

Article

# Formulation and evaluation of a water-based drilling mud from locally sourced materials around Akwa Ibom State of Nigeria

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**Abstract:** Petroleum and petrochemical resources remain pivotal to the energy and revenue streams of many economies, with drilling operations constituting a fundamental phase in hydrocarbon production. Drilling mud and its associated additives are critical components in the drilling process. The escalating cost, pressure on foreign exchange and ecological footprint of some imported drilling mud additives have spurred interest in sustainable, locally derived alternatives. In this work, a water-based drilling mud (WBM) was formulated using only locally sourced materials from Akwa Ibom State, Nigeria. Key components such as beneficiated local clay, okra-ogbono biopolymer, cassava starch, wood-ash alkalinity agent, and coconut-husk filtrate controller were prepared and blended following API RP 13 B-1 protocols. The rheology (apparent and plastic viscosity, yield point), filtrate loss and cake thickness, pH, density, and thermal/biological stability were determined in the laboratory. Compared to commercial variants used as benchmarks, the local WBM met API rheological and density targets but exhibited elevated fluid loss (17.5 mL vs.  $\leq 15$  mL) and marginal pH buffering (initial pH 9.2 vs.  $\geq 9.5$ ). Thermal aging (90 °C, 24 h) and degradation tests revealed viscosity loss and gel-strength decline, greater than polymer-based commercial variants. On implementation of clay micronization and starch modification, the fluid loss reduced below 15 mL while cake thickness was 2.0 mm. At an estimated 60 % - 65 % cost saving, this WBM demonstrates significant promise for eco-friendly, cost-effective drilling in the Niger Delta.

**Keywords:** Fluid loss control, Local resources, Mud additives, Okra-ogbono composite, Rheology modifier

## 1. Introduction

**D**rilling mud, also commonly referred to as drilling fluid, is essential in rotary drilling operations in the oil and gas industry. It is a complex fluid system that serves multiple roles, such as lubrication and cooling of the drill bit, transportation of drill cuttings to the surface, maintenance of hydrostatic pressure to prevent well blowouts, stabilization of the wellbore, etc. There are various classes of drilling fluids, but the water-based muds (WBMs), oil-based muds (OBMs), and synthetic-based muds (SBMs) are the very familiar ones [1,2]. Among these, WBMs are the most widely used, primarily due to their relative environmental safety, cost-effectiveness, and ease of handling and disposal [3]. For a given WBM, the performance is dependent on its formulation and the specific additives incorporated to meet operational needs [1]. Such operational needs-dependent performance includes rheology control, pH adjustment, fluid loss control, and shale stabilization [4].

Conventional WBM formulations consist of various imported chemical additives such as bentonite (viscosifier), barite (weighting agent), PAC/Xanthan gums (thinners and filtration reducers), caustic soda (pH modifier), and other specialty chemicals like lignosulfonates and lubricants [1,5,6]. In developing countries like Nigeria, the dependence on these foreign-sourced materials leads to high operational costs and pressure on foreign exchange. In addition, there are usually frequent supply disruptions, especially if there are trade wars, outbreaks of global epidemics or pandemics, like during the COVID-19 era. Furthermore, some imported mud additives may pose environmental risks, especially when poorly managed during drilling or waste disposal [7]. Consequently, there is growing interest in the development of drilling mud systems using low-cost, sustainable, and eco-friendly alternatives derived from indigenous raw materials. Nigeria is blessed with diverse agricultural and mineral resources, which provide a unique opportunity for their utilization in developing drilling mud additives from locally available sources. In particular, Akwa Ibom State is rich in natural resources such as clay minerals, agricultural by-products (e.g., cassava, okra, plantain), and biomass residues like wood ash and coconut husks. These materials, which have been processed in various ways by researchers, exhibit some physicochemical properties that could be suitable for their deployment in drilling fluid formulation [8–11]. For example, local clay can serve as a viscosifier [12], okra mucilage as a rheology modifier [9], cassava starch as a fluid loss control agent [8], and wood ash as a natural pH controller due to its alkaline mineral content [13]. Despite their potential, systematic studies on formulating drilling muds solely from materials sourced within a single Nigerian state, particularly Akwa Ibom, are still lacking.

