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Time-Dependent Characterisation of Locally Formulated Drilling Mud: A case study of Bulu Apelebiri Clay Deposit

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Abstract

In Nigeria, the oil and gas industry heavily relies on imported materials for drilling mud formulation, including bentonite. Despite the promising potential of local clay deposits, their suitability for drilling mud formulations is often limited by challenges related to time-dependent stability. Locally formulated drilling muds may experience degradation in properties such as viscosity, pH, and density over time, affecting their overall performance. This time-dependent behaviour can compromise critical functions like cuttings transport, wellbore stability, and hydrostatic pressure maintenance, thereby threatening drilling efficiency and safety. This research evaluates the time-dependent rheological and physical properties of locally formulated drilling mud from Bulu Apelebiri, including viscosity, pH, and density, to assess its stability and suitability for drilling operations. Results reveal that mud concentration significantly impacts stability, with the 17.5g sample exhibiting the highest variability due to insufficient buffering capacity, while the 24.5g sample demonstrated consistent pH levels and superior viscosity for suspension stability and wellbore cleaning. The 21g formulation emerged as the most stable in maintaining hydrostatic pressure, although low-shear inconsistencies were noted. While all samples exhibited neutral to slightly acidic pH, limiting their application in strongly alkaline environments, the findings underscore the adaptability and customization potential of locally formulated mud. Tailoring its properties to operational requirements offers a sustainable, cost-effective solution for diverse drilling scenarios.

Keywords*: drilling mud; bulu apelebiri clay; time-dependent characterisation; rheology; stability*

INTRODUCTION

In the drilling industry, drilling fluids play an indispensable role at nearly every stage of operations, influencing both efficiency and safety (Bourgoyne et al , 1986). These fluids, commonly referred to as drilling muds, significantly impact the success and cost-effectiveness of oil well drilling. Drilling mud is a heterogeneous mixture of chemicals formulated to enhance various aspects of the drilling process, including transporting cuttings from the wellbore to the surface (Kelessidis, 2007). The choice and performance of drilling muds are critical, as they ensure smooth operations in accessing subsurface crude oil reservoirs globally. Drilling fluids are generally categorized based on their base materials—water-based muds (WBM), oil-based muds (OBM), gas-based muds (GBM), and synthetic-based muds—each suited to specific conditions and operational requirements (Elhag, 2014). Among these, WBMs dominate the industry, accounting for approximately 98% of drilling fluid usage. The selection of a suitable drilling fluid base and its additives hinges on several considerations, including environmental safety, pressure control, and adaptability to operational challenges such as high-temperature and high-pressure conditions, time-dependent stability, and shale instability (Kelessidis, 2007).. The primary functions of drilling fluids include cleaning the wellbore, transporting cuttings to the surface, maintaining hydrostatic pressure to prevent blowouts, lubricating and cooling the drill bit, stabilizing the wellbore, and forming a protective filter cake to minimize formation damage. However, the properties of drilling mud are not static; they evolve as the fluid interacts with subsurface formations during drilling. These changes necessitate regular and precise monitoring of mud properties to maintain drilling efficiency and safety. Time-dependent changes in drilling fluid properties—such as rheology, viscosity, pH, and density—can adversely affect operations if not adequately managed. The rheological properties, particularly viscosity, play a pivotal role in determining the fluid's capacity to suspend and transport cuttings. A balance is required; excessively high viscosity increases friction, reducing circulation efficiency, while low viscosity compromises cuttings transport and wellbore stability (Knox, 2005).

One of the most common materials used to enhance drilling mud properties is bentonite, a clay mineral primarily composed of montmorillonite. Sodium montmorillonite, in particular, exhibits exceptional swelling capacity when hydrated, making it a highly effective viscosifier. Bentonite not only improves the mud's ability to clean the borehole but also forms a protective filter cake on the wellbore walls, reducing the risk of collapse. This clay is formed through the weathering of volcanic ash, influenced by factors such as climate, topography, and time of exposure. Bentonite typically contains montmorillonite (85%-90%), along with other minerals like kaolinite, feldspar, and quartz (Akinyemi et al., 2023). Its hydration behavior and resulting rheological properties make it an essential component of drilling mud formulations (Medhi et al., 2020). In Nigeria, the oil and gas industry heavily relies on imported materials for drilling mud formulation, including bentonite. This dependence on imports undermines the local content policy aimed at fostering indigenous capacity in the oil and gas sector. Yet, Nigeria is endowed with substantial clay deposits across its sedimentary basins, including over 70 million tons of bentonitic clay in Afuze, Edo State (RMRDC, 2005). Several studies, such as those by Omole, Malomo, and Akande (1989), have highlighted the potential of these local clay resources as substitutes for imported materials. The optimization and characterization of local clays for drilling mud formulation could significantly reduce drilling costs and stimulate economic growth in Nigeria.

