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Economical Cost Effect of Rheological Properties of Local Clay to Imported Bentonite

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ABSTRACT: Rheological properties of local clays obtained from Aviara and Uzere of Delta State Nigeria, compared to imported Bentonite clay, the industry standard for drilling mud formulation. The research aims to evaluate the suitability of local clay rheology as a cost-effective alternative to Bentonite in drilling operations. Laboratory analyses were conducted to determine Local clay rheological properties —apparent viscosity, plastic viscosity, and yield point – measurable to API standards. Each sample, dial readings were recorded at 600 RPM and 300 RPM which was used to calculate key rheological parameters: Apparent Viscosity (AV) – an indicator of the overall viscosity of the mud under flowing conditions: AV = 600 RPM reading. Plastic Viscosity (PV) – a measure of the mud's resistance to flow due to internal mechanical friction between solid particles: PV = 600 RPM reading – 300 RPM reading. Yield Point (YP) – the measure of the mud's ability to lift and suspend drilled cuttings under static conditions: YP = 300 RPM reading – PV. These parameters provided insight into two critical aspects of mud performance: 1. PV reflects the internal friction and solids concentration. 2. YP reflects the electrochemical attractive forces between particles, which directly influence cuttings-carrying capacity. Gel strength was also determined to assess the behavior of the mud—the ability to develop a gel structure when static and to break down upon agitation. For this, the mud sample was allowed to stand undisturbed in the viscometer for 10 seconds and 10 minutes. After each rest period, the viscometer rotor was turned at 3 RPM, and the maximum dial reading before gel breakage was recorded as the initial gel strength (10 seconds) and 10-minute gel strength, respectively. This entire rheological evaluation procedure was repeated for both the local clay-based muds and the bentonite-based muds, enabling a direct comparison of their flow characteristics, cuttings transport potential, and gelation behavior under standardized laboratory conditions. Results showed that Bentonite exhibited superior apparent viscosity, plastic viscosity and yield point confirming its established performance in drilling applications. However, the local clays demonstrated moderate apparent viscosity, plastic viscosity and yield point ratios, as potential for drilling mud. Limitation observed is lesser inherent capacity compared to imported Bentonite which can be mitigated through substantial chemical treatment to enhance adequate suspension of drill cuttings and hole cleaning to serve as partial or full substitutes for Bentonite, thereby lowering operational costs and reducing reliance on imported bentonite.

KEYWORDS: Yield point (structure), Overall viscosity (plastic viscosity), Chemical Additives

INTRODUCTION:

Nigerian clays, when properly beneficiated, have the potential to serve as effective substitutes for imported bentonite in drilling operations. Numerous studies (Odom, 1987; Okogbue & Ene, 2008; Egbuchinem et al., 2022; Chukwu et al., 2019) have demonstrated that various local clays can achieve physicochemical and rheological properties within API-recommended standards, particularly in terms of viscosity, swelling capacity, and filtration control. Chemical activation methods—such as sodium carbonate treatment, acid treatment with polymer blending, and thermal-mechanical activation—have proven effective in upgrading initially unsuitable clays.

More recent research has expanded to cover a wider range of geological locations and beneficiation methods. Egbuchinem et al. (2022) showed that Abakaliki clays, when treated with sodium carbonate, achieved swelling indices approaching those of commercial bentonite. Chukwu et al. (2019) observed similar improvements in clays from the Anambra Basin, with post-treatment viscosity and filtration properties meeting API standards.

Earlier, Imuentinyan and Adewole (2014) conducted a feasibility study on clays from the Ikpoba and Ovia rivers in Edo State. Although their detailed results were not publicly accessible, the study emphasized Nigeria's heavy reliance on imported bentonite and the potential of local substitutes to reduce foreign exchange expenditure (Imuentinyan & Adewole, 2014).

Nigeria possesses abundant clay deposits, yet millions of dollars are spent annually importing bentonite for drilling operations (Nwabineli et al., 2020). This heavy reliance on imported materials has prompted researchers to investigate the potential of locally sourced clays as cost-effective and sustainable substitutes for bentonite. Studies indicate that with suitable beneficiation, many Nigerian clays can achieve 12 physicochemical and rheological properties comparable to imported bentonite (Odom, 1987).