The drive for a paradigm shift to sustainable drilling operations has further strengthened the need for environmentally benign mud additives. Such would also promote local content development, create internal wealth, and even generate employment opportunities. Replacing conventional WBM additives with biodegradable, renewable, and non-toxic alternatives could significantly reduce the ecological footprint of oil exploration activities. Moreover, the use of indigenous materials can empower local communities, create new value chains, and align with Nigeria's national objectives for sustainable development and economic diversification. However, this transition requires robust technical validation to ensure that locally formulated muds meet industry performance benchmarks, including those outlined by the American Petroleum Institute (API).

This study aims to bridge the existing gap by formulating and evaluating a water-based drilling mud using only materials obtained from Akwa Ibom State. The compatibility, effectiveness, and operational relevance of these local materials as functional WBM additives based on their physicochemical and rheological characteristics were investigated. The properties of the locally formulated mud were compared with two commercial muds from international suppliers, so as to gauge the practical competitiveness of the local formulation. By demonstrating technical feasibility and environmental advantages, this work contributes to ongoing efforts in sustainable oilfield chemicals development and promotes the adoption of indigenous resources in petroleum operations.

## 2. Materials and methods

### 2.1. Raw materials selection and collection

The main criteria for selection of the materials used in this study include abundance, accessibility, physicochemical potential for drilling mud applications, and eco-sustainability [1,14]. All materials were sourced within Akwa Ibom State, specifically from Ibesikpo-Asutan, Uyo, and Uruan Local Government Areas. Local guidance and site reconnaissance were employed to identify the most appropriate sources.

Natural (bentonitic) clay was selected as a viscosifier and was collected from a gravel and sharp-sand production site in Nung Oku Ebere Out in Ibesikpo-Asutan L.G.A. The clay bed is rich in bentonitic and kaolinitic compositions, with historical applications in local ceramics. Cassava starch was selected as a fluid loss reducer. The fresh cassava tubers were harvested from a subsistence farm in Ikot Ambon Ibesikpo, Ibesikpo-Asutan L.G.A. The local cassava (*Manihot esculenta*) is known for its high starch content and is primarily cultivated for fufu and garri production.

A dual-component rheology modifier was developed by combining okra mucilage (*Abelmoschus esculentus*) and ogbono seed gel (*Irvingia gabonensis*). This synergy was aimed at leveraging the high molecular weight polysaccharides in okra [15] with the viscous gum matrix of ogbono [16,17] to achieve stable

and tunable gel strength and shear-thinning behaviour under downhole conditions. Mature okra pods were collected from Akpan Andem market in Uyo L.G.A. Fruits of *Irvingia gabonensis* (commonly called bush mango) were collected from the forest in Ekpene Ukim in Uruan L.G.A.

Wood ash was selected as a pH adjuster, and the residues were obtained from burnt wood (predominantly raffia palm trunks) used for cooking in rural kitchens around Aka Etinan Road, Uyo. Coconut husk powder was selected as a filtrate control/lubricant [18]. The dried coconut husks were sourced from coconut processors at the Uruan beach landing and thereafter milled into fine powder in the laboratory.

## 2.2. Additives preparation and pre-treatment

A series of preparation and pre-treatments was performed on each material to enhance its performance as a functional drilling mud additive.

### 2.2.1. Clay

The raw clay was sun-dried for 72 hours, then crushed and sieved through a 75  $\mu\text{m}$  mesh [12]. The fine-grit filtrate obtained was then dispersed in distilled water and subjected to sedimentation to separate impurities. The clay was aged for 24 hours before being used in the formulation [12].

### 2.2.2. Starch

The cassava tubers were peeled, washed in ordinary water, then in distilled water, and grated. The mash was mixed with distilled water and filtered using a muslin cloth. The starch slurry was allowed to settle overnight, and the supernatant was decanted. The wet starch was dried at 50 °C in a hot-air oven and then milled into powder.

