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Comparison of Physiochemical Properties of Local Clay Samples to Bentonite

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Abstract - **Physiochemical properties of local clays obtained from Aviara and Uzere of Nigeria were compared to commercial Bentonite clay, the industry standard for drilling mud formulation. The research aims to evaluate the suitability of local clay as a cost-effective alternative to Bentonite in drilling operations. Laboratory analyses of two samples were conducted to determine key parameters, counting moisture content, bulk density, specific gravity, pH, swelling capacity, plasticity index, kinematic viscosity, sand content, and fluid loss. The moisture content of the local clay samples (S1 and S2) was determined to be 13.5% and 17.2%, respectively compared to API standard of maximum of 13.0% by mud weight. Relatively higher moisture content in S2 indicates ability to retain more water in its natural state compared to S1 due to higher clay mineral content, finer particle size, or a more porous structure which influence the clay's ability to absorb and hold water as well as improve swelling behavior and plasticity. Kinematic viscosity measurement under gravity shows S1 = 2.47 mm²/s, S2 = 2.01 mm²/s, and Bentonite = 24 mm²/s. Results showed that, S1 and S2 are very low — thin fluids — and therefore will be poor at suspending cuttings and prone to solids settling if used unmodified and Bentonite exhibited excellent and superior swelling capacity, viscosity, fluid loss control, and plasticity, confirming its established performance drilling applications. However, additives of soda ash (Na_2Co_2) of 3 to 5 grams per 350 ml of water clay will increase the Ph to 9 as well as improve viscosity andalter calcium montmorillonite in local clay to high-swelling sodium.3 and 2 grams of Carboxymethyl cellulose and Tanni respectively can reduce filtration loss to API standard by 1 gram per 350 ml and Xanthan gum of 1gram to 350 ml can improve the rheology properties (viscosity, yield point, gel strength). Alternatively, this makes local clay as a substitute less costly to use than Bentonite from all sources.**

Keywords: Bentonite, swelling capacity, plasticity index, kinetic viscosity, Chemical composition, cation exchange capacity (CEC).

I. Introduction

Extreme value for moisture content was set to 13% (Trauger, 1994) while API value is set to be 15% as standard which is not very relevant in bentonite act. The moisture contents of the four samples obtained in literature were in between 4 and 7%. These values fall within the range stated by Ahonen *et al.* (2008). The pH ideals of the clays were alike to the pH reported by Nweke *et al.* (2015), Shah *et al.* (2013), and James *et al.* (2008) and were within the resonated given for both Na and Ca bentonite (8.5 to 10.5).

Ayotunde (2014) reviewed that the rheological properties of WBM do not always remain constant, which is undoubtedly a precursor to drilling challenges such as mud density as well as fluid loss. Khan *et al* (2018) stated that potential aqueous polymers improve swelling capacity of hydrophilic bentonite particles which increased mud rheology by 14% and reduce fluid loss by 12%.Alves *et.al*. (2019) reported that polymer, xanthan gum influence flow properties of water-based drilling fluid to 0.15% to 0.55% rise in plastic viscosity.

Parameter	*This study*		*Nweke et al. (2015)*	Ahonen et al. (2008)	James *et al.* (2008)	API Standard (Bentonite)
	S1	*S2*				
Moisture (%)	13.5	2.47	NA	6.0-16.0	NA	≤10–15%
pH	5.73	5.32	7.8-9.3	NA	8.82	8.5 – 10
Density (g/cm3)	1.176	1.150	1.45-1.68	NA	0.961	0.9-1.0g/cm³
Swelling test (ml/2g)	8.0	11.5	NA	23-30	NA	≥ 16 ml/2 g

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Opalinski, M, Chutkowski (2016) Stated that rheology flow shape of moistened samples is conspicuously and distinctly affected by both moisture content varying in the range of 0 – 15% w/w. and shear rate which shows complex meddling different shearing mechanisms in the presence of moisture. Klausner *et al*, (2000) reported that flow regime is usually based on the bed behavior which does not flow with similarity to that of a solid or a fluid. Tardos (1997) stated that theoretical considerations concerning flow regime are usually based on kinetic theory of gas which during slow or moderate flows, particles are in contact for extended periods of time and predominantly responsible for energy dissipation is particles frictional sliding.

