

BENEFICIATION POTENTIAL OF POLYMERIC ADDITIVE ON THE RHEOLOGICAL AND FILTRATION PROPERTIES OF LOCAL BENTONITE IN WATER-BASED MUD

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Abstract

The continuous importation of drilling fluid additives such as bentonite increases mud formulation costs and limits the growth of local content in the petroleum industry. This study examines the impact of a synthetic polymer, Hyperdrill AF251, on the rheological and filtration properties of a water-based mud (WBM) formulated with locally sourced bentonite, and compares its performance with that of foreign bentonite in accordance with API standards. Five polymer mud samples (C1-C5) were formulated with local bentonite and Hyperdrill concentrations ranging from 0.5 g to 3 g, along with a foreign bentonite control. Beneficiating the local bentonite with 0.3 g NaOH increased alkalinity from 7.44 to 9.3. Mud weight improved to 8.65 lb/gal for the beneficiated sample, compared with 8.45 lb/gal (local) and 8.55 lb/gal (foreign). Rheological results showed substantial gains: plastic viscosity (6-20 cP for C1-C5) represented an 83-95% increase over the foreign sample (5 cP); yield point increased by 60-92.7%; and apparent viscosity rose by 76.4-94.8%. Gel strength values remained within API-recommended limits. Filtration tests revealed a steady decrease in filtrate volume with increasing Hyperdrill concentrations, matching the performance of foreign bentonite at an additive concentration of 0.5 g. Optimal results occurred at 1.5-3 g Hyperdrill. For drilling operations, these improvements result in improved hole cleaning, enhanced cuttings suspension, reduced filtrate volume, and more stable borehole conditions. Adopting beneficiated local bentonite with Hyperdrill at the wider industry level can lower production and import costs, foster local employment, and strengthen indigenous capacity in drilling fluid formulation, reducing dependence on imported additives while meeting performance standards.

Keywords: Water-based mud; Filtration properties; Bentonite; Drilling Fluids; Hyperdrill; Rheological Properties

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Introduction

The performance of drilling fluids depends primarily on carefully monitoring solids, including their type, quantity, and particle size. These factors underpin most treatment strategies used in drilling operations (Omole *et al.*, 2013). Proper control of viscosity and filtration behavior is critical for efficient drilling, as it ensures effective cuttings removal, reduces the risk of wellbore instability, and minimizes downtime (Oyedoh *et al.*, 2016; Igwilo *et al.*, 2020). Polymers are commonly used to regulate these properties in water-based muds. In contrast, bentonite clay, a naturally occurring clay, provides essential thixotropic, swelling, and absorption characteristics required in various industrial applications (Onwuachi-Iheagwara, 2012; Adeyemi *et al.*, 2020; Anthony *et al.*, 2020).

Nigeria has extensive bentonite reserves, but they are not of the quality required for drilling activities, unlike natural clays. They are usually characterized by large amounts of calcium montmorillonite (Ca²⁺-smectite). They generally possess a lower cation exchange capacity (CEC), a lesser swelling capacity, and also contain more non-clay minerals, such as quartz, feldspar, kaolinite, or iron oxides (Onwuachi-Iheagwara, 2012). A lower montmorillonite content reduces gel strength and viscosity, whereas excessive calcium and magnesium ions disrupt dispersion and cause flocculation (Muhammad & Siddiqua, 2022). This results in low gel strength, high filtration rates, and low viscosity, and typically does not meet API specifications (Abdullahi, 2011; Olatunde *et al.*, 2012; Shuwa & Sabiu, 2019).

Heavy reliance on imported bentonite raises operational costs and imposes a significant financial burden. As a result, improving the performance of

local bentonite is essential to provide a cost-effective and sustainable alternative for the oil and gas sector (Wilfred & Akinade, 2016; Afolabi *et al.*, 2018). In contrast, foreign bentonite that meets API standards primarily consists of sodium montmorillonite (Na⁺-smectite) (American Petroleum Institute, 2013). It has a high CEC, swells easily in water, and contains few impurities such as quartz, feldspar, kaolinite, or iron oxides. This purity and sodium dominance give it excellent swelling power, gel strength, and viscosity (Ismaeel *et al.*, 2017; Muhammad & Siddiqua, 2022).

Beneficiation, or activation, involves modifying native bentonite to improve its rheological and filtration properties. Methods include chemical treatment, thermal modification, and the addition of polymers or bio-materials, transforming calcium-rich clays into sodium-based montmorillonite suitable for drilling fluids (Onwuachi-Iheagwara, 2012; Shuwa and Sabiu, 2019). Table 1 summarizes key studies on the beneficiation of Nigerian bentonite.

Hence, chemical treatment, especially with sodium carbonate, increases the yield point, plastic viscosity, and swelling capacity, thereby meeting international bentonite standards. Polymers are present in their natural form to increase viscosity and reduce filtrate volume (starches and biomaterials), while also controlling filtrate volume (polymer) and offering added stability and API compliance (synthetic polymers, such as CMC). Such observations suggest that beneficiation, followed by the inclusion of carefully selected additives, is a viable approach for developing high-performance drilling fluids from local clay.

