Evaluation of the Suitability of Arochukwu Clay for Drilling Mud Formulation: A Comparative Study with API Standards for Bentonite Clay

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Abstract
In line with the industrial adoption of bentonite, the Nigerian oil and gas industry has historically relied on imported bentonite to meet its drilling needs. The financial burden of this dependency is significant as imported drilling muds accounts for millions of dollars in annual expenditures. Thus, the urgent need for cost-effective and locally available alternatives has gained traction, especially in light of Nigeria's abundant clay deposits. This research seeks to determine whether Arochukwu clay can serve as a viable alternative to imported bentonite, thereby contributing to cost savings, resource optimisation, and the localisation of drilling fluid production in Nigeria. The evaluation of Arochukwu clay for drilling mud formulation highlights its potential as an alternative material, although certain properties fall short of API standards for bentonite. The study assessed pH, mud weight, sand content, and rheological properties, including plastic viscosity (PV), yield point (YP), and apparent viscosity (AV). Results showed that while higher clay concentrations maintained a more alkaline pH essential for mud stability, all samples failed to meet the API pH standard (9.5–12.5), necessitating chemical modification. Mud weight performance was reasonable, with higher concentrations achieving densities near the API range (8.65–9.0 ppg), but lower concentrations showed variability. Sand content generally aligned with API thresholds (<1%), though some variability was noted. Increasing clay concentration improved viscosity and gel strength, yet rheological properties remained below API standards, limiting cuttings suspension and fluid flow efficiency. Despite these limitations, Arochukwu clay shows promise for drilling mud formulation, particularly at higher concentrations, with further refinement required to meet API standards for modern drilling applications.

Keywords: *Arochukwu clay, Drilling mud formulation, Bentonite alternatives, Rheological properties, Nigerian oil and gas industry.*

INTRODUCTION

Drilling operations form the backbone of hydrocarbon exploration and production, serving as a critical phase in accessing subsurface reservoirs for oil and gas (Nweke et al 2015). These operations are inherently complex and resource-intensive, requiring precise engineering and optimal use of supporting materials to ensure success. Among these, drilling fluids—often referred to as "drilling muds"—are indispensable for maintaining operational efficiency, controlling wellbore stability, and mitigating potential hazards (Afolabi et al 2017). Drilling fluids perform numerous functions, including cooling and lubricating the drill bit, transporting cuttings to the surface, stabilising the borehole, and controlling formation pressures. Given their central role, the selection and management of drilling fluids are key determinants of both operational success and cost-efficiency in drilling projects (Nweke et al 2015). Drilling fluids can be broadly classified into three categories based on their base components: water-based, oil-based, and gas-based fluids. Each type is formulated to suit specific geological and operational conditions, with properties tailored to enhance efficiency while minimising risks such as formation damage and corrosion (Anthony et al 2020). The cost implications of drilling fluids are substantial, with research indicating that drilling activities account for approximately 25% of total oilfield development costs, a significant portion of which is attributed to the selection, formulation, and maintenance of drilling muds (Abdullahi et al., 2011). Although drilling fluids typically constitute 5–15% of total drilling costs, their proper design and application can mitigate up to 100% of potential drilling problems, underscoring their critical importance (Liu et al., 2021). A key operational function of drilling muds is to ensure wellbore stability by maintaining hydrostatic pressure that counterbalances formation pressures. This prevents uncontrolled influxes of fluids (kicks) and the collapse of unstable formations into the borehole. Additionally, drilling muds are designed to suspend and transport cuttings to the surface, where they can be removed, thus preventing their accumulation and regrinding by the drill bit. Properly engineered drilling fluids also minimise friction, reduce wear on drilling components, and enhance the longevity of equipment by lubricating the drill bit and string (Katende et al., 2020). The ability of a drilling fluid to maintain these critical properties—density, viscosity, gel strength, and filtration control—is directly linked to its chemical composition and formulation.

Furthermore, a key constituent of a good mud program is bentonite due to its unique properties. Bentonite, named after the Benton Shale formation in Wyoming, USA, is primarily composed of sodium montmorillonite, a mineral with remarkable swelling, gel-forming, and thixotropic characteristics (Hosterman and Patterson 1992). When hydrated, sodium bentonite forms a viscous suspension capable of suspending solids and forming a low-permeability filter cake, which prevents fluid loss into the formation (Maulani et al 2018). This behaviour is crucial for maintaining wellbore integrity and optimising drilling performance. The high gel strength of bentonite suspensions allows them to transition between solid-like and fluid-like states, enabling effective suspension of cuttings when drilling is paused and their subsequent removal when operations resume (Carlson, 2022). Additionally, bentonite's shear-thinning properties and low cost have made it the benchmark additive for viscosity and filtration control in drilling muds (Jeong et al., 2012). In line with the industrial adoption of bentonite, the Nigerian oil and gas industry has historically relied on imported bentonite to meet its drilling needs. The financial burden of this dependency is significant as imported drilling muds accounts for millions of dollars in annual expenditures (Liu et al 2021). Given that drilling fluids contribute 5–15% of the total cost of drilling a well, which can range from $1 million to $100 million, this reliance on imported materials poses a strain on foreign exchange reserves and limits the industry's local content development (Akinade & Afolabi, 2015). The urgent need for cost-effective and locally available alternatives has gained traction, especially in light of Nigeria’s abundant clay deposits.