II. Sample Collections and Method

Three local clay samples were collected from three different locations within Aviara town 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. 23 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. 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.

2.1 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.

2.2 Experimental procedure

The physiochemical properties of the local and Bentonite clay samples were determined in accordance with standard procedures. These properties include moisture content, bulk density, specific gravity, pH, swelling capacity, and plasticity index. The procedures used for each property are detailed below.

Determination of Moisture Content:

The moisture content of the clay samples was determined in accordance with the ASTM D2216 standard test method, which is widely used for measuring the water content of soils, clays, and similar materials. The procedure began by selecting a representative portion of each moist clay sample to ensure that the measured values accurately reflected the bulk material. A clean, dry crucible was first weighed using a precision balance, and this value was recorded as W_1. A portion of the moist clay sample was then placed into the crucible, and the combined weight was recorded as W_2. The crucible containing the moist clay was placed in a drying oven set at a constant temperature between 105°C and 110°C. This temperature range is sufficient to evaporate the free and adsorbed water present in the clay without altering its mineral structure. The samples were dried for 24 hours to ensure complete removal of moisture. After the drying period, the crucible was removed from the oven and allowed to cool in a desicator to prevent the reabsorption of atmospheric moisture during weighing. The final weight of the crucible plus the dried clay was then recorded as W1.

Determination of Bulk Density:

The bulk density test was conducted to determine the mass of the clay per unit volume, including the volume of the pore spaces between particles. This parameter provides insight into the clay’s packing characteristics, porosity, and its suitability for various drilling mud formulations. A clean, dry container of known volume (typically 100 cm^3) was first weighed to obtain its empty weight. Dry clay samples, previously oven-dried to remove moisture, were then gently poured into the container without applying any compaction, in order to simulate natural particle arrangement. The surface of the clay was carefully leveled with a straight edge to ensure an even top without pressing the material down. After this, the container filled with clay was weighed again, and the mass of the clay alone was obtained by subtracting the empty container weight from the combined weight.

Bulk Density (g/cm^3) = Mass of dry clay (g)/ Volume of container (cm^3)

Determination of Specific Gravity:

The specific gravity of the clay samples was determined according to ASTM D854 using the pycnometer method. About 10 g of oven-dried clay was weighed and transferred into a clean, dry pycnometer bottle. Distilled water was added, and the mixture was stirred to remove air bubbles. The bottle was then filled to the calibration mark and weighed. Separately, the pycnometer filled with only distilled water was also weighed.

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Specific Gravity = Mass of clay per unit volume / Mass of water with same volume as the clay solids

$$\frac{(W_2 - W_1)}{(W_2 - W_1) - (W_4 - W_3)}$$

Determination of pH:

The pH of the clay samples was determined following the ASTM D4972 procedure. This test was conducted by preparing a 1:2.5 suspension of clay in distilled water. Specifically, 10 grams of dry, sieved clay was mixed with 25 mL of distilled water in a clean beaker. The mixture was stirred thoroughly and left to stand for 30 minutes to allow for stabilization. A calibrated pH meter was then inserted into the suspension to measure the pH. The pH value gives an indication of the clay's acidity or aalkalinity, which affects its reactivity, dispersion, and compatibility with additives used in drilling mud.

Determination of Swelling Capacity:

Swelling capacity was assessed using a simple volume displacement method. Two grams of dry clay sample was placed in a 100 mL graduated cylinder, and distilled water was added up to the 100 mL mark. The cylinder was then shaken gently and allowed to stand undisturbed for 24 hours. After this period, the final volume occupied by the swollen clay was recorded. Swelling capacity was calculated as the increase in volume due to water absorption, which reflects the clay's ability to hydrate and expand. High swelling capacity is crucial in drilling mud as it contributes to viscosity and gel strength.