Several comparative studies reinforce these findings. Egbo and Ehinola (2021) examined the mineralogical and geochemical properties of clays from the Awgu area (Enugu State), noting lower smectite but higher kaolinite content than bentonite, indicating the need for beneficiation. A Springer (2022) study on calcium-based clays from the Dikwa Formation found that sodium carbonate activation significantly improved viscosity (from ~8 cP to 26–35.5 cP), yield point, and thixotropic behavior, though performance remained slightly below Wyoming bentonite.

Plasticity refers to the ability of clay to undergo deformation without cracking. Bentonite exhibits a high plasticity index, which makes it more adaptable in drilling fluid applications (Olatunde et al., 2011; Murray, 2007). In contrast, local clays with kaolinite-dominated mineralogy typically have moderate to low plasticity, limiting their workability in mud formulation unless blended with other additives (Adewole et al., Nigerian local clays contain higher proportions of kaolinite or mixed-layer minerals, which exhibit lower plasticity, reduced swelling potential, and lower CEC values (Ogunniyi et al., 2012; Bassey et al., 2020). These mineralogical differences largely determine their suitability for drilling mud applications.

In Edo State, Eze et al. (2020) demonstrated that sodium-based activation of local clays resulted in rheological properties that closely matched imported bentonite. Likewise, Mohammed and Salisu (2017) found that Sokoto clay, although initially unsuitable, could be upgraded via acid treatment and polymer blending for water-based drilling mud.

Treating clays with strong mineral acids (e.g., HCl, H_2SO_4) leaches out impurities, increases surface area, and enhances cation exchange capacity (CEC) (Kelessidis & Christidis, 2007; Ofoegbu, 2018). To improve the performance of local clays and make them comparable to imported bentonite (Olatunde et al., 2011), several modification and beneficiation techniques. The pH of clay suspensions affects dispersion, stability, and chemical reactivity in drilling fluids. Most bentonites exhibit mildly alkaline pH values (8–10), which favor wellbore stability and dispersion (Olarewaju et al., 2018; Olatunde et al., 2011). The pH of local clays varies depending on mineralogy, weathering history, and impurities (Bassey et al., 2020). Chemically, clays contain major oxides such as SiO_2, Al_2O_3, Fe_2O_3, MgO, and CaO, which influence thermal stability, density, and interaction with drilling fluid components (Murray, 2007; Bello et al., 2015).

METHODOLOGY:

Sample Collection

Three local clay samples were collected from three different locations within Aviara/Uzere towns to ensure sample representativeness and to account for spatial variability in clay composition. The collection was carried out in accordance with the American Petroleum Institute (API) standard procedures for sampling clay for drilling mud applications. Each sample was obtained from surface deposits to a depth of approximately 0.5 meters using clean, non-contaminating tools to avoid any alteration in the clay's natural properties. The samples were labeled and transported in airtight polyethylene bags to prevent moisture loss or contamination.

The bentonite clay used in this study was sourced from a nearby commercial dealer at Ughelli. It is commonly utilized in industrial and research applications due to its high swelling and binding capacity. The sample was confirmed to meet API Specification 13A for drilling-grade bentonite and was used as the standard reference for comparing the physicochemical properties of the local clay samples.

Sample Preparation

In the laboratory, the samples were air-dried at room temperature to remove excess moisture without altering their structure. The dried clays were then crushed and sieved using a 75 µm mesh to ensure uniform particle size suitable for analysis.