James et al. (2008) evaluated Yola clay deposits using dry and wet beneficiation methods, focusing on their rheological and filtration properties. Sodium treatment significantly improved the clay's performance, indicating the potential for local bentonite to meet API specifications with appropriate treatment. However, the study emphasized that raw samples required extensive modifications to match imported alternatives. Similarly, Ahmed et al. (2012) explored the mineralogical and chemical properties of bentonite sourced from Gombe State, Nigeria, and employed various beneficiation methods, including sieving, calcination, and acidification, to improve its properties. The study revealed that raw and beneficiated samples contained montmorillonite peaks, with higher peaks observed post-beneficiation. However, calcination degraded sodium montmorillonite, leaving magnesium montmorillonite as the dominant phase. Acidification further improved the clay's purity by removing ferric oxide. These findings highlight the potential of beneficiation in enhancing the suitability of local bentonite for industrial applications, though challenges remain in preserving the desirable properties of sodium montmorillonite critical for drilling fluid performance. Oyedoh et al.

(2016) examined the rheological and filtration properties of Afuze clay in Nigeria. Unbeneficiated samples displayed inadequate properties, including low gel strength and high filtration loss. However, beneficiation with sodium carbonate, caustic soda, and starch significantly improved its performance, achieving gel strengths suitable for transporting cuttings. Despite these improvements, the clay’s properties remained inconsistent across varying concentrations, emphasizing the need for further optimization. Wilfred (2016) conducted a comparative analysis of the rheological properties of locally sourced bentonite and foreign bentonite. The study found that while local mud initially failed to meet API standards, additives such as potash and drispac significantly improved pH and viscosity, respectively. The findings underscore the importance of additive treatment in enhancing the performance of local bentonite, particularly in achieving the rheological stability required for efficient drilling operations.

Anthony et al. (2020) investigated the rheological and flow properties of bentonite from Ibule-soro in Ondo State, Nigeria, comparing it with imported bentonite. The local clay exhibited low viscosity and high filtration loss, highlighting its limitations in raw form. The study identified the necessity of beneficiation and additive incorporation to enhance its performance for drilling applications. Igwe et al. (2016) assessed the chemical, mineralogical, and geotechnical properties of Abakaliki clay, identifying illite and montmorillonite as dominant minerals with low percentages of kaolinite. Despite its plasticity and natural pH values, the clay failed to meet API standards for drilling mud due to low Na_2O content and suboptimal rheological properties. However, the study demonstrated that additives such as sodium carbonate and carboxymethyl cellulose could significantly improve its performance. This aligns with the need for systematic evaluation and modification of local clays to achieve the desired standards. Ogolo et al. (2023) introduced a thermochemical treatment method to convert potassium-based bentonite into sodium-based bentonite. Using raw clay samples from Pindinga and Ubakala, the study achieved significant improvements in rheological properties, including viscosity, yield point, and thixotropy. The incorporation of soda ash and magnesium oxide in the treatment process proved effective in enhancing the clay's suitability for drilling applications, showcasing the potential of advanced treatment methods in addressing the limitations of local bentonite.

Despite the promising potential of local clay deposits, their suitability for drilling mud formulations is often limited by challenges related to time-dependent stability. Locally formulated drilling muds may experience degradation in properties such as viscosity, pH, and density over time, affecting their overall performance. This time-dependent behaviour can compromise critical functions like cuttings transport, wellbore stability, and hydrostatic pressure maintenance, thereby threatening drilling efficiency and safety. This study focuses on the time-dependent characterization of locally formulated drilling mud. By evaluating the temporal evolution of rheological and physical properties such as viscosity, pH, and density, the research aims to provide insights into the stability of locally sourced drilling mud. This approach is expected to highlight the challenges and potential of indigenous clay materials for sustainable drilling operations in Nigeria’s oil and gas industry. The findings will contribute to ongoing efforts to optimize local resources, reduce reliance on imports, and promote the adoption of cost-effective and environmentally friendly drilling solutions.

Aim of the Study

The aim of this study is to characterise the time dependent behaviour of the properties of locally formulated drilling mud.

Objective of the Study

The objectives of this study are outlined as follows:

i. To characterize the initial properties of the locally formulated drilling mud.
ii. To investigate the rheological profile of the locally formulated drilling mud subsequently over a total of 5 days and 24hr interval to understand its flow behaviour.
iii. To analyse the influence of mud weight on the stability and rheological properties of the locally formulated drilling mud clay.
iv. To analyze the time-dependent pH variations in the locally formulated drilling mud

Location and Geology of the Study Area

The local clay material used in this study was obtained from Bulu Apelebiri town in Patani local government area of Delta State, South-southern Nigeria. Its geographical coordinates are longitude 6° 6' 20" E, latitude 5° 8' 46" N, and 43 ft elevation. The topography within 2 miles of Patani is essentially flat, with a maximum elevation change of 82 feet and an average elevation above sea level of 59 feet. Within 10 miles is essentially flat (131 feet). Within 50 miles also contains only modest variations in elevation (322 feet). The area within 2 miles of Patani is covered by trees (52%), water (26%), and grassland (13%), within 10 miles by trees (54%) and shrubs (14%), and within 50 miles by trees (36%) and cropland (23%). Bulu Apelebiri is in a typical Niger Delta region characterized by the Benin, Agbada and Akata formations. It is basically a low land sedimentary region with flat topography in a continental fluid-tide environment characterized by fine whitish top soil underlain by silty formations.