Interestingly, Nigeria is endowed with substantial clay reserves distributed across its sedimentary basins, particularly in the SouthEastern region. These deposits, often associated with past sedimentary and weathering processes, offer a promising source of raw materials for industrial applications, including drilling mud formulation (Aghamelu & Okogbue, 2015). However, the industrial suitability of these clays varies, necessitating a thorough evaluation of their physical, chemical, and rheological properties against established standards. Local sourcing of clay for drilling fluids not only reduces costs but also supports the government's push for increased local content in the oil and gas sector, fostering economic growth and job creation.

Arochukwu, located in Abia State, southeastern Nigeria, is one such area with abundant clay deposits that invites research. Considering the vast potential of clay resource in that part of Eastern Nigeria, there is need to systematically assess its suitability for drilling mud formulation in alignment with the stringent requirements set by the American Petroleum Institute (API) for bentonite clay. The API standards serve as a benchmark for evaluating the performance of drilling mud additives, with properties such as viscosity, yield point, and filtration control being critical for effective application in the field. By examining its physical and rheological characteristics, this research seeks to determine whether Arochukwu clay can serve as a viable alternative to imported bentonite, thereby contributing to cost savings, resource optimisation, and the localisation of drilling fluid production in Nigeria. The findings of this study have the potential to address critical challenges in the oil and gas sector while supporting sustainable development goals through the utilisation of local resources.

Aim of the Study

This study aims to evaluate the suitability of locally sourced clay from Arochukwu in Abia State, Nigeria for mud formulation by comparing with API standards for bentonite clay.

Objective of the Study

The objectives of this study are outlined as follows:

i. To assess the mud density, sand content, pH, and rheological properties of Arochukwu clay.
ii. To analyse the effects of sample weight on the observed physical characteristics over time
iii. To compare these properties with API standards to determine the clay's suitability for use as drilling fluid.

Location and Geology of the Study Area

The local clay material used in this study was sourced from Arochukwu in Arochukwu Local Government Area of Abia State, located in southeastern Nigeria. Its geographical coordinates are approximately longitude 7° 54' 0" E and latitude 5° 23' 0" N, with an elevation of about 272 ft above sea level. The topography within a 2-mile radius of Arochukwu is moderately undulating, with elevation changes ranging between 200 and 350 ft. Within a 10-mile radius, the area displays rolling hills and valleys, while the broader 50-mile region features more pronounced variations, with elevations extending up to 1,000 ft above sea level, especially towards the Cross River Basin. Arochukwu lies within the southeastern sedimentary basin of Nigeria, characterised by complex geological formations that are part of the Lower Benue Trough. The Asu River Group, a sedimentary unit that dates back to the Albian age of the Early Cretaceous period, dominates the area. The Asu River Group primarily comprises shales, sandstones, and claystones interspersed with limestones and siltstones, which were deposited in a marine to deltaic environment. Older basement complex rocks underlie these formations. Arochukwu falls within the Afikpo Basin, characterized by sedimentary deposits primarily from the Cretaceous period. The geological formations in this region include: Ajali Formation, Mamu Formation and, Nkporo Shale.

The clay deposits in Arochukwu are typically associated with weathering and sedimentary processes that have enriched the area with fine-grained, kaolinitic clay materials. The soils in the region are generally light grey to reddish-brown in colour, reflecting variations in mineral content and oxidation states. The clay layers are often interbedded with silty and sandy formations, indicative of their depositional environment in fluvial and marine settings. The vegetation around Arochukwu reflects its location within the tropical rainforest zone, characterised by dense forest cover, with over 60% of the area within 2 miles covered by trees. Farmland accounts for about 20%, with the remainder consisting of grasslands and shrubs. Within 50 miles, the land cover transitions to include more cultivated lands and open forests, reflecting the economic activities of the region, which include agriculture and artisanal mining. Geologically, Arochukwu's clay-rich formations have been noted for their potential in industrial applications, including ceramics and bricks. The fine particle size, plasticity, and moderate swelling capacity of these clays make them particularly promising for such uses. Their development and evaluation, particularly for the oil and gas industry, could contribute to reducing Nigeria's dependence on imported materials while supporting local content initiatives.

METHODS

The following equipment were used for this research:



Rota shaker sieve   Mortar and Pestle   Mud Sample



Weighing Balance   Hamilton Beach mixer (model 936-1   Six Speed Rheometer – coquette type, coaxial cylinder rotational viscometer (model 286)

Baroid Mud Balance and Sand Content Test Kit

Sample Collection and Preparation

Clay samples from Arochukwu in Abia State were freshly sourced from an excavation pit at a depth of approximately 1.7 metres, targeting horizontal layers rich in sodium, calcium, and magnesium-based minerals. These samples were processed by crushing into smaller granules and subsequently oven-dried to facilitate further pulverisation and sieving. The dried samples were ground into fine powder using a mortar and pestle and sieved with a Rota shaker to achieve a particle size fraction of 63 µm, aligning with API standards for bentonite. The processed clay was stored in a labelled beaker, marked with masking tape for easy identification. Specific quantities of 17.5 g, 21.0 g, and 24.5 g of the fine clay sample were measured into separate mixer containers using an electronic weighing balance, with each container appropriately labelled. To each clay sample category, 350 ml of distilled water was measured using a 500 ml measuring cylinder and combined with the clay. A Hamilton Beach mixer (model 936-1) was employed to mix the samples thoroughly, ensuring homogeneity. The prepared mixtures were allowed to hydrate over a 24-hour period to facilitate full interaction between the clay particles and the water. Following hydration, the samples were re-agitated to achieve uniformity before conducting characterisation tests.