Determination of Plasticity Index:

The plasticity index (PI) of the clay was determined according to ASTM D4318 through the Atterberg limits test. First, the Liquid Limit (LL) was obtained using the Casagrande apparatus. Clay paste was placed in the brass cup and a groove was cut using the standard grooving tool. The cup was dropped from a fixed height, and the number of blows required to close the groove was recorded. The water content at which the groove closed in 25 blows was taken as the liquid limit. Next, the Plastic Limit (PL) was determined by rolling the clay into threads until they crumbled at a diameter of 3 mm. The corresponding water content was taken as the plastic limit.

Determination of Kinematic Viscosity:

The kinematic viscosity of the clay suspensions was determined in accordance with ASTM D445, which outlines the standard procedure for measuring the viscosity of transparent and opaque liquids using a glass capillary viscometer. This property is an important indicator of the internal resistance to flow of a liquid under the influence of 31 gravity, and in the context of drilling mud, it directly affects the fluid's ability to suspend and transport cuttings in the wellbore. The test employed a calibrated glass capillary viscometer—typically an Ubbelohde or Cannon-Fenske model—capable of providing precise measurements under controlled laboratory conditions. Before testing, each viscometer was inspected to ensure it was clean and free from any residues that might influence flow time or accuracy. A clay suspension was prepared by weighing out a known proportion of dry clay powder, generally in the range of 2–4% by weight, and mixing it thoroughly with distilled water. Mixing was done using a high-shear mechanical stirrer to ensure uniform dispersion of particles. The slurry was then allowed to hydrate completely— often for a period of several hours or overnight—to ensure that all clay particles had absorbed water and reached full swelling potential. To remove oversized particles and prevent blockages in the viscometer tube, the fully hydrated suspension was passed through a fine filter or sieve. The prepared suspension was then carefully introduced into the viscometer, which had been placed vertically in a constant-temperature water bath maintained at 25°C. This controlled temperature is critical, as viscosity is highly sensitive to thermal changes; even small fluctuations can produce significant variations in measured values. The test involved measuring the flow time for the clay suspension to travel between two clearly marked calibration points on the viscometer's capillary tube. This was done by drawing the liquid above the upper timing mark and then allowing it to flow under gravity while recording the time taken to pass from the first timing mark to the second using a calibrated stopwatch. Multiple readings were taken for each sample to ensure accuracy and repeatability, with the average time used for calculations. The kinematic viscosity was computed by multiplying the recorded average flow time (in seconds) by the viscometer constant (in mm^2/s^2), a value supplied by the manufacturer during instrument calibration:

Determination of Sand Content:

The sand content of the clay samples was determined to evaluate the proportion of coarse, non-clay particles present, as this parameter significantly influences the clay's plasticity, workability, and suitability for drilling mud formulations. Excessive sand content can reduce the clay's binding properties and increase its abrasiveness, potentially accelerating wear on drilling equipment. The procedure followed a simple wet sieving method adapted from the general principles of ASTM D7928-21 – Standard Test Method for Particle-Size Distribution (PSD) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis and

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Wet Sieving (ASTM International, 2021), using a 75 µm (No. 200) sieve to separate the coarse fraction from the finer clay and silt particles.

2.3 Physiochemical mud Analysis

Viscosity, which indicates a drilling mud's resistance to flow, is typically assessed through 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). In contrast, plastic viscosity represents the influence of the mud's solid content, serving as an indicator 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).

III. Results and Discussion

This chapter presents the results obtained from the laboratory analysis of the physiochemical properties of the local clay samples (S1 and S2) collected from Aviara, Delta State, and the imported Bentonite clay. The results are compared and discussed in relation to API standards for drilling mud and findings from previous studies.

