explained by the isomorphous substitution of the tetrahedral cation (Si^{4+}) by octahedral cation (Al^{3+}) and Mg^{2+} , Fe^{2+} , or Ca^{2+} which generates pools of negative charge in clay mineral lattice. The negative charges are compensated for by interlayer cations such as Na^+ and K^+ (Belhocine *et al.*, 2025). Treatment with NaHCO_3 (Ubakala) further increases the surface charge by replacing divalent cations such Mg^{2+} or Fe^{2+} with monovalent cations, Na^+ followed by subsequent hydration and hydroxylation of interlayer cations. Up to five water molecules may be bonded to a single exchangeable Na^+ forming a stronger intermolecular hydrogen bonding that requires more energy before degradation or decomposition hence the improved thermal stability.

The third weight loss was related to dehydroxylation of OH units in the tetrahedral layer and responsible for possible breakdown of the clay crystal structure. Untreated Uturu clay recorded 1.903 % weight loss at 893.88°C. Untreated and treated Ubakala clay lost 2.024% and 1.891% at 898.36 respectively. (Dhar & Bishnoi, 2024) reported similar results for the thermal analysis of smectite-illite clay minerals. However, the result is not in agreement with the reports of Escalera *et al.* (2014) who reported a minor weight loss (<0.5%) at 930 °C. The difference in the result could be attributed to the variation in mineral composition of the clay sample considered in this study. Generally, all the clay samples considered exhibited good thermal stability before treatment, improved thermal stability was observed after treatment in Ubakala clay. Understanding and improving the thermal sensitivity of clay minerals for drilling fluid purposes is very essential as drilling fluid encounter high temperature while drilling for crude oil and gas exploration.

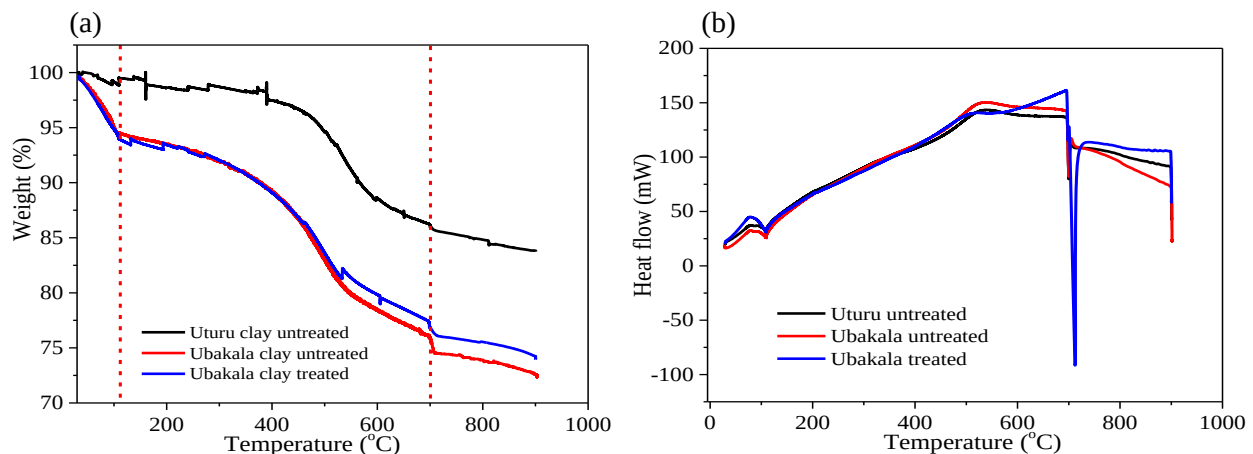


Figure 1: TGA and DSC of untreated and treated clay samples (1a) TGA (1b) DSC

Table 1: TGA results of untreated and selected treated clay samples

Sample		Uturu	Ubakala		Description
		Untreated	Untreated	Treated	
Step 1	WL (%)	0.928	5.180	5.981	Dehydration (adsorption water/water adsorbed by metal cation)
	Temp (°C)	106.17	110.74	110.74	
Step 2	WL (%)	13.223	18.563	17.785	Dehydroxylation (Structural OH units)
	Temp (°C)	706.20	712.11	712.11	
Step 3	WL (%)	1.903	2.024	1.891	Dehydroxylation of OH unit of tetrahedral layer /breakdown of montmorillonite crystal structure
	Temp (°C)	893.88	898.36	898.36	