Mud Weight Characterisation

The weight or density of the prepared drilling mud samples was evaluated to determine whether they met API-specified standards, a critical factor for maintaining wellbore stability during drilling. Adequate mud weight is necessary to provide sufficient hydrostatic pressure to counteract formation pressures and prevent influxes, while avoiding excessive density that could cause circulation loss, formation damage, or reduced drilling efficiency. The study examined the mud weight over five days, with measurements taken at 24-hour intervals. The primary equipment for this test included a Baroid mud balance, calibrated to an accuracy of ±0.1 lb/gal, and a Hamilton Beach mixer (model 936-1). Other materials included freshly prepared mud samples, clean rags, distilled water, masking tape for labelling, and a notebook for recording results. The procedure began with measuring the mud sample temperature to ensure compliance with standard calibration conditions. The mud balance base was positioned on a stable, level surface, and the mud balance cup was cleaned and dried. The cup was filled with the mud sample, and its cap securely attached to expel excess mud and remove air pockets. After sealing the vent hole, the exterior of the cup was cleaned to remove residual mud. The mud balance arm was then placed on the support base, and the rider adjusted along the graduated scale until the bubble level aligned with the centreline. The mud density was read at the left edge of the rider to the nearest 0.1 lb/gal and recorded in various units such as lbs/gal, lb/cu.ft, and specific gravity. The entire process was repeated daily for each mud sample over four additional days to monitor changes in density.

Mud Rheology Characterisation

Rheological analysis of the mud samples was conducted to evaluate properties such as viscosity at 600 rpm, 300 rpm, and 3 rpm, as well as plastic viscosity, apparent viscosity and yield point. These parameters are essential for assessing the flow characteristics of drilling mud and ensuring efficient drilling operations. The experiments utilised a six-speed rotational viscometer (Couette-type, model 286) designed to measure viscosities and apply the Bingham plastic model for drilling mud analysis. The materials used included freshly prepared mud samples, masking tape for labelling, a thermometer, a recording notebook, and a pen. The rheometer, equipped with a torsion spring-loaded dial, provided measurements proportional to shear stress. To begin, the viscometer was powered and set up according to the manufacturer's guidelines. Approximately two-thirds of a thermal cup was filled with a freshly prepared mud sample, which was then secured on the viscometer stand, ensuring the rotary sleeve was submerged to the scribed mark. The cup was locked in position, and a thermometer was inserted to maintain the mud sample at a standard temperature of 115° ±2°F. The viscometer's toggle switch was activated to the high-speed setting (600 rpm), and the rotor sleeve was allowed to stabilise. Once the dial reading stabilised, the value was recorded. The speed was then reduced to 300 rpm, and the same process was followed to document the stabilised reading. Lastly, the rheometer was set to operate at 3 rpm to measure the gel strength of the mud. This step required precise attention due to the low-speed nature of the measurement. Once stabilised, the reading at 3 rpm was recorded. These readings were used to compute key rheological properties, including plastic viscosity (difference between 600 rpm and 300 rpm readings) and yield point, which were crucial for assessing the flow and integrity of the drilling mud. This systematic procedure ensured accuracy and consistency in determining the rheological characteristics across multiple shear rates. The readings obtained at various rotational speeds formed the foundation for determining both plastic viscosity and yield point. The plastic viscosity (PV) and yield point (YP) were calculated based on the principles of the Bingham plastic model, represented mathematically as:

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

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

Where:

θ_{600} is the dial reading at 600rpm

θ_{300} is the dial reading at 300rpm

Plastic viscosity indicates the resistance to flow due to the internal friction between fluid layers while yield point represents the initial stress required to start fluid flow, indicating the mud's capacity to suspend and transport drill cuttings. The calculated PV and YP values were essential for assessing the mud's performance and suitability for field applications, such as maintaining wellbore stability, preventing formation damage, and ensuring efficient drilling fluid circulation.

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 serves as an indicator of its acidity or alkalinity, which is determined by the concentration of hydrogen ions present. This parameter is essential for assessing the chemical stability of the mud and identifying any contamination by substances such as cement or gypsum. A neutral pH of 7.0 signifies chemical equilibrium, whereas alkaline muds typically exhibit pH values ranging from just above 7 to 14, denoting increasing levels of alkalinity. Conversely, acidic muds have pH values below 7, with values approaching 1 indicating strong acidity. The ideal pH range for drilling mud depends on its composition and application, as it influences mud stability, performance, and compatibility with the well environment. For this study, the pH of freshly prepared mud samples was evaluated using a **Hamilton Beach mixer (model 936-1)** in conjunction with phydrion dispenser paper, a reference chart, and standard documentation tools such as masking tape, a biro, and a notebook. The testing began with thorough re-stirring of the prepared mud samples to ensure homogeneity. A strip of phydrion dispenser paper, approximately one inch in length, was placed gently on the surface of the mud. The paper absorbed the mud filtrate, initiating a colour change that corresponded to the pH level. After a brief waiting period to allow the reaction to stabilise, the paper strip was compared to the reference chart provided with the dispenser to determine the pH value.