Table 1. Summary of Nigerian Bentonite Beneficiation Studies

Study	Source / Location	Beneficiation / Additive Method	Key Outcomes
Falode <i>et al.</i> , 2008	Pindiga formation, NE Nigeria	12.5% potash & starch; 40 g/350 ml Na ₂ CO ₃	Yield point increased by 64%, Plastic viscosity increased by 750%, Swell volume increased by 3000%, Mud cake thickness reduced by 55%, filtrate volume reduced by 32%
Abdullahi (2011).	Upper Benue Basin	Sodium carbonate treatment	Similar rheological characteristics to commercial bentonite.
Olatunde <i>et al.</i> , 2012	Various	Guar gum (viscosifier), Arabic gum (stabilizer)	Increased filtration and viscosity.
Sarah & Isehunwa (2015).	SE & Niger Delta	Oyster shells (Crassostrea virginica)	Decreased loss of circulation; little influence on viscosity.
Ahmad <i>et al.</i> , 2018	Local	Cassava & maize starch	Better plastic, apparent viscosity, and yielding point at ambient temperature, thermal degradation at high temperatures.
Udeagbara <i>et al.</i> , 2019.	Local	Potassium chloride, soda ash, PAC-R	Rheological properties were met at the API level.
Igwilo <i>et al.</i> , 2020	Local	Mucuna solan, snail shell, and chemical additives	Bentonite Filtration and viscosity; similar or better than imported.
Shuwa and Sabiu, 2019	Local	Wet & dry Na ₂ CO ₃ + CMC	This results in increased rheology and decreased filtrate volume, making it a cost-effective solution

The additives play a significant role in enhancing the drilling muds developed using locally available bentonite. The effectiveness of local resources such as cassava, maize, oyster shells, and mucuna solanica in enhancing rheology and management of the filtration process has been attempted, and traditional polymers are still extensively used in the oil and gas industry (Iscan & Kok, 2007; Dankwa *et al.*, 2018; Ibrahim *et al.*, 2019). On the whole, polymers increase viscosity and yield point and regulate the loss of filtrate. Starches can be used at ambient temperatures, though they can deteriorate at high temperatures. The oyster shells are bio-materials that aid in dampening lost circulation, but not much in terms of viscosity. These studies demonstrate that the beneficiation approach can be combined with additive approaches to optimize the performance of Nigerian bentonite in drilling applications (Omole *et al.*, 2013; Afolabi *et al.*, 2017).

Hyperdrill AF 251 is an anionic polyacrylamide, a water-soluble synthetic polymer of acrylamide or a mixture of acrylamide with acrylic acid. It contains amine ($-NH_2$) and carbonyl ($C=O$) groups, which enable hydrogen bonding, thereby increasing particle aggregation and viscosity, as indicated in Figure 1. Key properties include:

- Hydrophilic and water-soluble
- Highly crystalline, allowing significant swelling when heated
- Low molecular weight, retaining water up to five times its weight and swelling 12-16 times its dry bulk (Voronova *et al.*, 2020).

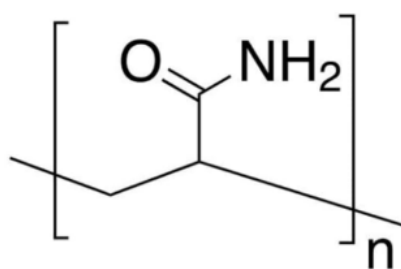


Figure 1. Chemical structure of polyacrylamide

Although previous researchers have demonstrated that beneficiation and additives can enhance the performance of Nigerian bentonite, little is known about the combined effect of synthetic polymers, such as Hyperdrill, on the performance of local clay under drilling conditions. The paper assesses Hyperdrill's impact on the rheological and filtration behavior of water-based

mud prepared using locally available bentonite, aiming to optimize performance and provide viable information on how drilling mud preparation can be optimized to reduce reliance on imported clays. (Onwuachi-Iheagwara, 2012)

Materials and Methods

Materials

The materials used, including local bentonite from Adamawa State, Nigeria; foreign bentonite, deionized water, PAC-R, sodium hydroxide, Barite, and Hyperdrill AF 251 polymer, were of analytical grade. The sourcing was done at the Drilling Fluid Engineering Laboratory of Covenant University, Ota, Ogun State, Nigeria. The foreign bentonite was purchased from the Trading and Supply Company in Ikoyi, whereas the Hyperdrill AF 251 polymer was acquired from PACEGATE Energy and Resources Limited in Ilupeju, Lagos, Nigeria.

Adamawa local bentonite, found in the northeast of Nigeria, is primarily calcium-bearing montmorillonite clay with a comparatively low natural swelling capacity. In its untreated state, such clay contains fine particles, yet it exhibits low plasticity and poor gel strength. It is composed of silica (SiO_2) and alumina (Al_2O_3), although it also contains impurities such as quartz, carbonates, and iron oxides. These, in combination with a high calcium content, reduce the clay's capacity to swell, hydrate, and exchange cations (Shuwa & Sabiu, 2019; Igwilo *et al.*, 2020). Table 2 summarizes the elemental makeup of the clays.

Mud Testing and Properties Evaluation

Formulation of water-based Muds

To prepare the mud, 400 ml of water was precisely measured using a measuring cylinder, poured into the Hamilton Beaker Mixer (HMO200-CE), and secured to the mixer. The mixer was plugged into a power supply. 25g of Bentonite was measured using an electric weighing balance, poured into the Hamilton beaker mixer, and stirred for 5 minutes to ensure even mixing and a lump-free mixed mud. (0.5g - 3g) The weight of the polymer was measured on the electronic chemical balance. It is poured into the Hamilton mixer, containing an evenly mixed water and bentonite, and stirred for 25 minutes to ensure it is evenly mixed and to avoid lumps (Abdullahi, 2011; Olaniyan & Sarah, 2024). The mud samples were sequentially blended using the OFITE Multimixer (Model 8008), as outlined in Table 3, in accordance with API Specification 13A for drilling fluid materials.

Table 2. Elemental composition of Local Bentonite and Wyoming (API-grade) Bentonite (Source: Nweke *et al.*, 2015; Bilal *et al.*, 2016; Chinwuba *et al.*, 2021).