3.2 Thermogravimetric Analysis of Additives

A TGA measures the amount and rate of change in mass of a sample as a function of temperature in a controlled environment. High temperature at the bottom of the well tends to reduce drilling fluid viscosity and density, thereby affecting the ability of the drilling fluid (DF) to effectively carry out its functions during drilling operation. To this end, it is therefore important to study the degradation and mode of decomposition of additives under the influence of heat. TGA plots in Figure 2a show the percentage weight loss of the additives as function of temperature under nitrogen gas at $20\text{ }^{\circ}\text{Cmin}^{-1}$. TG and the corresponding heat flow curve (Figure 2b) for barite samples were observed to have several weight loss steps, these steps were grouped into three major mass loss steps.

The first step ends at 112.25°C ; the second step ends at 701.01°C while the third step ends at 898.74°C . Corresponding weight loss for each step was estimated to be 1.332, 3.415 and 1.724% respectively. Weight loss for barite at these three stages may be attributed to loss of water, calcium carbonate decomposition and barium sulphate decomposition respectively. Barite used in this study can be said to have better thermal stability compared to the one reported by Nava *et al.* (2017) where the first stage starts at 73.5°C and ends at 230°C ; the second stage starts at 653°C and ends to 778°C , while the third stage occurs at 1359.4°C and ends at 1641°C . The mass loss estimated for the three stages is 6, 8 and 54%, respectively. The thermal degradation (TGA) and the corresponding heat flow curves (DSC) for the degradation process of CS, BFS, BMS and CF are shown in Figure 2 (a and b).

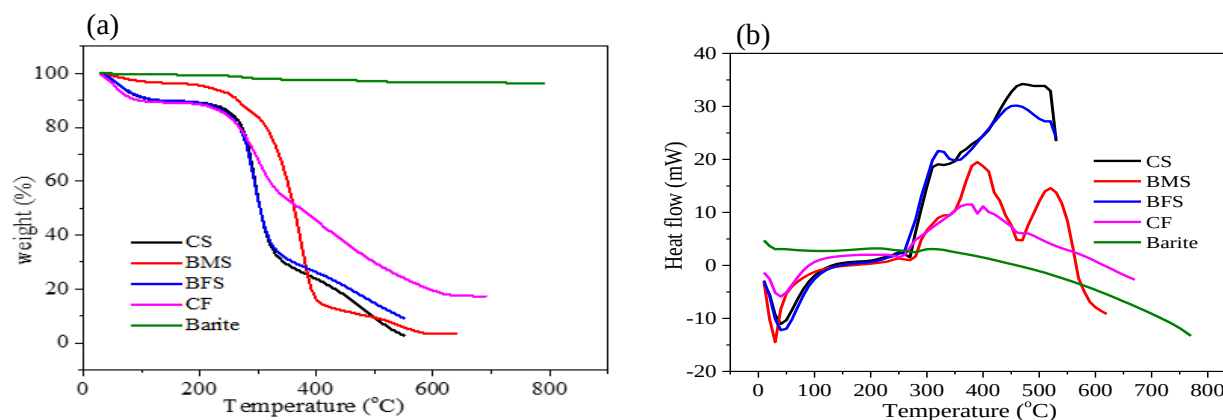


Figure 2: TGA and DSC of additives

Percentage weight loss and suggested types of reactions during heating are summarized in Table 2. Three distinct major weight loss steps were observed in the additives. The first degradation step involved weight loss of 9.165, 8.853, 2.838 and 7.083% at corresponding temperature of 106.75, 105.39, 103.91 and 108.80°C for CS, BFS, BMS and CF respectively. Weight loss at this step for all the additives is essentially due to moisture loss (dehydration). This result is in agreements with studies of (Lo Dico *et al.*, 2024). The second weight loss step involves the release of volatile matter in the samples. This step is the main thermal degradation step due to high level of weight loss. Weight loss at this stage was 77.464, 76.443, 92.193 and 75.808 at 703.09 , 703.24 , 697.81 and 702.71°C for CS, BFS, BMS and CF respectively. Degradation at this stage corresponds to degradation of starch content (amylase and amylopectin) in case of starch particles (Mano *et al.*, 2003) and degradation of hemicelluloses, cellulose and lignin for fibre (Apaydin Varol & Mutlu, 2023).