Note: The pH measurement process was conducted initially and then repeated daily over four days for each mud sample to monitor any changes.

Sand Content Determination

The determination of sand content in drilling mud is critical for evaluating its suitability for drilling operations, particularly due to the abrasive nature of sand-sized particles. High sand content can lead to excessive wear on drilling and pumping equipment, as well as the formation of a thick filter cake that interferes with the proper functioning of the wellbore. The method employed in this study for assessing the sand content of locally sourced Arochukwu clay follows the standard sieve analysis approach, recognised for its reliability and simplicity. The Baroid Sand Content Set was used for this study. The set includes a 200-mesh sieve (74-micron), a calibrated glass measuring tube marked from 0 to 20% to directly indicate sand content by volume, and a funnel. Additional materials included freshly prepared mud samples, clean water, a fine spray bottle, a clean rag, masking tape, a recording notebook, and a pen.

Freshly prepared mud samples formulated from Arochukwu clay were used for this analysis. Each sample was poured into the Baroid Sand Content Tube up to the mark labelled *"Mud to Here."* Clean water was added to the mark labelled *"Water to Here."* The tube was sealed with a thumb and shaken vigorously to thoroughly mix the mud and water. This step ensured the complete dispersion of particles for accurate sand separation. The mixture was poured through the 200-mesh sieve, ensuring all components were screened. The tube was rinsed with additional water, which was also passed through the screen to ensure no sand particles adhered to the tube walls. Sand particles retained on the sieve were carefully washed under a gentle stream of water to remove any adhering mud or shale particles. This step was performed meticulously to ensure that only sand-sized particles were retained on the screen.

The funnel was fitted over the screen, and the assembly was inverted. A fine spray of water was used to wash the retained sand back into the glass measuring tube. The sand was allowed to settle in the calibrated tube. The settled sand volume, including void spaces between grains, was observed and recorded as the sand content, expressed as a percentage of the total mud volume. To ensure consistency and accuracy, the procedure was repeated for all mud samples, and sand content determination was conducted periodically over the study period. This step aimed to evaluate any temporal variations in the sand content of the samples.

RESULTS AND DISCUSSIONS

The mud properties characterised in this study were evaluated against the API standard value for mud properties as presented in table 1 below;

Table 1 API Standard Value for Mud Properties

Mud Weight	**(8.65-9.0)ppg**
Mud Ph	9.5-12.5
600rpm	30cp(min)
300rpm	30cp(min)
Sand Content	<1.0
PV	(8-10)
YP	3PV

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

	Mud Ph		
	24.5g	21g	17.5g
Day 1	7.5	7.2	6.8
Day 2	7.3	7	6.5
Day 3	7.2	6.8	6.3
Day 4	7	6.5	6
Day 5	6.8	6.3	5.8

The pH values of the mud samples prepared with Arochukwu clay varied across different concentrations (24.5 g, 21 g, and 17.5 g) and over five days, highlighting the dynamic chemical properties of the clay when used in drilling mud formulation. Based on the data recorded, a chart of pH against time (in days) was plotted to visualise the trend properly.