Composition (wt.%)	Composition Name	Local Bentonite (Abia, Ca-type)	Wyoming Bentonite (Na-type)
SiO ₂	Silicon dioxide (Silica)	45 – 60 (commonly 48–55)	50 – 61 (avg. ~60.9)
Al ₂ O ₃	Aluminium oxide (Alumina)	12 – 18 (commonly 14–16)	10 – 12
Fe ₂ O ₃	Ferric oxide (Iron oxide)	1 – 6	1 – 4
MgO	Magnesium oxide	0.5 – 5	8 – 10
CaO	Calcium oxide	1.00 – 5.42	<2
Na ₂ O	Sodium oxide	<1 (very low)	Higher, measurable levels
K ₂ O	Potassium oxide	0.2 – 1.5	0.5 – 1
Trace oxides	TiO ₂ (Titanium dioxide), P ₂ O ₅ (Phosphorus pentoxide), MnO (Manganese oxide)	Minor amounts	Minor amounts
LOI	Loss on Ignition	8 – 15	8 – 10

Table 3. Composition of Water-based Mud Sample

Composition	Function	Mud Samples						
		Non-beneficiated muds		Beneficiated Muds				
		LWBM	FWBM	LWBM				
		A	B	C1	C2	C3	C4	C5
Deionized water, ml	Base fluid	400	400	400	400	400	400	400
Local Bentonite, g	Viscosity modifier and filtrate volume control agent	25	-	25	25	25	25	25
Foreign Bentonite, g	Viscosity modifier and filtrate volume control agent	-	25	-	-	-	-	-
Hyperdrill AF251, g	Viscosity modifier, filtrate volume control agent, and shale inhibitor	-	-	0.5	1.0	1.5	2	3
PAC – R, g	Filtration loss control agent	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Barite, g	Weighting material	10	10	10	10	10	10	10
NaOH, g	pH control agent	0	0	0.3	0.3	0.3	0.3	0.3

Mud Test

API-recommended practices were adopted to evaluate the mud pH, mud weight, rheological properties, and filtration properties of the mud samples (API-13B-2) (American Petroleum Institute, 2013).

1. Mud pH

The probe of a portable pH meter (PH 3C) was cleaned with distilled water and dried using a blotting method after calibration with a pH 10 buffer solution and stabilization. After the meter was calibrated with the buffer solutions, the probe was rinsed, blotted dry, and placed in the mud samples, where it was gently stirred to allow the readings to stabilize. The pH of each sample was recorded to the nearest 0.1, and the meter was then unplugged. The probe was cleaned with distilled water. The cap on the probe was saturated with cotton in a pH four buffer and placed on the probe (Bilal *et al.*, 2016; Dike *et al.*, 2024).

2. Mud Weight

The mud weight is calculated with the help of a Model 140 mud balance with the error value of ± 0.1 lb/gal. Water at $70^{\circ}\text{C} \pm 5^{\circ}\text{C}$ is used to calibrate the instrument, yielding a calibration result of

8.3 lb/gal. The mud balance base is placed on a flat, clean surface, and the mud sample is placed in the balance cup. The cap is firmly screwed upward to release any excess mud through the vent opening, thereby removing any air or gas that may be trapped. The cap is pressed on the cup with a thumb over the hole in the vent, and the outside is wiped clean and dry. The support base is put on the balance arm, and the rider is adjusted along the graduated scale until the level bubble is centered. The mud weight is recorded at the left-hand edge of the rider and reported to the nearest lb./gal (Al-Homadhi, 2007; Wilfred & Akinade, 2016).

3. Mud Rheology

The thermal cup of the Fann Model (35, 6-speed VG Meter) was filled with approximately two-thirds of the mud sample per turn and placed on the viscometer stand. The cup was then raised and left to stand until the rotary sleeve was immersed at the marked level. The sleeve was secured by turning the locking mechanism. The knob on the VG meter was set to the 600-rpm setting. Once the sleeve began rotating at 600 rpm, the dial reading in the top window of the VG meter was allowed to stabilize for at least 10 seconds before recording the recording

the 600-rpm dial reading (Dike *et al.*, 2024). The rotation was done at 300 rpm, 200 rpm, 100 rpm, 60 rpm, and 30 rpm, and their readings were taken. Plastic viscosity, apparent viscosity, and yield point were obtained from the RPM readings, and equations 1 to 3 below were used to obtain these properties.

$$\text{Plastic viscosity (PV), cP} = \Theta_{600} - \Theta_{300} \quad (1)$$

$$\text{Yield point (YP), lb/100 ft}^2 = \Theta_{300} - \text{plastic viscosity} \quad (2)$$

$$\text{Apparent viscosity (AV), cP} = 600\text{-rpm readings}/2 \quad (3)$$

$$\text{Power Law Model, PM, } \tau = K (\dot{\gamma})^n \quad (4)$$

$$\begin{aligned} \text{Where } K &= \Theta_{300} / (511)^n \\ n &= 3.32 \log (\Theta_{600} / \Theta_{300}) \\ \text{Herschel-Bulkley model, HBM, } \tau &= \tau_0 + K (\dot{\gamma})^n \end{aligned} \quad (5)$$

$$\text{Bingham Model, BM, } \tau = \text{YP} + \text{PV} (\dot{\gamma}) \quad (6)$$

Gel Strength GS (10-sec/10-min)

The viscometer's toggle switch was set to 600 rpm, and the mud sample was stirred for 10 seconds. After this, the knob was adjusted to a 3-rpm speed, and the toggle switch was turned off. The mud was then allowed to rest for 10 seconds. After this, the toggle switch was adjusted to the low position, and maximum dial deflection (10-second initial gel strength) in pounds per 100 square feet was noted. The location of the toggle switch was reset to the on position, and the knob was rotated to 600 rpm to stir the mud for an additional 10 seconds. The mud was left undisturbed to settle for 10 minutes, after which the knob was moved back to 3 rpm without turning off the toggle switch. The toggle switch was then returned to the low position, and the most significant amount of deflection of the dial (10-minute gel strength) was measured in pounds per 100 square feet. All mud samples were subjected to this (Adeyemi *et al.*, 2020; Arinkoola, 2020).