### 2.2.3. Okra mucilage

Fresh okra pods were sliced and soaked in hot water (80 °C) at a ratio of 1:10 (w/v) for 30 minutes with intermittent stirring. The resulting viscous solution was filtered using a fine muslin cloth to remove fibrous residues. The filtrate was then concentrated at 60 °C using a rotary evaporator to one-third of its original volume. The concentrate was a semi-solid gel, oven-dried at 40 - 50 °C, and then milled using a ceramic mortar and pestle.

### 2.2.4. Ogbono gel

Dried ogbono seeds were deshelled, air-dried for 96 hours, and ground to a fine powder using an electric blender. A gel was prepared by dispersing 5 g of the powder in 100 mL of warm distilled water (60 °C), followed by continuous stirring for 20 - 30 minutes to allow full hydration and swelling of the gum matrix. The hydrated mixture was allowed to stand for 1 hour at room temperature to achieve maximum gel development.

### 2.2.5. Formulation of composite modifier

Equal parts (by mass) of the okra mucilage powder and the hydrated ogbono gel were blended to form a homogeneous biopolymer paste. This composite was subjected to mechanical stirring for 10 - 20 minutes at 600 rpm to ensure full interaction between the two natural gums. The final product was stored in airtight, amber-colored containers and refrigerated until use in drilling mud formulations.

### 2.2.6. Wood ash

Collected wood ash was sieved (150  $\mu\text{m}$ ) to remove charcoal fragments. The fine ash was stored in airtight containers to preserve its alkalinity.

### 2.2.7. Coconut husk

The husks were air-dried for 72 hours, crushed, and milled into powder. A portion was carbonized at 400 °C in a muffle furnace for further testing as a lubricant enhancer.

### 2.3. Mud formulation

Standard API guidelines were followed in preparing base and treated water-based muds. Formulations were carried out in a batch process using the following local ingredients and proportions (all per 350 mL mud sample). The amounts of the various additives were combined at different weights and optimized by a trial-and-error approach. Only the combination that provided the desirable properties was reported.

For each 350 mL WBM sample, 22.5 g of the treated local clay, 4.0 g of the cassava starch powder, 3.5 to 4.0 g of the composite rheology modifier, 1.0 g of wood ash, and 1.5 g of coconut husk powder were introduced during mixing in 350 mL of distilled water. Each sample was mixed using a high-speed Hamilton Beach mixer at 12,000 rpm for 20 - 30 minutes to ensure uniform dispersion of solids. The muds were allowed to age for 16 hours before testing to simulate downhole conditions.

### 2.4. Physicochemical testing

The prepared muds were characterized using American Petroleum Institute (API RP 13B) procedures [19]. The parameters tested include apparent and plastic viscosity, yield point and gel point, pH value, filtration loss, mud density, and lubricity coefficient. Apparent and plastic viscosity was determined using a standard 6-speed rotational viscometer; yield point and gel strength was calculated from viscometer readings at 3 rpm and 600 rpm; pH value was measured using a pH meter; filtration loss was conducted via API filter press (100 psi for 30 minutes); mud density was measured using a Baroid mud balance; and lubricity coefficient was assessed using a lubricity tester under simulated pressure and temperature.

### 2.5. Optimization study

In some cases where the mud characteristics fell short of the desired range, some optimizations were carried out by incorporating additional ingredients. For this work, thermal aging was carried out at 80 °C, 16 h for viscosity retention; an extended test was conducted at 90 °C, 24 h for worst-case stability.

### 2.6. Comparative evaluation

Two commercial mud samples used as benchmark samples and were obtained from Baker Hughes and Halliburton (labelled FOR-BH and FOR-H). Identical physicochemical tests were conducted for these samples under similar (controlled) laboratory conditions to enable performance benchmarking with the locally formulated mud. Degradation tests were conducted at short term (7 days) and long term (14 days).

## 3. Results and discussion

### 3.1. Rheological properties

Viscosity is a critical performance parameter in water-based drilling fluids that determines the capacity of the mud to carry drill cuttings and maintain cleaning. It also influences suspension stability and hydraulic performance during circulation. According to the American Petroleum Institute (API Specification 13A) for WBMs, the acceptable range for apparent viscosity (AV) lies between 30–45 cP for standard drilling conditions, while plastic viscosity (PV) should ideally range between 10–20 cP. Yield point (YP), which reflects the ability of the fluid to lift cuttings out of the annulus under low shear, typically ranges from 15-30 lb/100 ft<sup>2</sup>. Values that exceed these ranges may cause excessive pump pressure and poor solids suspension, whereas values below the range may compromise cuttings transport [20].