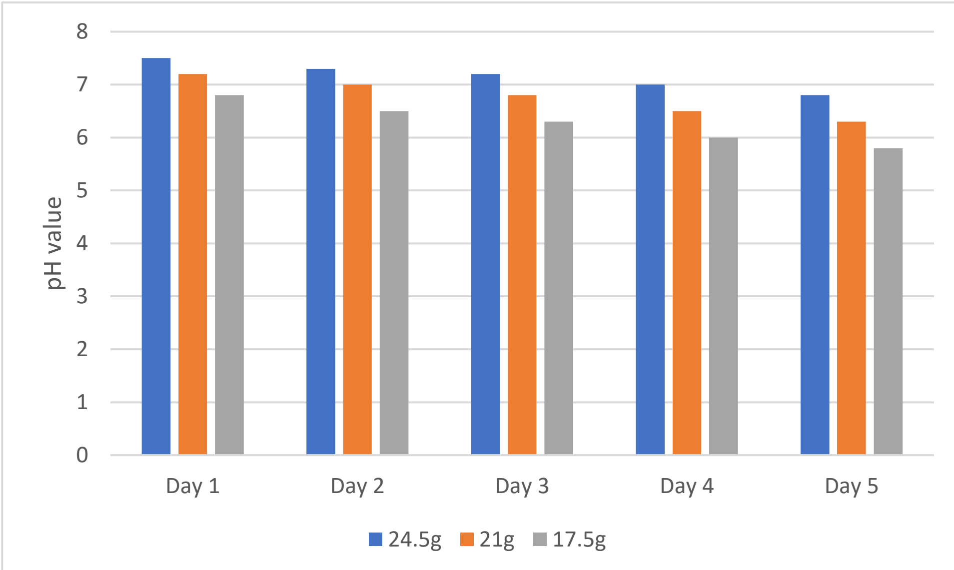

Figure 1: A chart showing the mud pH over time

The 24.5 g sample exhibited the highest initial pH value of 7.5 on Day 1, indicating a slightly alkaline nature, and gradually decreased to 6.8 by Day 5, transitioning towards neutrality. Similarly, the 21 g sample began with a pH of 7.2, showing moderate alkalinity on Day 1, but dropped steadily to 6.3 by the fifth day. The 17.5 g sample, representing the lowest concentration, started with an initial pH of 6.8, slightly below neutral, and reduced consistently to 5.8, indicating a mildly acidic trend by Day 5. These observations suggest that the pH of the mud is influenced by both the concentration of the clay and the aging period. Higher concentrations of clay (24.5 g) maintained a more stable and alkaline pH profile compared to lower concentrations (17.5 g), which exhibited a sharper decline in pH. The decline in pH across all samples over time may be attributed to chemical reactions within the mud, such as the leaching of acidic components or interaction with dissolved ions in the water. These findings reveal the importance of concentration and aging in maintaining the desired chemical balance of drilling muds. When compared to the API pH standard for bentonite clay, the different concentrations fell short of the API standard of 9.5 as the sample exhibited slightly acidic and neutral properties.

Table 3 Mud weight of the three mud samples over 5 day period

	24.5g	21g	17.5g
Day 1	8.6	8.5	8.3
Day 2	8.7	8.6	8.5
Day 3	8.8	8.7	8.6
Day 4	8.5	8.6	8.8
Day 5	8.8	8.5	8.4

Similarly, the mud weight was also observed over the same period and data recorded in Table 3. The mud weight characterisation of Arochukwu clay-based drilling muds revealed variations influenced by clay concentration and the aging period, which are critical parameters for evaluating drilling mud performance. The 24.5 g sample consistently exhibited the highest mud weight values, beginning at 8.6 lb/gal on Day 1 and reaching a peak of 8.8 lb/gal on Days 3 and 5, demonstrating its superior capacity to provide hydrostatic pressure. The 21 g sample maintained relatively stable mud weights, with minor fluctuations between 8.5 and 8.7 lb/gal over the testing period, indicating moderate adaptability for maintaining density within operational requirements. Conversely, the 17.5 g sample recorded the lowest mud weight values, starting at 8.3 lb/gal on Day 1, peaking at 8.8 lb/gal on Day 4, and declining to 8.4 lb/gal on Day 5, reflecting its limited capacity for sustaining consistent density.

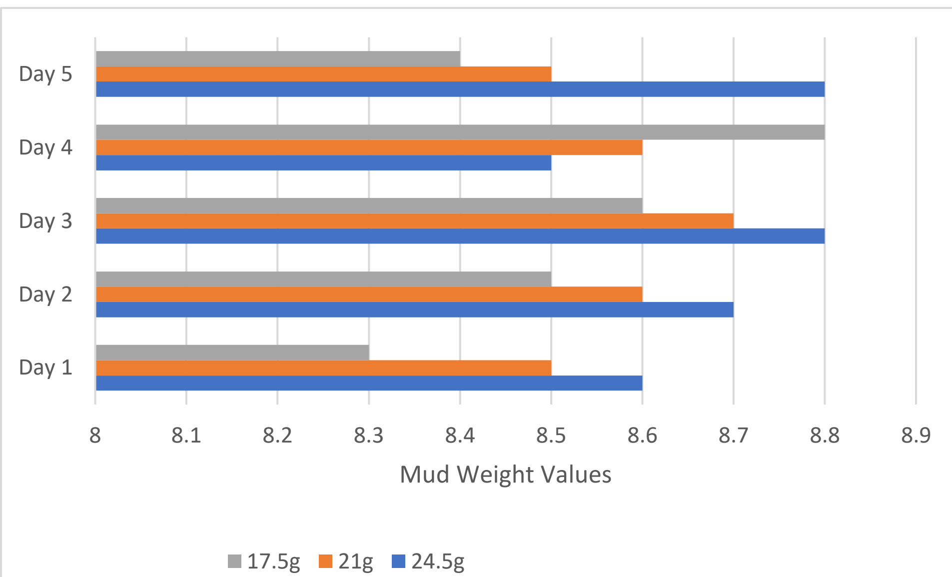

Figure 2: A chart showing the mud weight over time

The observed variations in mud weight was visualised in figure 2 above and further suggests that higher clay concentrations (24.5 g) enhance the density of the drilling mud, aligning more closely with API minimum standards for bentonite-based muds which is within 8.65ppg to 9.0 ppg. The periodic fluctuations in mud weight across all samples could be attributed to the hydration dynamics of the clay particles, dissolution of solid components, or slight inconsistencies in the re-agitation process during testing. These findings highlight the potential of Arochukwu clay for formulating drilling muds, particularly at higher concentrations, while indicating the need for optimisation to ensure sustained mud weight stability across prolonged operations. Such insights contribute to assessing its compatibility with industry standards and suitability for application in drilling operations.