METHODS

Materials

The following equipments were used for this research:

Rota shaker sieve Mortar and Pestle Mud Sample

Weighing Balance

Hamilton Beach mixer (model 936-1)

Baroid Mud Balance

Six Speed Rheometer – coquette type, coaxial cylinder rotational viscometer (model 286)

Sample Collection and Preparation

Clay samples were freshly obtained from a pit excavated to a depth of 1.7 meters, targeting specific horizontal strata where sodium, calcium, and magnesium base elements are commonly concentrated. The samples were crushed into finer particles and oven-dried to facilitate subsequent pulverization and sieving. Using a mortar and pestle, the dried samples were ground into a fine powder and sieved with a Rota shaker to produce a 63 µm fraction, meeting API specifications for bentonite. The processed clay sample was collected in a beaker and appropriately labeled with masking tape. Precise quantities of 17.5 g, 21.0 g, and 24.5 g of the fine clay sample were then measured into separate mixer cups using a weighing balance and labeled accordingly. For each sample category, 350 ml of distilled water was measured with a 500 ml measuring cylinder and added to the respective clay samples. The mixtures were blended to achieve homogeneity using a Hamilton Beach mixer (model 936-1). The resulting homogeneous mixtures were allowed to age for 24 hours to ensure complete hydration. After the aging period, the mixtures were re-stirred to re-agitate the mud before proceeding with characterization tests.

Mud Weight Characterisation

To characterize the mud weight or density, the prepared mud samples were tested to determine their weight per unit volume, a critical parameter in oil well drilling operations. Mud density must be sufficient to provide adequate hydrostatic pressure to prevent the influx of formation fluids while avoiding excessive density that could result in loss of circulation, formation damage, or reduced rate of penetration (ROP). The objective of this test was to evaluate whether the prepared local mud samples met the minimum API-specified weight required for drilling fluids and the mud samples would behave over a total period of 5 days and a interval of 24 hrs. The equipment used for this study included a Baroid mud balance, calibrated for ±0.1 lb/gal accuracy and verified with fresh water at a standard temperature of 70° ±5°F, along with a Hamilton Beach mixer (model 936-1). Materials utilized included freshly prepared mud samples, clean rags, water, masking tape for labeling, and a recording notebook.

The procedure commenced with temperature measurement of the mud sample to ensure conditions aligned with standard calibration. The mud balance base was positioned on a flat, level surface for stability. A clean, dry mud balance cup was filled with the mud sample to be tested. The cap was then rotated until it was securely seated, allowing excess mud to escape through the vent hole to eliminate any trapped air or gas. After placing a thumb over the hole to prevent leaks, the exterior of the cup was carefully wiped clean and dried. Subsequently, the balance arm was placed on the support base, and the rider was adjusted along the graduated scale until the level bubble was centered under the centerline. The mud density was read at the left-hand edge of the rider and recorded to the nearest 0.1 lb/gal. Results were documented in different drilling mud report units (lbs/gal, lbs/sg.in/1000ft, lb/cu.ft, sq.gr).

Note: The initial mud weight was characterised and the procedure was repeated for a period of 4 days for each of the mud samples.

Mud Rheology Characterisation

The rheological characterization of the mud sample was carried out to determine key properties, including viscosity at 600 rpm and 300 rpm, 3 rpm, plastic viscosity, yield point. These parameters are critical for evaluating the flow behaviour of drilling mud and ensuring optimal performance during drilling operations. The experiment utilized a Six Speed Rheometer – coquette type, coaxial cylinder rotational viscometer (model 286), a device designed to measure single or multi-point viscosities and to facilitate the application of the Bingham plastic model for drilling mud analysis. Reagents and materials included freshly prepared mud samples, masking tape for labeling, a recording notebook, and a pen. The rheological analysis followed a systematic procedure to ensure precision and consistency. The Rheometer has a torsion spring-loaded bulb that gives a dial reading proportional to torque, which is analogous to the shear stress.

Initially, the Rheometer was set up by connecting its power cord to a power source, and the power button was switched on. A sample of freshly prepared mud was poured into the thermal cup, filling it approximately two-thirds full. The cup was placed on the viscometer stand and raised until the rotary sleeve was immersed to the scribed line on the sleeve. This ensured consistent depth for accurate readings. The locking mechanism was engaged to secure the cup in position. A thermometer was inserted into the mud sample to monitor and adjust the temperature, ensuring it was heated or cooled to the standard test temperature of 115° ±2°F. Once the setup was complete, the Rheometer toggle switch on the rear side of the viscometer was flipped to the high position, activating the 600-rpm speed. The red knob on top of the Rheometer was set to the bottom position to align with the high-speed setting. The rotor sleeve was allowed to rotate for a few seconds to stabilize, after which the top window of the Rheometer displayed the dial reading. The stabilized dial reading at 600 rpm was recorded. After completing the measurements at 600 rpm, the rheometer switch was shifted to the low position to activate the 300-rpm speed. The mud sample was allowed to stabilize under this new setting, ensuring sufficient time for the dial reading to achieve equilibrium. Once the reading stabilized, it was carefully recorded.Subsequently, the rheometer was further adjusted to a lower setting to operate at 3 rpm. This step required meticulous attention, as measurements at such low speeds are crucial for determining the gel strength of the mud. The rotor was again allowed to stabilize, and after a sufficient period, the final stabilized reading at 3 rpm was documented.