Samples	Moisture content (%)	Kinematic viscosity (mm²/s	Bulk density (kg/m³)	Specific gravity	pH	Swelling capacity (ml)	Plasticity index (%)	Sand content (%)
S1	13.5	2.47	1.176	2.61	5.73	8.0	21	23
S2	17.2	2.01	1.150	2.54	5.32	11.5	25	21
Bentonite	-	24.0	1.60	2.0	8.7	18.0	40	0.5

The moisture content of the local clay samples (S1 and S2) was determined to be 13.5% and 17.2%, respectively. However, moisture content for the Bentonite sample could not be measured as the clay was received in a completely dry and processed form. This is typical for commercial Bentonite, which is usually oven-dried or sun-dried before packaging to ensure consistent performance in drilling applications. The relatively higher moisture content in S2 indicates that it retains more water in its natural state compared to S1. This can be attributed to several factors, such as higher clay mineral content, finer particle size, or a more porous structure. These factors 42 influence the clay's ability to absorb and hold water, which plays a role in its swelling behavior and plasticity.

Kinematic viscosity measures resistance to flow of a fluid (here, clay suspension) under gravity and is important for suspension and cuttings transport in a mud. The results are S1 = 2.47 mm²/s, S2 = 2.01 mm²/s, and Bentonite = 24 mm²/s. The very high viscosity of Bentonite explains its excellent suspension and gel-forming ability: it creates a thick fluid that holds cuttings and forms stable filter cakes. By contrast, S1 and S2 are very low — thin fluids — and therefore will be poor at suspending cuttings and prone to solids settling if used unmodified. In practice this means S1 and S2 need rheology modifiers (e.g., increased clay concentration, sodium activation, or polymers like CMC/PAC to raise viscosity and develop sufficient gel strength for drilling operations.

Bulk density is the mass of the material per unit volume including pore spaces; it tells us how compact the material is when handled in bulk. The measured values were S1 = 1.176 g/cm³, S2 = 1.150 g/cm³, and Bentonite = 1.600 g/cm³. Bentonite's notably higher bulk density indicates a denser, less-porous product — so a smaller volume of Bentonite will deliver the same solid mass compared with the local clays. For drilling mud formulation this means S1 and S2 would require a larger volume of material to reach the same solids concentration and mud weight as Bentonite. Practically, lower bulk density in the local clays suggests they are more porous or loosely packed; when using them you should account for higher transport and storage volumes and consider compaction or drying steps to improve handling. If the objective is to match mud weight or solids content, either more local clay or addition of a weighting agent (e.g., barite) will be needed.

Specific Gravity: Specific Gravity of Aviara local clay (S1 and S2) and bentonite clay. Specific gravity is the density of the solid particles relative to water (solids-only), important for predicting contribution to mud weight. Measured: S1 = 2.61, S2 = 2.54, Bentonite = 2.75. These SG values are typical for clay minerals and show that Bentonite particles are slightly denser; consequently, Bentonite contributes more mass per unit volume of solids. For mud design this means S1 and S2 will require greater mass to reach a target mud density, or alternatively they can be blended with a denser material to increase SG without excessive volume.

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pH indicates acidity/alkalinity and affects dispersion, additive chemistry, and corrosion. Results: S1 = 5.73, S2 = 5.32, Bentonite = 8.7. The local clays are acidic while Bentonite is alkaline in the desired API range. Acidic pH in S1/S2 can cause poor dispersion of clay platelets, reduced swelling, and incompatibility with common mud chemicals; it may also increase corrosion risk. The practical remedy is to condition the clay/mud with an alkaline treatment (e.g., sodium carbonate or caustic soda) to raise pH into the alkaline range (around 8.5–10) before formulating mud.

Swelling capacity measures how much volume the clay gains hydration which is directly linked to viscosity and filter-cake formation. Values: S1 = 8.0 mL, S2 = 11.5 mL, Bentonite = 18 mL. Bentonite's strong swelling explains its superior viscosity and sealing ability. The lower swelling of S1 and S2 explains their low kinematic viscosity and higher fluid loss: they cannot expand enough to plug pore spaces efficiently. Practically, sodium activation (e.g., with Na_2CO_3) or blending with Bentonite can increase swelling and improve mud performance.