Third weight loss step ended at 743.95 , 746.61 , 732.17 and 746.70°C with corresponding weight loss of 12.789, 13.773, 4.373 and 15.861% for Cs, BFs, BMS and CF respectively. Comparatively, it was observed that BMS losses lesser weight in the first and third thermal degradation steps. This can be attributed to the lipid-polymeric components of the seed. Due to the lipid content, BMS is expected to have less moisture

content. Ionita *et al.* (2023) reported that melting point of lipid content and thermal degradation of polymeric content of BMS to be 40.26 and 232.5°C. It is therefore expected to loose more volatile matter in the temperature range considered for TGA in this study. Apaydin Varol & Mutlu (2023) attributed the third weight loss step to oxidation of organic matter which forms carbon.

As shown on the TG curves, thermal decomposition of CS, BFS, BMS and CF started at 295, 298, 264 and 283°C respectively. This observation is in close agreement with the study of (de Carvalho *et al.*, 2023) who reported that thermal reaction of starch starts around 300°C. Based on the TGA, it can be concluded that the additives are suitable for drilling fluid formulation due to the high temperature encountered while drilling for natural oil and gas exploration. Akpabio *et al.* (2013) reported the highest temperature encountered in the Niger-delta wells to be 122°C at a depth of 8000 ft which is still far below the degradation temperature of the additives considered in this study.

Table 2: Summary of TG and DSC of the additives

	Sample	CS	BFS	BMS	CF	Description
Step 1	Weight loss (%)	9.165	8.853	2.838	7.083	Dehydration
	Temp. (°C)	106.75	105.39	103.91	108.80	
Step 2	Weight loss (%)	77.464	76.443	92.193	75.808	Degradation of components (amylase, amylopectin, hemicelluloses, cellulose, lignin)
	Temp. (°C)	703.09	703.24	697.81	702.71	
Step 3	Weight loss (%)	12.789	13.773	4.373	15.861	Oxidation of organic matter, decomposition of lignin
	Temp (°C)	743.95	746.61	732.17	746.70	

3.3 Effect of Ageing on Rheological Properties

Drilling fluids are time-dependent and exhibits visco-elastic behaviour (Uwaezuoke, 2022). Due to logistics and technical issues, drilling engineers may have reasons to suspend the drilling process for specified period. During this period, the drilling fluid is said to age. Ageing is the process whereby a drilling fluid that has been previously subjected to shear is allowed to fully develop its rheological and filtration properties. In this section, drilling fluids were subjected to static ageing to determine the long-term stability of the DF. This is important because inability to maintain the DF properties during the inactive period could result in challenges such as blow out, formation damage and may subsequently lead to total abandonment of the well (Abdullah *et al.*, 2024). Rheological properties including gel strength (GS) for the 2 clay samples immediately after mixing, 24 hrs, 48 hrs and 72 hrs are presented in Table 3. Viscosity at 600 rpm immediately after mixing for Uturu clay mud was 26.62 cp. Viscosity increases to 28.91 cp after 24 hrs and 48 hours static ageing. A percentage decrease of 11.21% (25.67 cp) was recorded after 72 hrs of static ageing. Viscosities at 600 rpm after mixing, 24, 48 and 72 hrs for drilling fluid developed using Ubakala clay were 27.01, 28.98, 26.24, 23.43 cp respectively.

Increase in viscosity after 24 hrs can be attributed to the fact that the DF was fully hydrated and has developed its rheological properties during this period. This also explains the low PV values obtained after mixing. Qitian-Ardila *et al.* (2024) reported that internal gel structure of drilling fluid will be fully developed only after proper hydration. After mixing, the PV was found to be very low (3.38 cp), PV increases (8.91 cp) after ageing for 24 hrs and remained almost constant at 48 and 72 hours for DF developed using Uturu clay. PV for drilling fluid developed using Ubakala clay after mixing, 24, 48 and 72 hrs are 3.01, 9.67, 6.70 and 6.77 cp respectively. YP decreased (19.86, 11.09, 9.34, 8.81 lb/100ft²) with increasing ageing time for DF developed using Uturu clay. The effect of static ageing on YP for drilling fluid developed using Ubakala clay was not too orderly.

Gel formation when drilling fluid is at rest is very important in order to suspend drill cutting and prevent it from settling (Quitian-Ardila *et al.*, 2025). It is the shear stress of the drilling fluid measured at low shear rate when the drilling fluid is static for a period of time (Alsabaa *et al.*, 2022). Gel strength at 10 seconds and 10 mins according to the standard API method and the values obtained were comparable to the API recommendations for the ageing period considered. Results obtained compared favourably with the studies of Abdullah *et al.*, (2024) on short and long term stability of nano-based drilling fluid. The results have demonstrated an adequate time-dependent stability of the developed DF and can therefore be used effectively for drilling operations.