This step-by-step process ensured precision and reliability in capturing the rheological properties across varying shear rates. These measurements at different speeds provided the basis for calculating the plastic viscosity and yield point. Plastic viscosity (PV) and yield point (YP) were derived using the Bingham plastic model, expressed mathematically as:

$$PV, cP = \theta_{600} - \theta_{300}$$

$$YP, lb/100\ ft^2 = \theta_{300} - PV$$

Plastic viscosity was calculated as the difference between the 600-rpm and 300-rpm readings, indicating the resistance of mud to flow under mechanical forces. Yield point, a measure of the mud's ability to carry cuttings at low flow rates, was determined by subtracting the PV from the 300-rpm reading.

Note: The initial mud rheology was characterised and the procedure was repeated for a period of 4 days for each of the mud samples.

pH Characterisation

The pH of drilling mud, which reflects its acidity or alkalinity, is determined by measuring its hydrogen ion concentration. This value is crucial for evaluating the chemical balance of the mud and detecting potential contaminants, such as cement or gypsum. Neutral muds exhibit a pH of 7.0, while alkaline muds display pH values ranging from slightly above 7 to 14, indicating varying levels of alkalinity. Conversely, acidic muds have pH values below 7, with readings less than 1 signifying the strongest acidity. The optimal pH level for drilling mud depends on the specific mud type being used, as this affects its performance and stability. In this study, the Hamilton Beach mixer (model 936-1) was utilized alongside freshly prepared mud samples, phydrion dispenser paper, a recording book, masking tape, and a biro to determine the pH. The procedure began by re-stirring the prepared mud to achieve a homogeneous mixture. A strip of phydrion dispenser paper, approximately one inch long, was carefully placed on the mud's surface. The strip was allowed to absorb the mud filtrate, during which its colour changed, reflecting the pH level. After a few seconds, the soaked strip was compared against the reference chart on the dispenser to identify the corresponding pH value.

Note: The initial mud pH was characterised and the procedure was repeated for a period of 4 days for each of the mud samples.

For each of the mud samples evaluated, the sand content was considered to be negligible.

RESULTS

Table 1 Mud pH of the three mud samples over 5 day period

	Mud pH				
Mud Sample	**DAY 1**	**DAY 2**	**DAY 3**	**DAY 4**	**DAY 5**
17.5	7	8	8	6	5
21	6	5	5	6	6
24.5	6	6	6	6	6

The pH of the three different mud samples was measured over a period of 5 days and recorded in table 1 above. Based on the data recorded, a chart of pH against time (in days) was plotted to visualise the trend properly.