4. Filtration Properties

The filtration behavior of the drilling fluid samples was investigated at low-temperature, low-pressure conditions using an API filter press (MFP-4A, 4 units). The cell bottom was locked into position by turning the cell body until the peg was locked into the J slot. The primary air valve was opened by turning the handle counterclockwise, and the regulator was adjusted to read 100psi. The mud sample was poured within 1/2 in. of the top of the cell and placed onto a filter press rack. The lid was positioned on top of the cell body, and the filter press handle was turned clockwise until it was hand-

tight. The valve located on the filter press manifold was pulled by turning the black knob counterclockwise. A dry and uncontaminated graduated cylinder was placed under the drain tube of the filtration cell assembly to collect the filtrate, and the interval timer was set for to 30 minutes (Iscan & Kok, 2007; Sarah & Isehunwa, 2015). At the end of 30 minutes, the volume of filtrate collected in the graduated cylinder was recorded. The bleeder valve was opened to release trapped line pressure. The filter paper was carefully removed from the screen, and the thickness of the filter cake was measured and recorded.

Results and Discussion

Locally sourced bentonite muds were enhanced with 0.5-3g of Hyperdrill, and their performance was evaluated against foreign bentonite muds. Table 4 outlines the characteristics of the formulated mud samples. The obtained properties were verified by comparing them with data from previous studies and the API Specification 13-A for water-based mud (Oriji & Joel, 2012; Omole *et al.*, 2013).

Physical Properties of Mud Samples

Mud pH & Alkalinity

The average pH meter values were 7.44 and 9.34 before and after 0.3 g of NaOH was added. In the case of beneficiated mud samples (C1-C5), the pH values were also mostly similar, ranging from 7.38 to 7.48 before the addition of NaOH and from 9.28 to 9.36 after addition, indicating a difference in the interaction of each bio-additive with the base fluid. Table 3 and Table 4 provide the formulation composition and physical properties of the different samples. The average pH of all the mud samples (9.34) was determined by adding 0.3 g of NaOH as a pH-stabilizing additive.

Such a pH level indicates that the samples are in an alkaline medium and are therefore suitable for field operations, as they help extend the life of the drilling equipment in contact with the down-hole formation. The findings are comparable to the API-recommended standards for mud in water (Bilal *et al.*, 2016). The same was also observed in the research by Elhag (2014) on improving the locally available Saudi bentonite as a drilling fluid, in which the resulting fluid had a pH of 9.

The author proposed maintaining the NaOH concentration within a specific range to keep the pH at 9, thereby ensuring the mud remains alkaline. Excess NaOH can dramatically raise the pH and cause work complications, necessitating regulation (Onuh *et al.*, 2020).

Table 4. Physical Properties of the Mud Samples

Properties	Bentonite Muds						
	Locally-sourced A	Foreign B	Beneficiated				
Colour	Brown Liquid	Semi-brown liquid	Brown liquid				
Physical Appearance	Viscous Liquid	Viscous Liquid	Viscous Liquid				
Weight (lb/gal)	8.45	8.55	8.55 - 8.65				
Specific Gravity	1.04	0.90	C1	C2	C3	C4	C5
			0.97	0.98	0.98	0.98	0.99
Mud pH	7.44	8.85	9.28	9.30	9.33	9.34	9.36

Table 5. Rheological characteristics of Non-beneficiated and beneficiated muds

Mud Samples Readings	Non-beneficiated Muds		Beneficiated Local Muds				
	Local A	Foreign B	C1	C2	C3	C4	C5
600	5	32	20	31	43	60	89
300	4	27	13.5	22	29	45	69
200	3.5	22	13	18	25	40	62
100	3	14	9	14	17	27	45
60	2.5	12	7	10	15	24	38
30	2	5	2.5	7	7.5	18	34
PV	1	5	6	9	14	15	20
YP	3	22	7.5	13	15	28	41
AV	2.3	16	9.75	15.5	21.5	31	44.5
Gel strength, 10 Seconds	3	5.5	2	3	3	3	12
Gel strength, 10 Minutes	3.5	11	2.5	4	4.5	5	13

Mud Weight

The weights of the muds, sample A (non-beneficiated local bentonite) = 8.45 lb/gal, sample B (foreign/API-grade bentonite) = 8.55 lb/gal, and the beneficiated muds (C1-C5) were between 8.55 and 8.65 lb/gal. The weights of the beneficiated mud are as follows: C1: 8.55 lb/gal, C2: 8.57lb/gal, C3: 8.60 lb/gal, C4: 8.63 lb/gal, and C5: 8.65 lb/gal. The API-grade clay is compatible with the weighting, which increases with the concentration of the additives. This rise in mud weight indicates that the beneficiated muds can experience overbalance with formation pressure during drilling, thereby reducing the potential for reservoir fluids to creep into the wellbore (Onwuachi-Iheagwara, 2012; Adeyemi *et al.*, 2020). The specific gravity of the unbeneficiated (base) mud (1.04) was slightly higher in comparison to the beneficiated muds (C1-C5, average 0.98). This decrease in density following the addition of Hyperdrill is predicted because Hyperdrill is a lighter, polymer-based additive that changes the arrangement of solids and influences the balance of water to solids in the mud (Voronova *et al.*, 2020).

Rheological Properties

Table 5 provides a comprehensive overview of the plastic viscosity, apparent viscosity, and gel strength of the mud samples, highlighting the

influence of Hyperdrill on the locally derived bentonite, as visually represented in Figures 2-5.