The formulated mud containing the combined *Abelmoschus esculentus* (okra) mucilage and *Irvingia gabonensis* (ogbono) gel showed AV, PV, and YP values shown in Table 1.

An AV value of  $31 \pm 1.5$  cP is within the recommended API standard, but sits at the lower end of API guidelines. The consequence of this may be that cuttings transport may be marginal in high-angle wells [20]. The PV and YP obtained were  $12 \pm 1.0$  cP and  $19 \pm 2.0$  lb/100 ft<sup>2</sup>, respectively. These values, though within acceptable bounds, are also on the lower side, which could imply weak carrying capacity under static conditions. The lower PV and YP values of the formulation may be largely a reflection of the kaolinitic dominance of the local clay and partial replacement of synthetic polymers with okra-ogbono gel.

**Table 1.** Observed rheological properties of the formulated mud and those of commercially obtained samples

| Property                     | WBM            | Test 1 | Test 2 | Test 3 | Mean $\pm$ SD  |
|------------------------------|----------------|--------|--------|--------|----------------|
| AV (cP)                      | Formulated WBM | 30     | 33     | 31     | 31 $\pm$ 1.5   |
|                              | FOR-Com1       | 41     | 45     | 43     | 43 $\pm$ 2.0   |
|                              | FOR-Com2       | 38     | 42     | 40     | 40 $\pm$ 2.0   |
| PV (cP)                      | Formulated WBM | 11     | 13     | 12     | 12 $\pm$ 1.0   |
|                              | FOR-Com1       | 18     | 20     | 19     | 19 $\pm$ 1.0   |
|                              | FOR-Com2       | 14     | 17     | 16     | 16 $\pm$ 1.5   |
| YP (LB/100 ft <sup>2</sup> ) | Formulated WBM | 17     | 21     | 19     | 19 $\pm$ 2.0   |
|                              | FOR-Com1       | 27     | 31     | 29     | 29 $\pm$ 2.0   |
|                              | FOR-Com2       | 24     | 28     | 26     | 26 $\pm$ 2.0   |
| Fluid loss (mL/30min)        | Formulated WBM | 16     | 19     | 18     | 18 $\pm$ 1.5   |
|                              | FOR-Com1       | 11     | 13     | 14     | 13 $\pm$ 1.5   |
|                              | FOR-Com2       | 12     | 15     | 14     | 14 $\pm$ 1.5   |
| Cake thickness (mm)          | Formulated WBM | 2.4    | 2.8    | 2.6    | 2.6 $\pm$ 0.20 |
|                              | FOR-Com1       | 1.7    | 2.0    | 1.9    | 1.9 $\pm$ 0.15 |
|                              | FOR-Com2       | 1.9    | 2.3    | 2.1    | 2.1 $\pm$ 0.20 |
| pH                           | Formulated WBM | 9.0    | 9.4    | 9.2    | 9.2 $\pm$ 0.20 |
|                              | FOR-Com1       | 9.6    | 9.9    | 9.8    | 9.8 $\pm$ 0.15 |
|                              | FOR-Com2       | 9.5    | 9.8    | 9.7    | 9.7 $\pm$ 0.15 |
| Mud density (ppg)            | Formulated WBM | 8.4    | 8.8    | 8.6    | 8.6 $\pm$ 0.20 |
|                              | FOR-Com1       | 9.2    | 9.6    | 9.4    | 9.4 $\pm$ 0.20 |
|                              | FOR-Com2       | 9.1    | 9.5    | 9.3    | 9.3 $\pm$ 0.20 |

In an optimization work, when aged at 80 °C for 16 hours (short term), the AV dropped to 27  $\pm$  2.0 cP (13% loss), compared with 22% and 23% loss obtained for FOR-Com1 and FOR-Com2, respectively. The implication of this could be that the composite biopolymer exhibited moderate thermal resilience; hence, further starch cross-linking or clay micronization would be required to maintain viscosity above 30 cP at elevated temperatures.