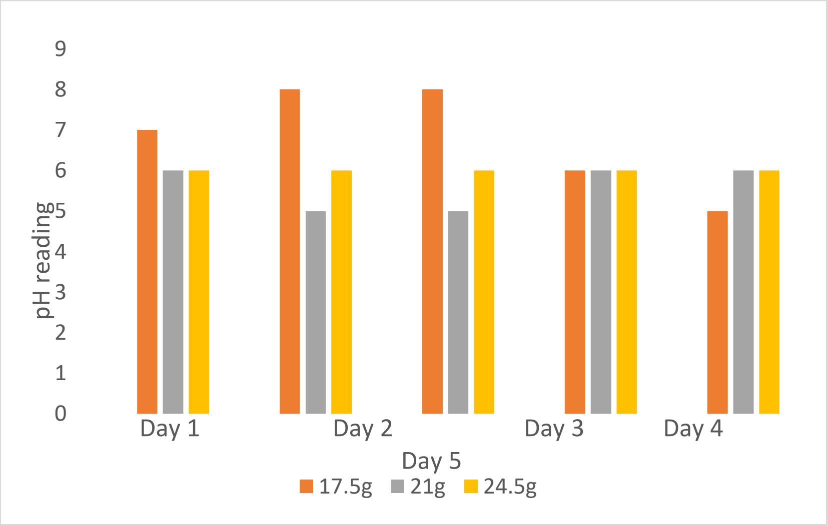


Figure 1: A Chart showing the mud pH over time

The 17.5g mud sample as shown in figure 1 showed significant fluctuations in pH over the five-day period. Initially neutral at 7.0 on Day 1, the pH increased to 8.0 on Days 2 and 3, indicating slight alkalinity. This increase may suggest the presence of basic constituents or a reaction between the mud's components and environmental factors, such as atmospheric CO_2. However, the pH dropped sharply to 6.0 on Day 4 and further declined to 5.0 by Day 5, transitioning into acidic territory. The declining trend highlights potential destabilization or contamination, possibly from microbial activity or chemical breakdown of additives. Such variability might compromise the mud's performance and necessitate chemical stabilization for operational use. The 21g as shown in figure 1 mud sample demonstrated relatively stable but slightly acidic behavior throughout the test period. Starting at a pH of 6.0 on Day 1, it dipped to 5.0 on Days 2 and 3, before returning to a pH of 6.0 on Days 4 and 5. This pattern suggests limited buffering capacity and susceptibility to minor fluctuations, which may be attributed to the composition of the additives used. Consistently low pH levels could indicate a need for pH adjustment to meet operational requirements for alkaline mud systems, as low pH can increase the likelihood of corrosion and reduce mud stability. The 24.5g mud sample as shown in figure 1 exhibited the most stable pH profile of the three concentrations, maintaining a constant pH of 6.0 across all five days. This consistency indicates that this concentration has a higher resistance to external and internal factors that typically cause pH shifts, such as chemical reactions or environmental contamination. The stability of this sample suggests it may be better suited for operational use where minimal pH fluctuation is desirable. However, its slightly acidic nature may still necessitate adjustments to align with the desired alkaline pH range, depending on the specific drilling requirements.

Table 2 Mud weight of the three mud samples over 5 day period

	Mud Weight				
Mud Sample	**DAY 1**	**DAY 2**	**DAY 3**	**DAY 4**	**DAY 5**
17.5g	8.5lbs/gal 450lbs/sg.in/1000ft 63lb/cu.ft 1.02sq.gr	8.3lbs/gal 445bs/sg.in/1000ft 62.7lb/cu.ft 1.00sq.gr	8.3lbs/gal 440lbs/sg.in/1000ft 63.5lb/cu.ft 1.01sq.gr	8.51lbs/gal 445lbs/sg.in/1000ft 63.8lbs/cu.ft 1.03sq.gr	8.5lbs/gal 440lbs/sg.in/1000ft 64.5lb/cu.ft 1.02sq.gr
21g	8.5lbs/gal 445lbs/sg.in/1000ft 63lb/cu.ft 1.02sq.gr	8.5lbs/gal 445lbs/sg.in/1000ft 63lb/cu.ft 1.02sq.gr	8.5lbs/gal 445lbs/sg.in/1000ft 63lb/cu.ft 1.02sq.gr	8.5lbs/gal 445lbd/sg.in/1000ft 63lb/cu.ft 1.02sq.gr	8.5lbs/gal 460lbd/sg.in/1000ft 64lb/cu.ft 1.03sq.gr
24.5g	8.5lbs/gal 450lbs/sg.in/1000ft 64lb/cu.ft 1.02sq.gr	8.4lbs/gal 450lbs/sg.In/1000ft 64lbs/cu.ft 1.03sq.gr	8.6lbs/gal 440lbs/sg.In/1000ft 6l.4lbs/cu.ft 1.03sq.gr	8.4lbs/gal 440lbs/sg.In/1000ft 65lbs/cu.ft 1.02sq.gr	8.6lbs/gal 450lbs/sg.In/1000ft 65lbs/cu.ft 1.02sq.gr

Similarly, the mud weight was also observed over the same period and data recorded in Table 2.

The 17.5g sample as shown in table 2 exhibited minor fluctuations in mud weight over the five-day period. Starting at 8.5 lb/gal on Day 1, the mud weight slightly decreased to 8.3 lb/gal on Days 2 and 3. This reduction may be attributed to sedimentation or water contamination during storage, which could lower the mud's density. By Day 4, the mud weight increased to 8.51 lb/gal before stabilizing back to 8.5 lb/gal on Day 5. These variations, though minimal, highlight potential challenges in maintaining consistent mud weight in lower-concentration formulations. The slight instability observed could compromise the mud's ability to provide adequate hydrostatic pressure and prevent wellbore collapse during drilling. The 21g sample as shown in table 2 demonstrated remarkable stability in mud weight, maintaining a consistent value of 8.5 lb/gal across all five days. This stability indicates that the formulation is resistant to external factors such as sedimentation or evaporation, which commonly cause variations in mud weight. The consistency of this sample suggests its potential as a reliable formulation for drilling operations requiring stable hydrostatic pressure and rheological properties. The 24.5g as shown in table 2 sample showed slight fluctuations in mud weight over the observation period. It started at 8.5 lb/gal on Day 1, dropped to 8.4 lb/gal on Day 2, increased to 8.6 lb/gal on Day 3, then fell back to 8.4 lb/gal on Day 4 before rising again to 8.6 lb/gal on Day 5. These variations, although minor, may be attributed to inconsistencies in the homogeneity of the mud or environmental factors affecting the formulation. Despite the fluctuations, the mud weight remained within acceptable operational limits, suggesting that the higher concentration formulation can withstand moderate disturbances without significant performance degradation

The rheological profile of drilling mud provides valuable insight into its flow behavior, particularly under varying shear rates. This study evaluates the dial readings of locally formulated drilling mud at 300 rpm, 600 rpm, and 3 rpm over five days for samples of 17.5g, 21g, and 24.5g concentrations. The data were plotted on 3 different histograms (figure 2,3,4) to highlight the trends in mud viscosity and low-shear-rate flow behavior, critical for effective cuttings transport and wellbore stability.

Table 3 Mud rheology (dial reading) characterisation of the three mud samples for 5 days.