Plastic Viscosity

The beneficiated samples were marked C1-C5. Locally-sourced samples A and B, used as controls, respectively, were made up of foreign bentonites (Table 4). The effects of the polymeric material of C1-C5 on its rheological properties at varying concentrations are represented graphically in Figures 2-5. Figure 2 showed that the plastic viscosity (PV) of the beneficiated samples followed an increasing pattern (6-20 cP) of the initial PV value of 1 cP with an increase in the concentration of Hyperdrill from 0.5 to 3 g. The beneficiated samples were found to have higher plastic viscosity than local and foreign bentonite muds (Omole *et al.*, 2013). This is explained by the fact that polymeric Hyperdrill is highly crystalline, which increases swelling upon heating (Voronova *et al.*, 2020).

Carbonyl functional groups (C=O) and amine functional groups (-NH₂) encourage hydrogen bond formation and therefore, increase their affinity towards water. This enhances the aggregation of solid particles within the mud, whose surfaces carry ionic charges, thereby strengthening surface attraction and increasing the viscosity of the mud's viscosity (Olaniyan & Akintola, 2024). This mud system can provide the required viscosity for

effective cuttings transport to the surface. However, because the polymeric material has swelling capacity, increasing the concentration may not be necessary to avoid excessive viscosity, thereby increasing the horsepower requirement and the cost. Hence, determining the optimum concentration becomes essential. Figure 2 portrays Non-beneficiated (NBM) and Beneficiated mud (BM) plastic viscosity.

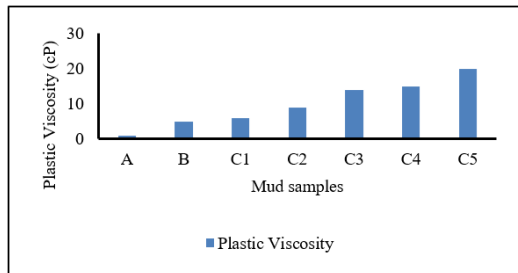


Figure 2. Plastic Viscosity of NBM and BM.

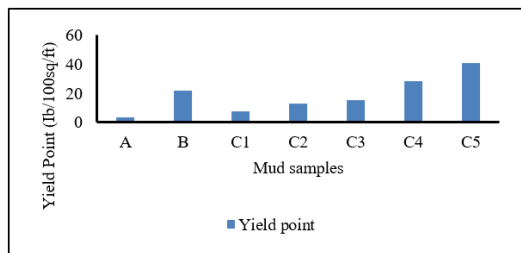


Figure 3. Yield point of NBM and BM

Yield point

Figure 3 shows the yield points of the beneficiated mud samples, both locally sourced and foreign bentonite. The foreign bentonite showed a more significant yield strength behaviour than the beneficiated muds at concentrations of 0.5, 1.0, and 1.5 g, respectively. However, at higher concentrations of 2 and 3 g (C4 and C5), the yield points of the beneficiated muds became greater. A similar performance is observed in the plot of mud samples versus AV (cP), as shown in Figure 4. This phenomenon occurs through an ion exchange mechanism, where calcium ions are substituted for sodium ions. (Oriji & Joel, 2012; Oyedoh *et al.*, 2016). This can be attributed to the strong attractive interactions between the surface charges of the polymeric Hyperdrill. According to Nwabueze & Ighalo (2020), the yield point values of C3, C4, and C5 met the API standards; however, the YP values of C1 and C2 can be deployed according to the drilled formation requirements. This ensures lifting

the cuttings from the space between the hole and the formation. These muds provide good fluid flow in the annulus, enhancing hole cleaning and cutting lifting (Dike *et al.*, 2019; Anthony *et al.*, 2020).

Apparent Viscosity

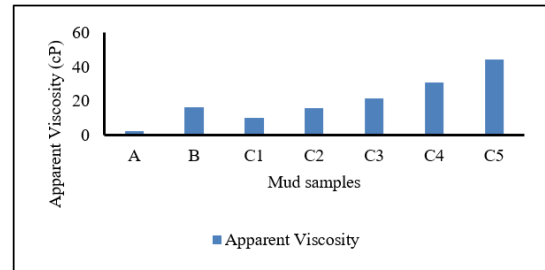


Figure 4. Apparent Viscosity of NBM and BM

Gel Strength

The gel strength of a mud formulation is crucial to the drilling process, as it determines how solid the mud will react when stopped to carry out other tasks (Agwu *et al.*, 2015). After 10 seconds and 10 minutes, the gelling characteristics of the mud samples were measured, and the results were plotted in Figure 5. The time interval is the progression period. A value higher than 10 seconds implies a higher gelling strength of the mud, which may pose a serious challenge to the drilling operation. In Table 5, the 10-second and 10-minute gel strength values for the foreign bentonite (Sample B) are 5.5 and 11 lb/100ft², respectively, while Sample A recorded 3 and 3.5 lb/100ft² values. For the beneficiated samples, the gel strength at 10 seconds and 10 minutes was 2 and 2.5 lb/100 ft², respectively, for a sample weight of 0.5g. Still, a constant value of 3 lb/100ft² in the 1.0-2 g of addition of the Hyperdrill, and at 3 g, increased to 12 and 13, respectively. These values at 3 g of the additive indicate a progressive gelling property of the mud, suggesting that the optimum concentration for effective gel property is at 2 g. Beyond this, the mud will begin to pose a challenge to the reinitiation of drilling operations. Additional pump horsepower may be required to break the bond to initiate the mud flow (Dike *et al.*, 2019; Chinwuba *et al.*, 2021). The progressive gelling of the mud at 3 g is attributed to the flocculating properties of the polymeric material used in the beneficiation of the sample mud, resulting from attractive forces between charged ions (Onuh *et al.*, 2020).

Figure 5 presents the gel strength plot of the mud samples.