Table 3 Sand concentration of the three mud samples over 5 day period

Mud Sand Content %			
	24.5g	21g	17.5g
Day 1	0.35	0.25	0.5
Day 2	0.35	0.25	0.25
Day 3	0.35	0.25	0.25
Day 4	0.35	0.3	0.25
Day 5	0.35	0.3	0.25

The sand content results obtained from the testing of locally sourced Arochukwu clay for potential use in drilling mud formulation indicate a consistent pattern across the five-day testing period. For the 24.5g sample, the sand content remained steady at 0.35% throughout the test duration, showing minimal fluctuation. In contrast, the 21g sample exhibited a slightly variable sand content, with values remaining at 0.25% for the first three days before increasing to 0.3% by the fourth and fifth days. The 17.5g sample showed a more variable pattern, with sand content peaking at 0.5% on Day 1, before decreasing to 0.25% on subsequent days and maintaining this value throughout the rest of the test period. These results suggest that the Arochukwu clay, when formulated into drilling mud, exhibits relatively low and stable sand content, which is desirable for maintaining optimal mud properties. The sand content of the 24.5g sample remains particularly consistent, indicating that the clay formulation may be suitable for use in scenarios where stable mud characteristics are required. The slight increase observed in the sand content of the 21g sample by Day 4 and Day 5 could be due to changes in the clay's interaction with water or minor variations in sample composition. The fluctuation in sand content for the 17.5g sample, especially the initial spike on Day 1, may indicate that the clay requires further conditioning or preparation to ensure uniformity in its composition. This is represented in figure 3.

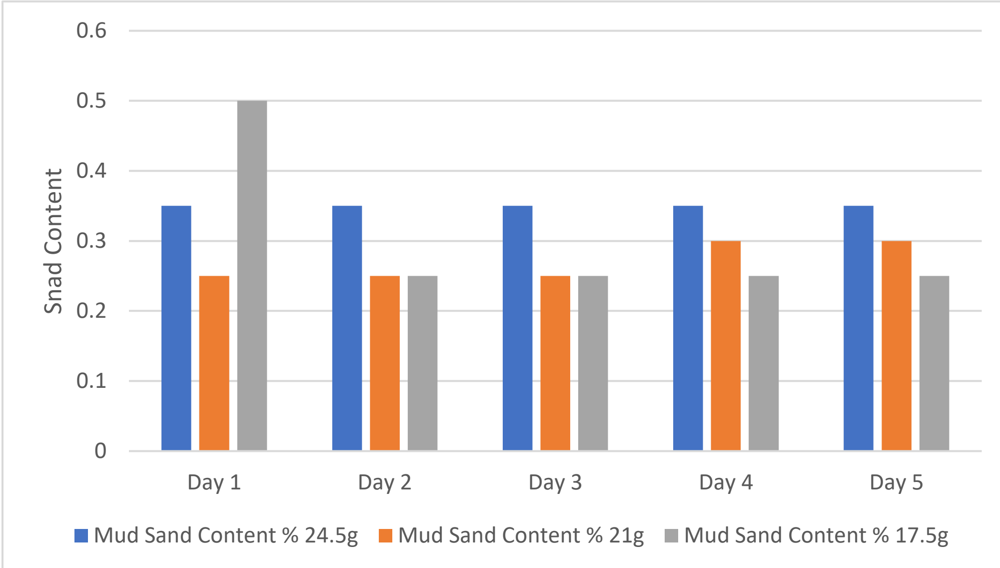

Figure 3: A chart showing the mud sand content over time

In comparison with API standards for bentonite clay, which typically specifies low sand content of less than 1% to prevent excessive wear on drilling equipment and to ensure proper fluid circulation, the Arochukwu clay samples generally show promising results. However, the sand content in the 17.5g sample could potentially exceed acceptable limits for some drilling operations, highlighting the importance of ensuring consistency and minimal variation in sand levels during mud formulation. Regular monitoring of sand content is essential for fine-tuning the formulation process, ensuring that it meets industry standards for performance and reliability.

Table 5 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	3	4	1	3.5	4.5	1	3	4	1.5	2.5	3.5	1	2.5	3	1
21	2.5	3	1.75	2	3	1.5	2	3.5	1	3	3.5	0.5	2	2.5	1.5
24.5	2.4	3.5	1.5	2.5	3	1	3	4	1.75	2	3	1	2.5	3	1

The rheological behaviour of drilling mud samples formulated with Arochukwu clay was evaluated using viscometric readings at 3, 300, and 600 RPM over five days for three clay concentrations (17.5 g, 21 g, and 24.5 g) and presented in table 5 above and also visualised in figure 5 below. These parameters provide insight into the plastic viscosity (PV), yield point (YP), of the mud, which are critical for assessing its suitability as an alternative to API-standard bentonite clay. For the 17.5 g sample, the viscometric readings (θ_3, θ_{300}, θ_{600}) indicated consistent but low rheological values across the evaluation period. At 600 RPM, θ_{600} ranged from 3cp to 4.5cp, while θ_{300} ranged from 2.5cp to 3.5cp and θ_3 exhibited minor fluctuations around 1cp to 1.5cp. These results reflect a low overall viscosity and gel strength, which may limit the mud's ability to suspend drill cuttings and maintain stability in high-temperature or high-pressure environments. Notably, the decrease in θ_{600} and θ_{300} from Day 4 to Day 5 suggests potential degradation in the suspension capacity over time.