Table 3: Effect of Static Ageing on Drilling Fluid at Room Temperature

Clay Sample	Duration	μ (300 rpm cp)	μ (600 rpm cp)	PV (cp)	AV (cp)	YP (lb/100ft ²)	GS 10s	GS 10mins
Uturu	AM	23.24	26.62	3.38	13.31	19.86	1.26	1.8
	24 hrs	20.00	28.91	8.91	14.45	11.09	1.76	2.1
	48 hrs	19.12	28.90	9.78	14.45	9.34	2.89	3.42
	72 hrs	17.24	25.67	8.43	12.83	8.81	2.23	3.11
Ubakala	AM	24.00	27.01	3.01	13.50	20.99	1.92	2.0
	24 hrs	19.29	28.98	9.67	14.49	9.62	3.2	5.6
	48 hrs	19.64	26.34	6.70	13.17	12.94	3.2	5.6
	72 hrs	16.66	23.43	6.77	11.71	9.89	3.0	5.4

AM = After mixing

3.4 Effect of Temperature on Rheological Properties

Determining the effect of temperature on drilling fluid properties is imperative as most drilling problems occur down holes at elevated temperatures. High temperature conditions are one of the most challenging situations encountered while drilling ultra-deep well. Polymers tend to degrade at higher temperatures, which often lead to loss of rheology and filtration issues (Liu *et al.*, 2023). To understand the effect of temperature changes on the viscosity of developed DFs, the fluids were subjected to a range of temperature from ambient, 50, 80 and 110°C and the results are presented in Figure 3(a-d). This range of temperature was chosen to mimic typical down hole conditions usually encountered in the Niger Delta where the majority of drilling for natural oil and gas exploration takes place. Viscosities increased significantly with temperature for all drilling fluids. The increase was attributed to fluid loss due to high temperatures. DF developed using Ubakala clay had the highest viscosity. It is noteworthy to mention that the formulated drilling fluids exhibited shear thinning properties when subjected to temperature higher than the room temperature. This was evident in the results as the dial readings at 300 rpm were greater than the viscometer dial reading at 600 rpm.

This observation can be explained by the fact that when shear is increased, the internal structure of DF tends to break more rapidly and reversibly. Moreover, as thermal energy is introduced, molecular distance within the fluid increases due to reduction in the intermolecular forces (Lei *et al.*, 2025). Consequently, when shear and temperature are increased, these energies will reduce the attractive force within the fluid molecule, particles can move more freely due to reduction in intermolecular forces thus, viscosity tends to reduce. The developed DF displayed shear thinning behaviour with much higher viscosity at elevated temperature. Similar results were reported by Sun *et al.* (2025) who studied the effect of cellulose nanoparticle on rheology and filtration loss of bentonite water-based fluid. The authors reported that addition of cellulose nanoparticles to bentonite dispersions resulted in higher stability and improved shear thinning properties. DFs that exhibit high viscosity at low shear rate have more tendencies to suspend and hold drill cuttings while low viscosities at high shear rate enable the DF to be rapidly pumped and easily release the drill cutting (Sun *et al.*, 2025). The result obtained has convincingly shown that the developed DF can be used for drilling operations even when harsh conditions such as high temperatures are being encountered.