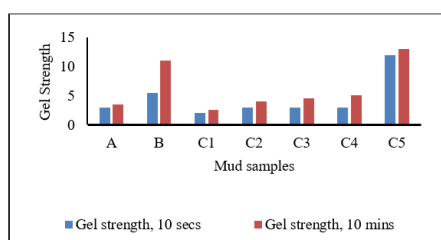


Figure 5. Gel Strength of NBM and BM

Filtration properties

The mud samples' filtration behaviour (volume and cake formation) (NBM and BM muds) is presented in Table 6 and the plot in Figure 6. The result shows a decreasing trend in filtrate volume as the concentration of the polymeric material increases from 0.5 to 3g, due to its affinity for water (Voronova *et al.*, 2020). Sample C5 has the lowest filtrate volume value. However, the more the viscosity of the beneficiated mud, the lower the filtration (Chinwuba *et al.*, 2021). This implies that using the mud formulated with beneficiated mud will reduce filtrate entry into the formation. Hence, the interaction between the formation and drilling fluid will have minimal impact on the formation's permeability (Dankwa *et al.*, 2018). In contrast, the filtrate volume and filter cake thickness for the locally sourced bentonite muds tended to be high, exceeding the API recommendations, as shown in Table 7.

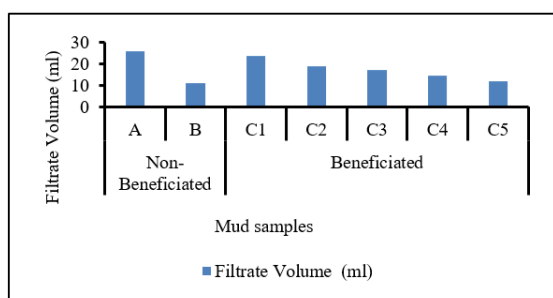


Figure 6. Filtrate volume of NBM and BM

Table 6. Filtration properties of the Non-beneficiated (NBM) and Beneficiated muds (BM)

Samples	A	B	C1	C2	C3	C4	C5
Filtrate volume (ml)	26	11.0	24.0	19.0	17.5	14.5	12.0
Filter cake thickness (cm)	2.5	0.29	0.12	0.13	0.16	0.18	0.20

The impurities in local bentonite, such as non-montmorillonite minerals and high calcium/magnesium content, weaken its drilling performance and prevent it from meeting API specifications. However, adding Hyperdrill, a polyacrylamide-based polymer, helped Abia Bentonite perform more like foreign/API-grade clay. The polymer bridges the gaps between clay platelets and water, mimicking the thickening effect of sodium montmorillonite to boost viscosity. It entraps water molecules in a pseudo-gel, and drilled cuttings and barite are suspended within it. It also adheres to the surfaces of the clay particles, creating a more compact, less permeable filter cake that counteracts calcium bentonite's inability to control fluid loss. The Hyperdrill stabilizes dispersion, eliminating the influence of undesired Ca^{2+} and Mg^{2+} ions, thereby improving the swelling of the clay and its rheological properties. It improves viscosity, sustains solids in suspension, and creates thin, low-permeable filter cakes, allowing for better control of fluid loss, even in the presence of quartz, kaolinite, or carbonates (Falode *et al.*, 2008).

The filter cake data reveal a distinct difference between non-beneficiated and beneficiated muds. The samples of mud that were not beneficiated existed as a thick filter cake in sample A, and a relatively thin layer in sample B, of 2.5cm and 0.29 cm, respectively. Conversely, the beneficiated muds (C1 to C5) developed thinner filter cake with C1 showing a thickness of 0.12 cm, C2 a thickness of 0.20 cm, C3 a thickness of 0.31 cm, and C4 a thickness of 0.41 cm, and finally C5 a thickness of 0.53 cm with a gradual increase in thickness across the sample, as in Figure 7. This means that preferencing the mud increases the control of filtration, resulting in the creation of thinner and more manageable filter cakes. In actual drilling processes, it is beneficial: thinner filter cakes reduce the risk of formation damage, reduce the likelihood of differential sticking, and increase overall wellbore stability (Omole *et al.*, 2013).

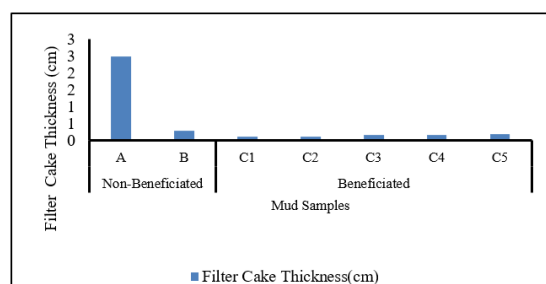


Figure 7. Filter cake thickness of NBM and BM

Table 7. Comparison of both beneficiated and non-beneficiated mud with API specifications

Readings	Sample A	Sample B	Samples C4 & C5	API Specification (Source: Dike <i>et al.</i> , 2025)
Mud weight (lb/gal)	8.45	8.55	8.63/8.65	8.65 – 9.60
Filtrate volume (ml)	26	11	14.5/12.0	15.0 – 25.0
PV (cP)	1	5	15/20	8 - 35
YP (lb/100ft ²)	3	22	28/41	5 - 50
Gel strength (lb/100 ft ²) @ 10sec	3	5.5	3/12	3 - 20
Gel strength (lb/100ft ²) @ 10min	3.5	5.5	5/13	8 - 30

Comparison of NBM and BM with API Standards

The results indicate that samples C4 and C5 exhibited properties comparable to those of foreign bentonite muds. This is evident in the rheological characteristics of drilling mud derived from the beneficiated clays, which align closely with the API Specification 13-A for drilling-grade bentonite, as presented in Table 7, which compares the NBM-A and B mud properties and BM-C4 & C5 muds with API standards (Al-Homadhi, 2007; Nwabueze & Ighalo, 2020).