Analysis of Mud:

Viscosity, postulates a drilling mud’s struggle to flow, typically assessed by two key parameters: apparent and plastic viscosity. Apparent viscosity reflects the fluid’s resistance at a defined shear rate and plays a crucial role in preventing drilling complications, thus enhancing wellbore cleaning efficiency (Al-Khdheeawi and Mahdi, 2019). While, plastic viscosity is the effect of the mud’s solid content, serving as a pointer of the concentration of solids present in the fluid (Abdelrahman et al. 2019). The plastic viscosity (PV), apparent viscosity (AV), yield point (YP), power law index (n), and consistency index (K) was determined using Eq. (1-5) (Ali et al. 2022)

�� = �600 −�300 ------1

�� = �600/ 2 ------------2

�� = log �600/�300 ----------3

� = log � (600/�300)/log2---------- 4

� = �600/ 511� --------5

Determination of Rheological Properties:

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Rheological properties describe how drilling mud behaves and flows under various shear conditions, a factor that is critical for effectual cuttings transportation, borehole cleaning, and preserving wellbore stability during drilling operations. Proper rheological control guarantees that drilled cuttings are lifted effectively from the bit to the surface while lessening formation damage and maintaining pressure balance in the well.

For this study, rheological evaluation was conducted on both local clay-based muds (prepared from samples collected in Aviara/Uzere and imported bentonite muds for comparison. The testing procedure followed the recommended practices outlined in API RP 13B-1. The process began by preparing each mud sample at a standard concentration of clay solids—22.5 g of clay per 350 ml of distilled water. The clay and water were placed in a mixing container and stirred forcefully using a mechanical mixer to achieve a uniform suspension free of knobs. The prepared slurry was then allowed to age for 24 hours under ambient conditions to ensure complete hydration of the clay minerals, as adequate hydration influences viscosity development and overall rheological behavior. Rheological measurements were taken using a rotational direct-indicating viscometer (Fann 35 or equivalent), which is widely used in drilling fluid analysis to degree shear stress at several shear rates.

For each sample, dial readings were recorded at 600 RPM and 300 RPM. These readings were then used to calculate key rheological parameters: Apparent Viscosity (AV) – an indicator of the overall viscosity of the mud under flowing conditions: AV = 600 RPM reading ÷ 2 Plastic Viscosity (PV) – a measure of the mud's resistance to flow due to internal mechanical friction between solid particles: PV = 600 RPM reading – 300 RPM reading 36 Yield Point (YP) – the measure of the mud's ability to lift and suspend drilled cuttings under static conditions: YP = 300 RPM reading – PV.

These parameters provided insight into two critical aspects of mud performance: 1. PV reflects the internal friction and solids concentration. 2. YP reflects the electrochemical attractive forces between particles, which directly influence cuttings-carrying capacity. In addition to these flow parameters, gel strength was determined to assess the thixotropic behavior of the mud—the ability to develop a gel structure when static and to break down upon agitation. For this, the mud sample was allowed to stand undisturbed in the viscometer for 10 seconds and 10 minutes. After each rest period, the viscometer rotor was turned at 3 RPM, and the maximum dial reading before gel breakage was recorded as the initial gel strength (10 seconds) and 10-minute gel strength, respectively.

This entire rheological evaluation procedure was repeated for both the local clay-based muds and the bentonite-based muds, enabling a direct comparison of their flow characteristics, cuttings transport potential, and gelation behavior under standardized laboratory conditions. Comparative Analysis Data obtained from all laboratory tests were systematically tabulated for clarity and ease of interpretation.

Table below presents the API-recommended standard values for the selected physiochemical properties of clay used in drilling mud formulations. These values serve as the baseline reference for the comparative evaluation presented in the subsequent sections of this study.

Property	API/Standard (Bentonite)
Apparent Viscosity (AV	≥ 15 CP
Plastic Viscosity (PV)	10–15 CP
Yield Point (YP)	15–30 lb/100 ft²
Gel Strength (10s/10min)	3–10 lb/100 ft² (10s), up to 30 lb/100 ft² (10min)

RESULT AND DISCUSSION

RPM	300	600	AV (cp)	PV (cp)	YP (lb/100 ft²)	GS (lb/100 ft²) 10sec	GS (lb/100 ft²) 10min
S1	4.2	8	4	3.8	0.4	0.44	0.60
S2	4	6	3	2	2	2.02	3.0
Bentonite	18	24	12	6	12	12.06	18.0