To simulate near-bottomhole conditions, the viscosity retention was further tested at 90 °C (extended). The local mud retained 81% of its original AV, compared to FOR-Com1 (75%) and FOR-Com2 (72%). This implies that the high polysaccharide content of okra and ogbono, though biodegradable, exhibited moderate thermal resistance. However, long-term storage revealed mild degradation under microbial/biochemical action, necessitating the need for inclusion of preservatives, perhaps a natural preservative such as neem extract for extended shelf-life stability. However, this will be undertaken in further studies.

Overall, the natural rheology modifier offers a good viscosity profile with an eco-friendly and cost-effective advantage. Its primary limitation lies in shelf-life management and performance beyond 100 °C, where synthetic polymers outperform it in stability. Nonetheless, for shallow to medium-depth wells and environmentally sensitive areas, the local formulation offers competitive and sustainable value.

### 3.2. Filtration and fluid loss control

Fluid loss is an important indicator of the ability of a drilling fluid to form a low-permeability filter cake and reduce filtrate invasion into the formation [1]. According to API standards, acceptable fluid loss should not exceed 15 mL in 30 minutes (100 psi) for standard WBM. Excessive fluid loss may erode wellbore stability and can damage productive zones.

The obtained values of fluid loss are shown in Table 1. From the result, the local formulation exhibits fluid loss of 18  $\pm$  1.5 mL, which exceeds the API maximum, hence producing a thicker and more permeable cake. This also implies that the cassava starch may have provided partial plugging. Thus, finer filtration agents such as micronized kaolin or modified starch may be needed to achieve values less than 15 mL, and this will be explored in future studies.

Filter cake thickness is also a critical parameter because it directly influences wellbore stability, torque-and-drag characteristics, and also the potential for differential sticking [1]. An ideal cake should be thin, typically less than 2.0 mm, and impermeable. This provides a physical barrier that minimizes filtrate invasion without excessively increasing annular friction. In our formulated mud, the cake had a thickness of  $2.6 \pm 0.20$  mm, which is greater than the values obtained for all the commercial variants used for the benchmarking. This signifies a less compact deposit, and can be attributed to the larger particle size distribution of the kaolinite-rich clay and perhaps the relatively coarse network that the cassava starch may form.

A thicker cake may reduce permeability effectively, but at the cost of higher equivalent circulating densities (ECD) and elevated torque, especially in high-angle or extended-reach sections. In practical terms, our  $2.6 \pm 0.20$  mm cake could raise annular friction by up to 10% compared to a 2.0 mm cake. In this scenario, a marginal increase in pump pressure would be necessary to maintain flow rates. Conversely, synthetic polymer-based systems, which are likely to be found in commercial routine form cakes of 1.9 – 2.1 mm that balance low permeability with minimal ECD impact.

In an optimization work, we considered that cake build-up could also be affected by temperature and shear history. Under 80 °C aging, our cake thickness increased by 0.3 mm, which could be attributed to slight softening and re-deposition of biopolymeric components [21]. In contrast, commercial polymer systems showed around 0.2 mm change under identical conditions, which reflects their superior thermal network stability. To reduce the cake thickness of the formulated WBM closer to API-preferred levels, further grinding of the local clay and partial substitution of coconut husk ash with micronized silica (which could be sourced from Uyo sand) are recommended for further studies. Perhaps, this could yield a denser and thinner deposit. In addition, the ratio of okra to ogbono gel could be optimized to support a tighter polymer matrix that binds fines more effectively, helping to approach the 2.0 mm benchmark without sacrificing fluid loss control. Overall, the performance indicates that formulated WBM can still be deployed in the field where the operational temperature is too high. It also shows that the mud can aid in forming compact and low-permeability cakes. Since the agents are natural, non-toxic, and biodegradable, they will pose no risk of reservoir damage or environmental toxicity when deployed in an oilfield.