Rheogram of NBM and BM

Figure 8 compares the shear stress behaviour of the non-beneficiated muds: Sample A (local) and Sample B (foreign). The local mud exhibits very low shear stress across all shear rates, with only slight increases in shear stress as deformation increases. This weak performance aligns with earlier reports on untreated local bentonite (Adeyemi *et al.*, 2020). The foreign mud, on the contrary, provides a significantly greater rheological reaction. It exhibits a sharp shear stress that rises with low shear rates and then increases steadily, a characteristic typical of increased viscosity and improved structural stability, which are also observed in imported bentonite (Akinwumi *et al.*, 2015). Despite the shear-thinning behavior of both samples, Sample B shows much higher values of stress at all shear rates, and it has been confirmed that the sample is better at resisting flow than the untreated local mud.

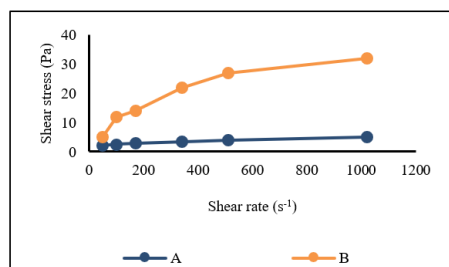
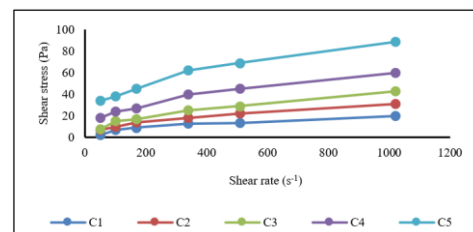
**Figure 8. Shear stress and Shear rate diagram of Non-beneficiated muds**

Figure 9 demonstrates the rheograms of the beneficiated muds. Nevertheless, their shear stress values are significantly higher than those of the raw local mud, indicating improved rheological performance after treatment. The curves of the rheogram in Figure 9 indicate that the shear stress of every beneficiated mud sample rises with shear rate as the concentration of Hyperdrill increases by increasing the concentration of C1 to C5. This effect indicates the thickening of Hyperdrill that increases the viscosity of the mud and improves its ability to carry cuttings. The optimal level was established by maintaining a constant viscosity that allows for the circulation and cleaning of the holes. Field-wise, the right level of Hyperdrill concentration should be maintained to strike a balance between adequate annular velocity and manageable pump horsepower requirements for smooth drilling activity. The observed improvement in the treated samples indicates that beneficiation helps offset the drawbacks of the native bentonite and aligns its behavior with that of the foreign bentonite. Additionally, all the treated formulations exhibit non-Newtonian, shear-thinning behavior, similar to that of the untreated samples.

**Figure 9. Shear stress vs. shear rate graph for Beneficiated muds**

Batching all the mud samples together, as shown in Figure 10, reveals that Sample A (local unbeneftiated) is the weakest, nearly flat, and unsuitable where cuttings suspension is important. Sample B (the unbeneftiated foreign bentonite) shows moderate and consistent build-up of shear

stress with shear rate; it behaves similarly to mid-range beneficiated samples, such as C2 and C3. That means the foreign, unbeneficiated bentonite can be used without beneficiation in many drilling scenarios, especially in lighter or conventional operations.

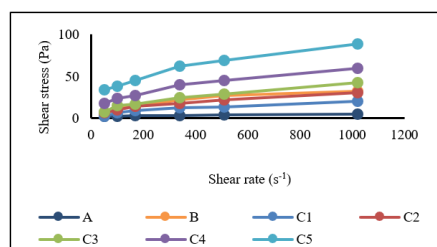


Figure 10. Graph illustrating the relationship between shear stress and shear rate for both beneficiated and non-beneficiated mud

The beneficiated Hyperdrill series (C1-C5) still generally outperforms the unbeneficiated local clay: C1/C2 show modest improvements over A, C3 is balanced and dependable, while C4 and C5 deliver the best rheological performance with high shear stress even at lower shear rates (excellent for deep or challenging holes). The beneficiation of local clays can produce materials (C4/C5) that can outperform even the foreign unbeneficiated clay in demanding situations.

Rheological Model

The experiment outcomes were modeled mathematically to understand the dynamics of the flow of beneficiated and non-beneficiated mud samples. Table 8 and Table 9 provide a breakdown of the Power Law Model (PM), the Herschel-Bulkley model (HBM), and the Bingham Model (BM), as defined by equations 4, 5, and 6, respectively.

Figure 9 is a graph of the rheological patterns of the C1-C5 enhanced mud samples. The shear-thinning effect occurs in the muds over a range of deformation rates from 10s⁻¹ to almost 100s⁻¹. The consistency and similarity of the curves are apparent indicators of the improved viscosity profiles, which also exhibit comparable non-Newtonian flow behavior over a wide range of shear rates after the addition of Hyperdrill (Khan *et al.*, 2017; Adeyemi *et al.*, 2020). Due to its highly crystalline structure, Hyperdrill improved the mud rheology, demonstrating that the beneficiated mud can function similarly to mud formulated with imported bentonite. There exists a direct relationship between the shear stress and shear rate when the fluid is starting to flow. A locally

collected bentonite mud is known to significantly enhance viscosity and reduce filtration loss as the rotational speed of the viscometer is varied between 100 and 600 rpm (Sarah & Isehunwa, 2015). An increase in viscosity of 83.3% - 95% was observed, and the consistency of the beneficiated curves indicated that the process enhanced the flocculation capacity of the clay particles, thereby improving the mud's flow characteristics (Akinwumi & Funsho, 2015). Figure 10 presents the combined plots of shear stress for the prepared muds.