Mud Rheology

Mud Sample	Day 1			Day 2			Day 3			Day 4			Day 5		
	θ_{300}	θ_{600}	θ_3	θ_{300}	θ_{600}	θ_3	θ_{300}	θ_{600}	θ_3	θ_{300}	θ_{600}	θ_3	θ_{300}	θ_{600}	θ_3
17.5	2.5	3	1.5	2.5	3.5	0.5	2.5	3	1.5	2.5	3	1	2.5	3	1.5
21	2.5	3.5	0.5	2	4	1.5	2	3.5	1	2	2.5	0.5	2	2.5	1
24.5	2	2.5	1	2	4.5	1	3	4	1.5	2	3	1	2.5	3	1

The 17.5g sample as shown in figure 2 demonstrated consistent behaviour at 300 rpm, maintaining a dial reading of 2.50 throughout the five days. At 600 rpm, an initial increase in the reading was observed from 3.0 on Day 1 to 3.50 on Day 2, followed by stabilization at 3.0 from Day 3 to Day 5. These results suggest a temporary increase in the mud's high-shear viscosity, possibly due to thixotropic properties that caused structure build-up after initial preparation. At 3 rpm, the sample exhibited more variability, with readings fluctuating between 1.50 and 0.50. A dip to 0.50 on Day 2 suggests a temporary weakening of gel strength, which recovered by Day 3. This inconsistency in low-shear behavior indicates potential challenges in suspension stability under static conditions, which could affect the mud's ability to hold cuttings during periods of non-circulation.

Figure 2: Rheological measurement for 17.5g mud sample

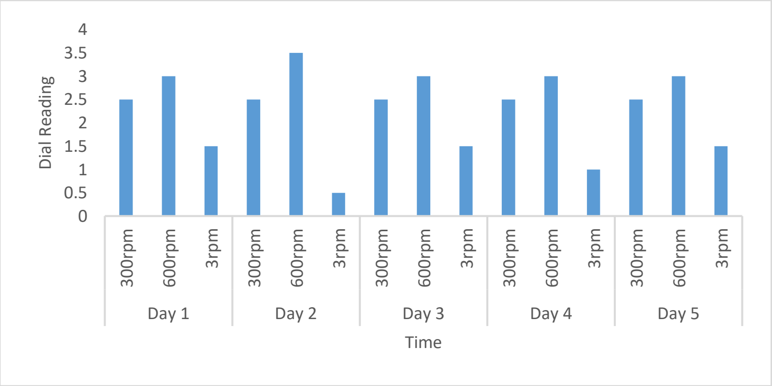
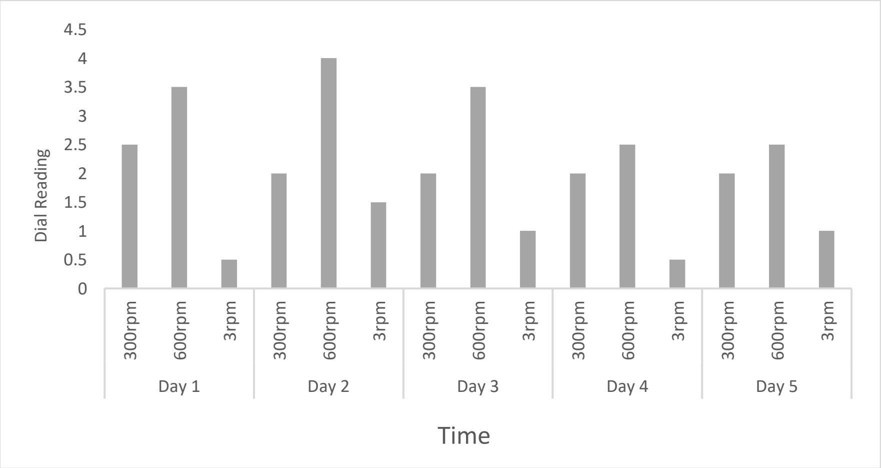


Figure 3: Rheological measurement for 21g mud sample



The 21g sample as shown in figure 3 revealed declining readings at 300 rpm, starting at 2.50 on Day 1 and dropping to 2.0 from Day 2 onwards. This decline indicates a gradual reduction in the mud’s medium-shear-rate viscosity, possibly due to structural breakdown over time or dilution effects. At 600 rpm, the dial reading peaked at 4.0 on Day 2 before declining to 2.50

by Day 4, suggesting temporary thickening followed by structural degradation. At 3 rpm, low-shear behavior was inconsistent, with readings ranging from 0.50 to 1.50.