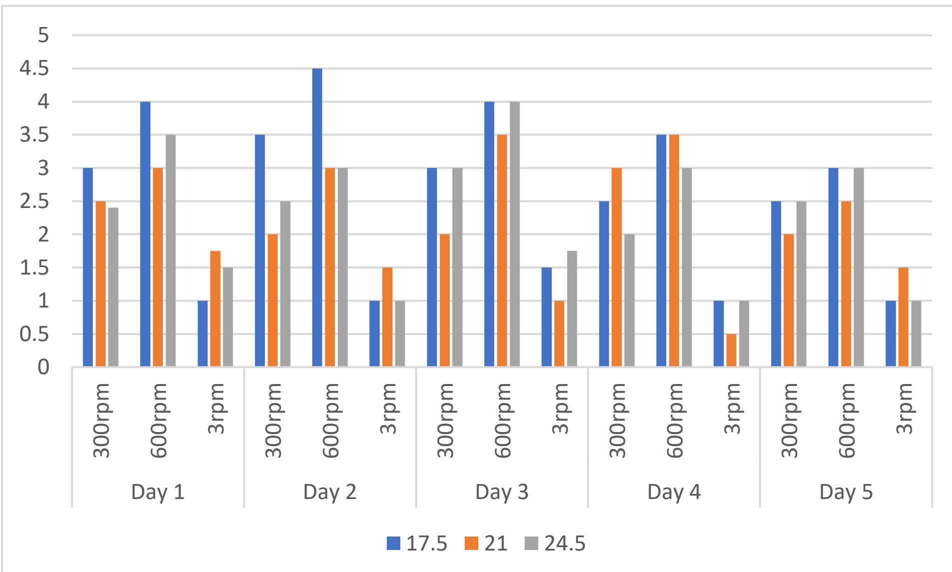

Figure 4: A chart showing the mud viscometer readings over time

The 21 g sample demonstrated slightly better rheological performance, with θ_{600} values peaking at 3.5cp and θ_{300} values stabilising between 2cp and 3cp. However, θ_3 showed less consistency, fluctuating between 0.5cp and 1.75cp over the test period. For the 24.5 g sample, the θ_{600} and θ_{300} readings were more consistent, with θ_{600} ranging from 3 to 4 and θ_{300} varying from 2 to 3.5. Notably, the θ_3 values were relatively stable, peaking at 1.75 on Day 3. This sample exhibited the highest overall among the tested concentrations, suggesting that increasing clay concentration improved the mud's rheological properties. However, the results remain below API-recommended standard of 30 cp, which require higher values for critical parameters to ensure the mud's functionality in typical drilling conditions.

Table 6 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	1	2	0.5	1	2.5	0.5	1	2	0.5	1	1.5	0.5	0.5	2	0.25
21g	0.5	2	0.25	1	1	0.5	1.5	0.5	0.75	0.5	2.5	0.25	0.5	1.5	0.25
24.5g	1.1	1.3	0.55	0.5	2	0.25	1	2	0.5	1	1	0.5	0.5	2	0.25

For the 17.5 g mud sample, the PV as shown in table 6 remained constant at 1 cP from Day 1 to Day 4 before reducing to 0.5 cP on Day 5, indicating minimal resistance to flow. The YP showed slight variations between 1.5 lb/100 ft² and 2.5 lb/100 ft² over the testing period. Similarly, the AV consistently exhibited low values, averaging 0.5 cP throughout. These results indicate that the 17.5 g concentration might not provide adequate viscosity for effective hole cleaning, especially at higher annular velocities, when compared to API standards for drilling-grade bentonite, which typically require a minimum yield point of 3 lb/100 ft².