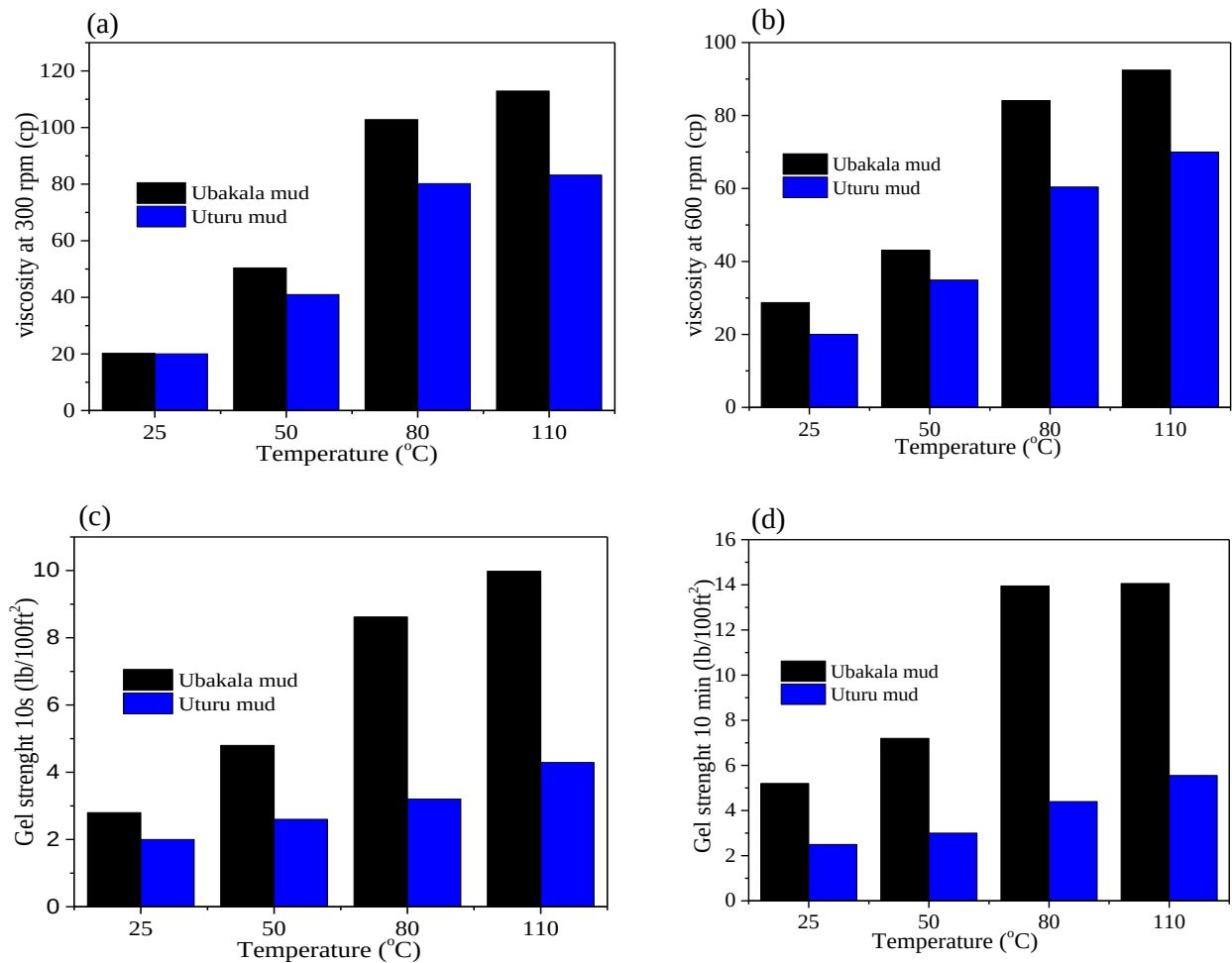


Figure 3: Effect of temperature on (a) viscosity at 300 rpm (b) viscosity at 600 rpm (d) get strength at 10s (d) gel strength at 10 mins

Rheogram plots for Ubakala mud and Uturu mud are shown in Figure 4 (a and b). The rheogram reveals notable differences in the temperature-dependent rheological behaviour of the drilling fluid systems. In both plots, the shear stress–shear rate relationships confirm non-Newtonian, shear-thinning behaviour across all temperatures, with curves showing a nonlinear increase indicative of pseudoplastic flow. However, the extent of thermal influence and structural stability differs significantly between the two drilling fluid samples. Rheogram plots in Figure 4 (a-b) indicated that shear stress of the DFs increased with temperature. At ambient temperature, DF exhibited dilatant behaviour. This behaviour changes to pseudoplastic at higher temperature. From the flow curves, it could be deduced that the developed is not a power law fluid, especially at elevated temperature.

In Figure 4(a), increase in temperature from 30°C to 110°C shows a consistent and orderly reduction in shear stress, reflecting predictable thermal thinning and gradual weakening of the internal fluid structure. The curves at 80°C and 110°C converge closely, suggesting a stable rheological response at elevated temperatures and minimal structural breakdown beyond a certain thermal threshold. In contrast, the second rheogram exhibits a less uniform response, particularly at 50°C where the curve shows pronounced fluctuations and a noticeable plateau or decline in shear stress at higher shear rates. This irregularity indicates possible structural instability or partial breakdown of the internal gel network under shear and thermal stress. Additionally, the separation between the 80°C and 110°C curves is more pronounced

compared to the first plot, implying that temperature continues to significantly influence viscosity even at higher thermal conditions.