Parameters	Plastic limit (%)	Liquid Limit (%)	Plasticity index (LL – PL) (%)
S1	24.10	47.10	21.2
S2	26.20	50.30	24.5
Bentonite	110	150	40

The Atterberg limits (Liquid Limit – LL, Plastic Limit – PL, and Plasticity Index – PI)

For the local clays, S1 recorded a PI of 21.20, PL of 24.10%, and LL of 47.1%, while S2 recorded a PI of 24.50%, PL of 26.20%, and LL of 50.30%. These LL values fall within the moderate plasticity range typical for kaolinite–smectite mixed clays in Southern Nigeria (35–60%), as reported by Nwankwo and Igboekwe (2011) and Awodola and Oyediran (2020). The slightly higher PI of S2 compared to S1 suggests that S2 can retain a greater amount of water before transitioning from the plastic to liquid state, indicating a marginally better performance in suspension stability. The bentonite sample exhibited a PI of 40.00%, PL of 110.00%, and LL of 150.00%. This very high LL reflects the exceptional water-absorbing capacity and swelling potential of bentonite, especially sodium bentonite, which is known to have LL values ranging from 150% to over 500% (Ofoegbu & Odoh, 2016). The large difference between LL and PL (i.e., high PI) means bentonite maintains its plasticity over a much broader range of water contents compared to the local clays. This explains its superior performance in maintaining drilling mud viscosity, forming a gel structure, and effectively suspending drill cuttings. The observed differences have practical implications: while S1 and S2 could potentially be used in drilling mud preparation, their lower PI and LL values compared to bentonite indicate they may require beneficiation (e.g., sodium activation) to match bentonite's performance. Among the two local clays, S2 is more promising due to its slightly higher PI and LL, which suggest improved workability and water retention.

Sand (coarse, non-clay particles) is undesirable in drilling mud because it abrades pumps and bits and prevents a uniform cake. Results: S1 = 23%, S2 = 21%, Bentonite = 0.5%. The local clays have very high sand content and thus require screening/washing or tempest to remove coarse particles prior to use. Bentonite's low sand content is one reason as superior for drilling fluids.

Fluid loss (API filtrate after 30 minutes) indicates how much liquid escapes into the formation. Measured: S1 = 19 mL, S2 = 13 mL, Bentonite = 10 mL. Lower fluid loss is better; many drillings' specifications target ≤15 mL. S2 meets this practical target (13 mL) and therefore shows acceptable filtration control; S1 exceeds it (19 mL) and would risk formation invasion and instability. Bentonite's low fluid loss (10 mL) confirms its ability to form thin, low-permeability cakes. For S1, use of fluid-loss control additives (polymers, starches, PAC, or increased fine fraction) is recommended.

IV. Conclusion

This study evaluated the physiochemical properties of two local clay samples (S1 and S2) obtained from Aviara and Uzere, Isoko South LGA, Delta State, in comparison with commercial Bentonite clay, which serves as the industry benchmark for drilling mud formulation. The comparative analysis revealed that Bentonite consistently outperformed the local clays in key performance indicators, including kinematic viscosity, swelling capacity, yield point, gel strength, and fluid loss control — properties critical to efficient cuttings suspension, wellbore stability, and filtration control in drilling operations. Nevertheless, the local clays demonstrated moderate moisture content, specific gravity, and plasticity indices, which fall within ranges reported in previous studies for kaolinite–smectite clays in Southern Nigeria and indicate baseline suitability for drilling applications. S2, in particular, showed slightly better swelling capacity, lower fluid loss, and higher plasticity index than S1, suggesting it may respond more favorably to beneficiation. Identified limitations include high sand content (21–23%), acidic pH (5.32–5.73). These shortcomings can be addressed through mechanical beneficiation (e.g., wet sieving, typhoon) to reduce sand content, and chemical treatments such as sodium activation and pH adjustment with alkaline agents (e.g., Na_2CO_3) to enhance dispersion, swelling, and gel strength. Overall, while untreated Aviara and Uzere clays in their natural state do not

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meet API specifications for drilling mud, their physicochemical profile indicates that with targeted modification, they could serve as cost-effective partial substitutes or local alternatives to imported Bentonite. Adoption of such beneficiated clays could reduce 55% dependence on imports, lower drilling operational costs, and promote sustainable exploitation of indigenous mineral resources in Nigeria.

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