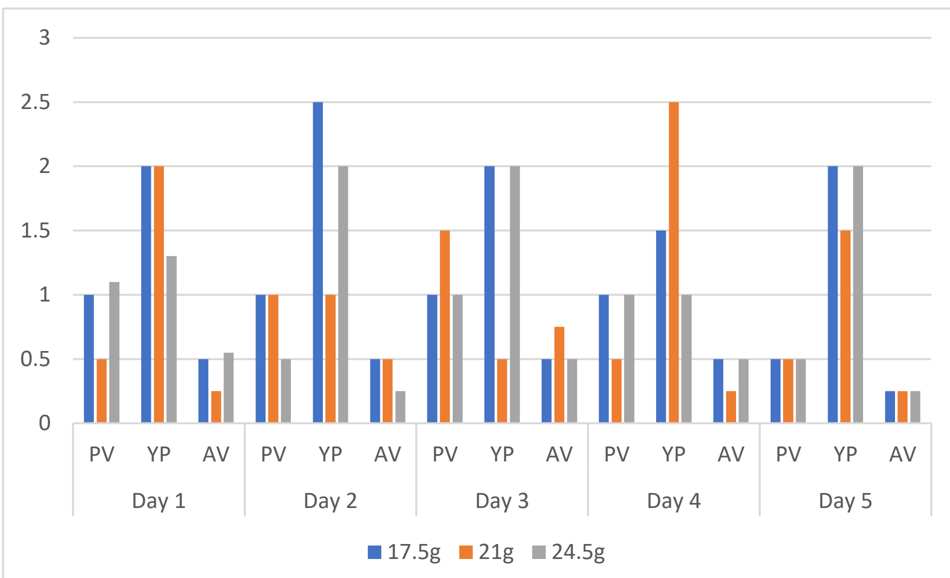

Figure 4 A chart showing the mud PV, YP and AV measurement over time

The 21 g sample demonstrated a more dynamic response in rheological properties, with PV fluctuating between 0.5 cP and 1.5 cP, and YP ranging from 0.5 lb/100 ft² to 2.5 lb/100 ft² over the five days. The AV values remained low, peaking at 0.75 cP on Day 3. While this sample exhibited slightly improved rheological behaviour compared to the 17.5 g sample, its overall performance was still suboptimal when benchmarked against API standards, which recommend higher plastic and apparent viscosities for effective suspension of drill cuttings. The 24.5 g sample showed relatively consistent rheological properties over time, with PV values ranging from 0.5 cP to 1.1 cP, and YP values stabilising between 1 lb/100 ft² and 2 lb/100 ft² across the testing period. The AV values remained consistently low, reaching a maximum of 0.55 cP on Day 1. While the increase in clay concentration improved some properties, such as PV and YP, these values still fell below the API benchmarks for high-quality bentonite, which typically requires a PV of at least 8 cP, YP of at least 3x PV and an AV of 15 cP for effective rheological performance in water-based drilling muds.

CONCLUSIONS

The evaluation of Arochukwu clay for drilling mud formulation reveals promising potential, although certain properties fall short of the established API standards for bentonite clay. The study assessed various mud properties, including pH, mud weight, sand content, rheological characteristics, and the plastic viscosity (PV), yield point (YP), and apparent viscosity (AV) to determine the clay's suitability for use in drilling operations. The pH of the mud samples showed a gradual decline over the five-day testing period, with higher clay concentrations maintaining a more alkaline profile, which is essential for controlling corrosion and ensuring the stability of the drilling mud. However, all samples did not meet the API standard of a pH between 9.5 and 12.5, suggesting that the Arochukwu clay, particularly at lower concentrations, may require modification or additional chemical treatments to optimise its pH for drilling applications. In terms of mud weight, the Arochukwu clay-based muds demonstrated reasonable performance, with the 24.5 g sample achieving a stable density near the API standard range of 8.65 to 9.0 ppg. While the higher concentrations showed potential for maintaining consistent hydrostatic pressure, the lower concentration samples (17.5 g) exhibited more variability in mud weight, which could limit their operational effectiveness in maintaining wellbore stability.

Nonetheless, the sand content of the Arochukwu clay samples generally aligned with the API standard, maintaining values below the 1% threshold. The 17.5 g sample exhibited some variability in sand content, suggesting that further conditioning or refinement of the clay could enhance its consistency. The rheological properties of the Arochukwu clay-based muds, as indicated by the viscometric readings, demonstrated that increasing the concentration of clay improved the mud's overall viscosity and gel strength. However, the rheological performance was still below the API standards for bentonite, especially in terms of PV, YP, and AV, which are critical for ensuring efficient cuttings suspension and fluid flow in drilling operations. The 24.5 g sample showed the best rheological performance but still did not meet the API benchmark for high-quality drilling muds. Overall, Arochukwu clay holds significant potential as an alternative material for drilling mud formulation, particularly at higher concentrations. However, further refinement and optimisation are necessary to meet all API standards, particularly in terms of pH, rheological properties, and viscosity, for it to be fully compatible with the rigorous demands of modern drilling operations.

RECOMMENDATIONS

Based on the findings of this study, several recommendations are made below to enhance the suitability of Arochukwu clay for drilling mud formulation, particularly in comparison with API standards for bentonite clay:

1. **Clay Concentration Optimization**: The study indicates that higher concentrations of Arochukwu clay (24.5 g) provide more stable mud properties. To optimise its use in drilling mud formulations, this study recommends to experiment with even higher clay concentrations

and investigate their impact on mud properties such as viscosity, pH, and density. However, care must be taken to balance the concentration to avoid excessively high densities, which could result in operational difficulties.

2. **Chemical Additives for pH Adjustment**: Given that the pH values of the mud samples fell below the API standard range (9.5–12.5), this study recommends to explore the addition of chemical additives, such as alkaline agents or pH stabilisers, to improve the alkalinity of the mud. This would enhance the mud's ability to control corrosion and optimise its performance during drilling operations.
3. **Enhance Rheological Properties**: The rheological properties of the Arochukwu clay-based muds were found to be below the API standards, particularly in terms of plastic viscosity (PV) and yield point (YP). Thus, this study recommends the experimenting with combinations of Arochukwu clay and other rheological enhancers, such as viscosifiers, to improve the mud's flow characteristics and gel strength. This will ensure better suspension of drill cuttings and improve the mud's performance in high-temperature and high-pressure environments.
4. **Pilot-Scale Testing and Field Trials**: While laboratory tests offer valuable insights, pilot-scale testing and field trials are essential to fully assess the performance of Arochukwu clay in actual drilling operations. Conducting trials in wellbores with varying geological conditions and comparing the results with commercially available drilling muds would provide a clearer understanding of the clay's operational viability and its potential for scale-up.

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