According to Table 8, sample A (local bentonite) exhibits low shear stress at all shear rates, which means that it is relatively thin and has a weak structure. The Power Law model exhibits low consistency ($k = 0.54$) and a flow behavior index of $n \approx 0.32$, indicating a shear-thinning behavior. It is very easy to flow under high shear but not strong at low shear. The Herschel-Bulkley and Bingham models also indicate a low yield stress; therefore, this mud will not be effective at suspending cuttings without additives. Sample B (foreign/API-grade bentonite) has a significantly greater shear stress with $k \approx 5.86$ and $n \approx 0.25$, with greater consistency and increased shear-thinning characteristics. The enhanced yield stress of the Herschel-Bulkley and Bingham models implies superior cutting suspension and stability at low shear rates. Therefore, local bentonite is weak and thinner, whereas foreign/ API grade mud is thick and strong, as well as capable of holding solids. That is why additives such as Hyperdrill are required to enhance the rheology of the local clay and approach the performance of API-grade mud (American Petroleum Institute, 2013).

The local bentonites (C1-C5) treated with Hyperdrill exhibit a distinct curve of increasing rheological properties as the polymer dosage increases (Table 9). At low shear rates, shear stress increases with increased Hyperdrill content, which means increased mud structure and enhanced solids suspended. The consistency in Power Law (k) goes between 0.394 in C1 and 6.996 in C5, indicating a considerable thickening effect. The flow behavior index (n) in all samples is lower than 1, and, therefore, it confirms the suggestion that the muds are shear-thinning, pumpable, and will suspend cuttings at rest. The yield point (YP) also increases from 8lb/100 ft² (C1) to 41lb/100 ft² (C5), indicating that the capacity to hold drilled cuttings in suspension is higher. In summary, Hyperdrill polymer effectively enhances the viscosity, yield stress, and overall structural integrity of the local bentonite, making it more comparable to oilfield-grade mud and suitable for use in demanding drilling environments.

Table 8. Rheological models of Non-beneficiated muds (A and B)

Shear Rate (S ⁻¹)	A	PM	HBM	BPM	B	PM	HBM	BPM
600	5	4.220	7.220	603.0	32	28.090	50.090	3022.000
300	4	3.376	6.376	303.0	27	23.702	45.702	1522.000
200	3.5	2.963	5.963	203.0	22	21.461	43.461	1022.000
100	3	2.370	5.370	103.0	14	18.109	40.109	522.000
60	2.5	2.011	5.011	63.0	12	15.979	37.979	322.000
30	2	1.608	4.608	33.0	5	13.483	35.483	172.000
	PV = 1	K = 0.54			PV = 5	k = 5.86		
	YP = 3	n = 0.32			YP = 22	n = 0.25		

Table 9. Rheological models of beneficiated muds

Shear Rate (S ⁻¹)	C1	PM	HBM	BPM	C2	PM	HBM	BPM	C3	PM	HBM	BPM	C4	PM	HBM	BPM	C5	PM	HBM	BPM
600	20	14.8	22.3	3607.5	31	23.8	36.8	5413.0	43	31.8	46.8	8415.0	60	48.1	76.1	9028.0	89	73.2	114.2	12041.0
300	13.5	10.0	17.5	1807.5	22	16.9	29.9	2713.0	29	21.4	36.4	4215.0	45	36.1	64.1	4528.0	69	56.7	97.7	6041.0
200	13	7.9	15.4	1207.5	18	13.8	26.8	1813.0	25	17.0	32.0	2815.0	40	30.5	58.5	3028.0	62	48.9	89.9	4041.0
100	9	5.4	12.9	607.5	14	9.8	22.8	913.0	17	11.5	26.5	1415.0	27	22.9	50.9	1528.0	45	37.9	78.9	2041.0
60	7	4.0	11.5	367.5	10	7.6	20.6	553.0	15	8.6	23.6	855.0	24	18.5	46.5	928.0	38	31.4	72.4	1241.0
30	2.5	2.7	10.2	187.5	7	5.4	18.4	283.0	7.5	5.8	20.8	435.0	18	13.9	41.9	478.0	34	24.4	65.4	641.0
		k	n			k	n			k	n			k	n			k	n	
PV	6	0.394	0.567		9	1.007	0.494		14	0.840	0.568		15	3.387	0.415		20	6.996	0.367	
YP	8				13				15				28				41			

Conclusions

The study findings indicate that locally sourced bentonite, enhanced with Hyperdrill, has strong potential as a technically viable alternative to imported bentonite. These properties demonstrated that the beneficiated mud samples possess rheological qualities superior to those of non-beneficiated muds. Furthermore, the following conclusions were reached:

The polymer mud samples (C1-C5) from the local bentonite yielded mud weights ranging from 8.55 to 8.65 lb/gal, whereas the mud weights of the foreign and local bentonite controls were 8.45 and 8.55 lb/gal, respectively.

Improved rheological characteristics were seen when the pH was adjusted to around 9.34.

With 0.5-3g of Hyperdrill, plastic viscosity increased by up to 95%, apparent viscosity by nearly 95%, and yield point by more than 90%, all within API-recommended specifications at low temperature and pressure conditions.

The result shows a decreasing trend in filtrate volume as the concentration of the polymeric material increases from 0.5 to 3g.

The study established that Adamawa bentonite, when beneficiated, can enhance drilling operations.

A Hyperdrill concentration of 1.5-3g was identified as optimal, balancing enhanced rheology and manageable gel strength for field applications.

Hyperdrill has been recognized for its viscosifying and filtrate volume control properties. Therefore, enhancing locally sourced bentonite and utilizing it in drilling operations will help lower costs, reduce reliance on imports, create jobs, and promote the utilization of local content.

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List of Abbreviations

WBM	Water Base Mud
CMC	Carboxy Methyl Cellulose
PAC	Polyanionic Cellulose
API	American Petroleum Institute
YP	Yield Point
PV	Plastic Viscosity
NBM	Non-beneficiated Mud
BM	Beneficiated Mud
PM	Power Law Model
HBM	Herschel-Bulkley model
BM	Bingham Model
g	Grams

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