The results were then subjected to statistical comparison to identify significant differences or notable similarities between the local clay samples (S1 and S2) and the commercial bentonite clay. In order to determine the suitability of the local clay samples for use in drilling mud preparation, it was necessary to compare their measured physiochemical properties with established industry specifications. The American Petroleum Institute (API) provides widely accepted guidelines that define the recommended ranges for key clay properties in drilling mud formulations. Such comparison is essential because deviations from these standards may lead to operational challenges such as poor cuttings transport, excessive fluid loss, formation damage, or accelerated equipment wear.

The rheological properties are crucial in determining mud performance in the drilling process, particularly its ability to transport drill cuttings, maintain wellbore stability, and minimize fluid loss. The key rheological parameters evaluated in this study are apparent viscosity (AV), plastic viscosity (PV), and yield point (YP), measured at 300 and 600 rpm for two local clay samples (S1 and S2) and Bentonite clay. The apparent viscosity is a measure of the fluid's overall resistance to flow and is indicative of the mud's thickness. In this study, Bentonite exhibited the highest apparent viscosity value of 12 centipoise (cP), which is significantly greater than that of the local clay samples S1 and S2, which recorded AV values of 4 cP and 3 cP, respectively. The higher apparent viscosity of Bentonite suggests it forms a thicker, more cohesive mud system, which is advantageous for suspending and transporting drill cuttings to the surface during circulation. Plastic viscosity, representing the internal resistance caused primarily by the solid particles suspended within the mud, is derived from the difference between the readings at 600 rpm and 300 rpm. The Bentonite sample had the highest plastic viscosity of 6 cP, compared to 3.8 cP and 2 cP for S1 and S2, respectively. This elevated plastic viscosity reflects a higher concentration of solids and stronger particle interactions in Bentonite mud, which contributes to a more stable and robust mud structure. Conversely, the lower plastic viscosity values of the local clays imply a less viscous slurry with weaker inter-particle bonding, which may reduce its effectiveness in wellbore cleaning.

The yield point is a critical parameter that reflects the minimum stress needed to initiate fluid flow and is indicative of the mud's ability to suspend solids when circulation ceases. Bentonite demonstrated a yield point of 12 lb/100 ft^2, considerably higher than the values recorded for S1 (0.4 lb/100 ft^2) and S2 (2 lb/100 ft^2). The high yield point of Bentonite suggests superior gel strength and enhanced capacity to prevent solids from settling during pauses in drilling operations. Among the local clays, S2 showed a moderate yield point, which indicates a somewhat better suspension capability than S1. The notably low yield point of S1, however, indicates a weak gel structure, posing a risk of solids settling that can lead to operational issues such as stuck pipe or poor hole cleaning.

CONCLUSION

In summary, the rheological analysis clearly indicates that Bentonite clay possesses superior drilling mud properties compared to the local clays tested. Its higher apparent viscosity, plastic viscosity, and yield point contribute to a mud system that is more effective in carrying cuttings, maintaining wellbore stability, and preventing sedimentation. The local clays, while showing some potential, particularly S2, would likely require chemical or physical modification to enhance their rheological properties for effective use as drilling muds. Without such improvement, their lower viscosities and weak gel strengths may compromise drilling performance, increasing the risk of operational problems. The results show that bentonite possesses excellent gel strength properties, making it capable of effectively holding cuttings in suspension during pauses in drilling. This is a critical requirement in drilling operations as it prevents cuttings from settling at the bottom of the hole, which could lead to stuck pipe and inefficient hole cleaning when circulation resumes. On the other hand, S1 and S2 exhibited much lower gel strength values, indicating limited ability to keep solids suspended. This means that, in their natural state, these local clays may not meet the American Petroleum Institute (API) recommended range for gel strength and would require beneficiation—such as chemical treatment or blending with bentonite—to improve their performance which is less economical in cost compared to the imported Bentonite with high exchange rate that affect its purchase as well as availability at standard quantity for operation.

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