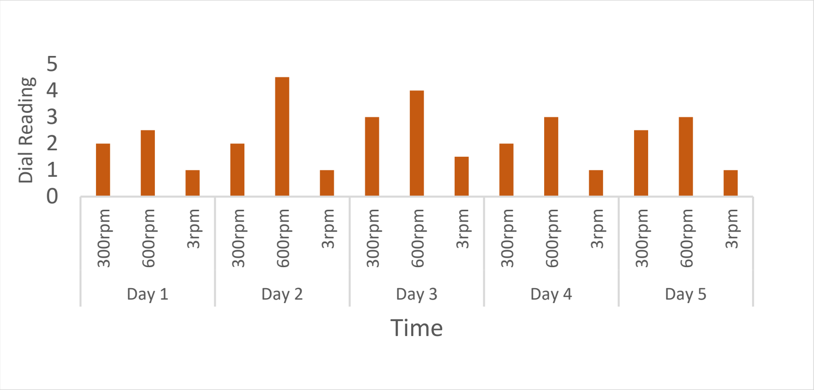


Figure 4: Rheological measurement for 24.5g mud sample

A sharp increase on Day 2 suggests temporary gel strength improvement, followed by fluctuations that may indicate instability in the mud's static suspension capacity. This variability highlights the need for further optimization to enhance low-shear-rate performance. The 24.5g sample as shown in figure 4 exhibited the most significant fluctuations across all shear rates. At 300 rpm, the reading increased from 2.0 on Day 1 to 3.0 on Day 3, indicating improved medium-shear viscosity before stabilizing at 2.50 on Day 5. At 600 rpm, the sample showed a peak reading of 4.50 on Day 2, followed by stabilization at 3.0 from Day 3 onward. These trends suggest that the higher concentration formulation can retain higher viscosity under shear but may still be prone to early structural changes. Low-shear behavior at 3 rpm remained largely consistent, with readings hovering between 1.0 and 1.5 across the five days. This stability in gel strength under static conditions suggests that the 24.5g sample is better suited for holding cuttings during non-circulation compared to the lower-concentration samples.

Table 4 Mud rheology (PV, AV &YP) characterisation of the three mud samples for 5 days.

	Mud Rheology														
Mud Sample	**Day 1**			**Day 2**			**Day 3**			**Day 4**			**Day 5**		
	PV	**YP**	**AV**	**PV**	**YP**	**AV**	**PV**	**YP**	**AV**	**PV**	**YP**	**AV**	**PV**	**YP**	AV
17.5g	0.5	2	1.5	1	1.5	1.75	0.5	2	1.5	0.5	2	1.5	0.5	2	1.5
21g	1	1.5	1.75	2	0	2	1.5	0.5	1.75	0.5	1.5	1.25	0.5	1.5	1.25

24.5g	0.5	1.5	1.25	2.5	0.5	2.25	1	2	2	1	1	1.5	0.5	2	1.5

This study also evaluated the plastic viscosity (PV), apparent viscosity (AV), and yield point (YP) data for the locally formulated drilling mud over five days, with 24-hour intervals. These properties as presented in Table 4 are critical in determining the flow behavior of drilling mud under various operational conditions, such as cuttings transport, wellbore cleaning, and barite suspension during circulation and static conditions. The data were plotted on a histograms as shown in figure 5 to highlight the trends in these derivatives from mud viscosity and low-shear-rate flow behavior, critical for effective cuttings transport and wellbore stability.

For the 17.5g sample, the PV as shown in figure 5 remained stable at 0.5 cP for most of the testing period except for Day 2, where it increased to 1.0 cP. This stability indicates a consistent low solids concentration, making it suitable for scenarios where low frictional pressure losses are required. However, the increase on Day 2 may suggest minor structural changes or sedimentation over time. As noticed in the 21g sample, the PV varied significantly, peaking at 2.0 cP on Day 2 before dropping to 0.5 cP by Day 4 and Day 5. The fluctuation reflects changes in the mud's solid-liquid interaction, possibly due to shear thinning or breakdown of flocculated structures over time. Notwithstanding, the PV of the 24.5g sample as shown in figure 5 showed a peak of 2.5 cP on Day 2, followed by a gradual decline to 0.5 cP by Day 5. This trend suggests a higher solids content initially but reduced particle interaction or dispersion as the mud aged.

Furthermore, YP represents the stress required to initiate mud flow, reflecting the ability to suspend cuttings during non-circulation. The YP of the 17.5g sample as shown in figure 5 remained steady at 2 lb/100 ft² across all days except Day 2, where it dropped to 1.5 lb/100 ft². This consistent value indicates reliable cuttings suspension capability for a low-concentration mud sample, with minimal gel strength reduction over time. For the 21g sample, the YP as shown in figure 5 showed significant variability, starting at 1.5 lb/100 ft² on Day 1, dropping to 0 on Day 2, and fluctuating between 0.5 and 1.5 lb/100 ft² afterward. The temporary loss of yield strength on Day 2 highlights potential stability issues that may reduce suspension efficiency during static conditions. When evaluating the 24.5g sample, the YP as shown in figure 5 exhibited considerable variation, peaking at 2 lb/100 ft² on Day 3 and Day 5 but dropping to 0.5 lb/100 ft² on Day 2 and Day 4. This inconsistency in gel strength may lead to challenges in maintaining solids suspension under static conditions, despite the higher mud concentration.