Furthermore, Uturu drilling fluid (Figure 4b) shows a lower overall shear stress at intermediate temperature (50°C) relative to both lower and higher temperatures, which deviates from the monotonic trend observed in the Ubakala drilling fluid. This behaviour may be attributed to non-uniform hydration, weaker particle interactions, or transitional structural rearrangements within the fluid. The more stable and smoother profiles in Ubakala drilling fluid rheogram therefore suggest better thermal stability and structural integrity of the fluid system compared to the second. The improved characteristics can be attributed to the prior clay treatment. Overall, while both fluids demonstrate desirable shear-thinning characteristics, Ubakala drilling fluid rheogram indicates superior rheological stability and predictable temperature response, whereas Uturu drilling fluid highlights susceptibility to structural disruption under certain thermal conditions. This distinction is critical for drilling operations, as fluids exhibiting stable rheological behaviour across varying temperatures are more reliable for maintaining wellbore stability and efficient cuttings transport.

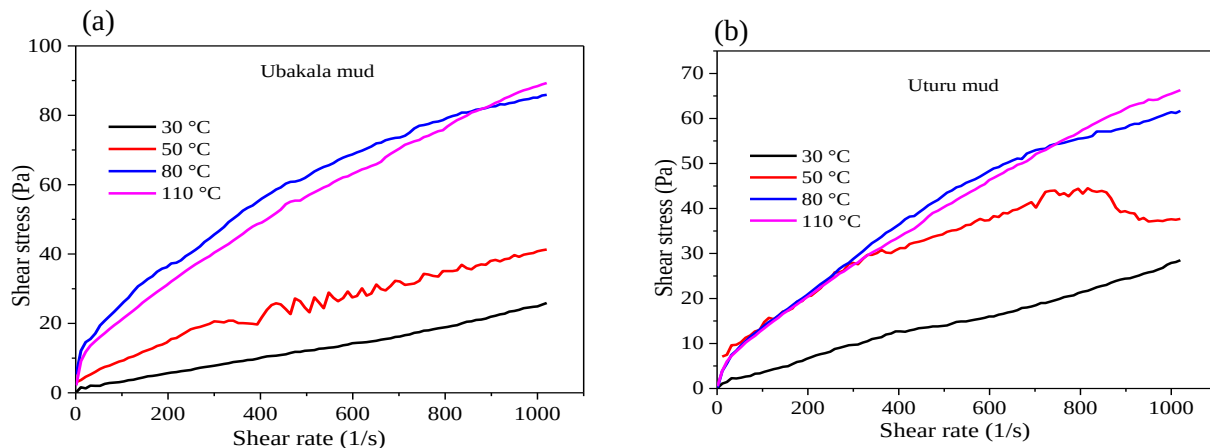


Figure 4: Rheogram plots of (a) Ubakala drilling fluid at 30, 50, 80 and 110 °C (b) Uturu drilling fluid 30, 50, 80 and 110 °C

4. CONCLUSION

The effect of static ageing and increasing temperature on drilling fluids formulated from Nigerian clays sourced from Ubakala and Uturu and natural polymers, was successfully investigated. The results of the study indicate that ageing plays a significant role in modifying the rheological properties of the drilling fluids. Specifically, it was observed that ageing for 24 hours led to an increase in viscosity, suggesting improved structuring and hydration of the clay-polymer system. However, when the ageing period was extended to 48 and 72 hours, a reduction in viscosity occurred, which may be attributed to structural breakdown or reorganization within the fluid. Temperature was found to significantly influence the rheological behaviour of the drilling fluids. Viscosity of all investigated DF samples increased significantly with increasing temperature, demonstrating the strong dependence of the rheological characteristics on thermal conditions. Furthermore, the fluids exhibited non-Newtonian behaviour, being dilatant (shear-thickening) at room temperature, but transitioning to pseudoplastic (shear-thinning) behaviour at elevated temperatures. A comparative assessment of the two clay sources revealed distinct performance differences. Ubakala drilling fluid displayed enhanced rheological stability, maintaining consistent flow characteristics and exhibiting a well-defined response to temperature variations. In contrast, the Uturu drilling fluid showed reduced structural integrity, indicating a higher susceptibility to thermally induced degradation and instability under certain temperature conditions.

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