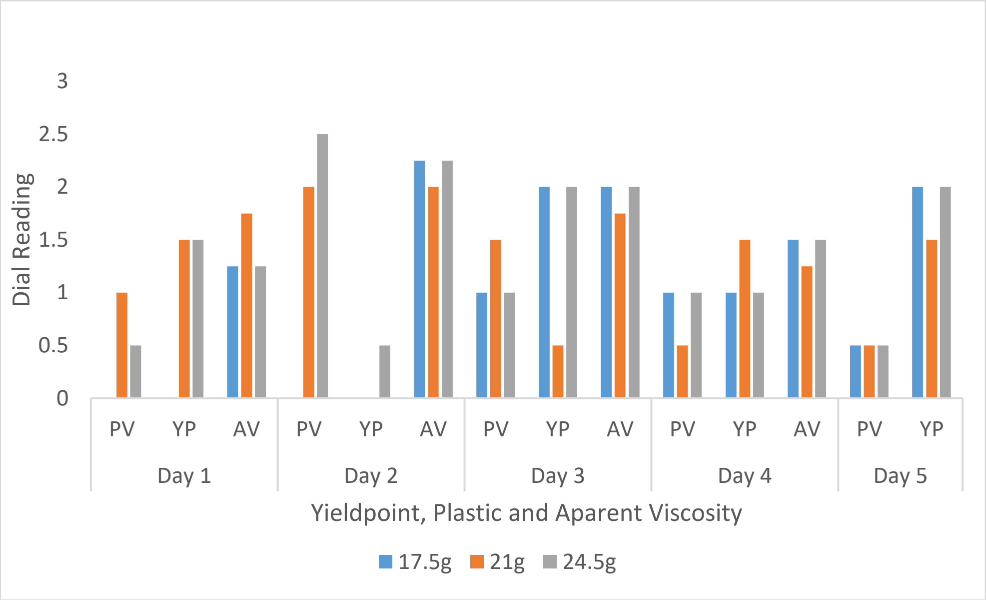


Figure 5 Mud rheology (PV, AV &YP) characterisation of the three mud samples for 5 days.

For the 17.5g sample, the AV as shown in figure 5 remained consistent at 1.5 cP throughout the five days, indicating steady flow behavior and minimal structural changes. This consistency makes it suitable for routine drilling operations with low solids handling requirements. However, for the 21g sample, the AV as shown in figure 5 peaked at 2.0 cP on Day 2, followed by a gradual decline to 1.25 cP by Day 4 and Day 5. The decline reflects potential shear thinning and structural degradation over time, reducing the mud's efficiency in cuttings transport. Conversely, the AV of the 24.5g sample as shown in figure 5 demonstrated greater variability, peaking at 2.25 cP on Day 2 and dropping to 1.25 cP by Day 5. The higher AV on Day 2 suggests enhanced viscosity due to flocculation or higher solids concentration, but the decline over time indicates reduced flow resistance and potential sedimentation.

From the above rheological data, it is evident that The 17.5g mud is suitable for low-pressure loss scenarios with minimal solids transport requirements, making it effective for shallow formations or routine drilling operations. The 21g mud offers a balance between viscosity and flow behaviour, suitable for moderate depths but requires additives to stabilize its rheological properties over time while he 24.5g mud demonstrates higher solids handling capacity and is more effective for deeper formations with higher cuttings loads. However, the instability in YP and AV necessitates further optimization to improve its long-term suspension and flow performance.

CONCLUSION

This research is focused on the time-dependent characterization of locally formulated drilling mud. By evaluating the temporal evolution of rheological and physical properties such as viscosity, pH, and density, the research provides insights into the stability of locally sourced drilling mud. The results indicate a clear relationship between mud concentration and pH stability. The 17.5g sample, with the lowest concentration, showed the greatest variability, suggesting its formulation lacks the buffering capacity needed to maintain a stable pH. Conversely, the 24.5g sample maintained consistent pH levels, likely due to a higher concentration of stabilizing agents or additives. However, all samples exhibited either neutral or slightly acidic pH levels, which could limit their effectiveness in environments requiring strongly alkaline mud. The variations in mud weight across samples highlight the influence of concentration on the stability of drilling mud. Lower concentrations, as seen in the 17.5g sample, may be more prone to environmental influences, while higher concentrations, like the 24.5g sample, exhibit greater resistance but still show slight inconsistencies. Maintaining stable mud weight is essential for ensuring effective cuttings removal, preventing wellbore collapse, and optimizing overall drilling efficiency. Across all samples, the 21g mud formulation demonstrated the greatest stability in mud weight, making it a preferable choice for maintaining consistent hydrostatic pressure during drilling operations. The 17.5g and 24.5g samples, although relatively stable, exhibited slight fluctuations that may require additional monitoring and adjustments during storage and use. The rheological profiles indicate that the 24.5g mud sample exhibited the highest overall viscosity and relatively stable low-shear behaviour, making it the most effective for maintaining suspension stability and wellbore cleaning. The 21g sample, while stable at high shear rates, demonstrated inconsistent low-shear behaviour, which could impact its performance during static intervals. The 17.5g sample showed good stability at high and medium shear rates but exhibited significant fluctuations at low shear, raising concerns about its cuttings suspension capability. Thus, this research demonstrates that locally formulated drilling mud, with its inherent adaptability and potential for customization, can be optimized to meet the demands of diverse drilling environments. By tailoring its properties to specific operational needs, this approach offers a practical, cost-effective, and sustainable solution for successful implementation in drilling programs, ensuring efficiency and environmental compatibility.

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