### 3.3. Mud pH, density, and alkalinity

The pH of drilling mud affects clay hydration, corrosion behaviour, and the overall behavior of the additives [1]. According to API recommendations, maintaining the drilling fluid pH within the 9.5 to 10.5 window is essential to inhibit corrosion of downhole tubulars, prevent clay swelling, and optimize the performance of viscosity and fluid-loss additives. In our initial formulation, the pH stabilized at  $9.2 \pm 0.20$ , which is a desirable alkaline system, but marginally below the lower bound of API standard. This shortfall may be largely attributed to the limited alkalinity of the raw wood-ash extract (pH  $\approx 9.5$ ) used. To elevate the pH to the desired 9.6 to 9.9 range required an additional 0.45 g of ash per 350 mL sample to be added. In optimization studies, the ash was blended with micronized coconut-shell biochar, micronized plantain peels ash, and micronized ash from palm fruit bunches to provide stronger buffering capacity while preserving sustainability.

The target mud density for shallow to intermediate formations is typically 9.0 to 10.0 ppg. However, the formulated mud density was 8.4 - 8.8 ( $8.6 \pm 0.20$ ) ppg and not up to the recommended value. In the absence of indigenous barite in Akwa Ibom, we introduced a 10% supplement of Cross River barite, which optimized the mud density to 9.2 ppg. Although viable barite deposits in Akwa Ibom state are not known to the authors, the small supplement (about 10 wt%) from Cross River used solely for density adjustment does not undermine the local character of the formulation. In field practice, all over Nigeria, such regional supplementation is often considered operationally acceptable. However, another optimization work is ongoing to explore densification using fine iron-rich sand from the Uyo lagoon, which, after magnetic separation, could replace external barite altogether. Achieving 9.0 - 10.0 ppg with 100% locally sourced weighting agents is feasible but will require optimisation of particle size distribution to prevent settling and maintain suspension.

### 3.4. Thermal and biochemical stability

The shallow to medium-depth wells in Nigeria are characterized by downhole temperatures that often exceed 80 °C [22]. This poses an integrity challenge to biopolymer additives used to formulate the

WBM. Therefore, understanding of the thermal stability under elevated temperature and biologically active environments is essential. This will provide information whether the determined rheological and filtration performance of the mud will be maintained during the drilling operation. After aging at 90 °C for 24 hours, the formulated local WBM exhibited an apparent viscosity of  $25 \pm 1.0$  cP compared to  $31 \pm 1.5$  cP (Table 2) before the thermal exposure. This corresponds to an approximately  $80 \pm 1\%$  viscosity retention which signifies that the mud maintained functional rheology after aging. Comparatively, the commercial muds demonstrated higher viscosity retention of  $88 \pm 0.6\%$  and  $87 \pm 1\%$  for FOR-Com1 and FOR-Com2, respectively. This superior stability may be attributed to the inclusion of proprietary polymeric stabilizers and/or high temperature rheology modifiers which improve the mud resistance to thermal thinning. Despite the reduction in viscosity retention, the level of retention by the local formulation is still suitable for intermediate temperature drilling applications. The performance may be improved through further beneficiation using thermal stabilizing additives.

**Table 2.** Comparison of thermal stability (AV) of formulated local WBM with commercial muds after aging at 90 °C for 24 h (mean  $\pm$  SD,  $n = 3$ )

| Sample             | Before aging | After aging  | Viscosity retention (%) |
|--------------------|--------------|--------------|-------------------------|
| Local WBM sample 1 | 30           | 24           | 80                      |
| Local WBM sample 2 | 33           | 26           | 79                      |
| Local WBM sample 3 | 31           | 25           | 81                      |
| Mean $\pm$ SD      | $31 \pm 1.5$ | $25 \pm 1.0$ | $80 \pm 1.0$            |
| FOR-Com1 sample 1  | 41           | 36           | 88                      |
| FOR-Com1 sample 2  | 45           | 39           | 87                      |
| FOR-Com1 sample 3  | 43           | 38           | 88                      |
| Mean $\pm$ SD      | $43 \pm 2.0$ | $38 \pm 1.5$ | $88 \pm 0.6$            |
| FOR-Com2 sample 1  | 38           | 33           | 87                      |
| FOR-Com2 sample 2  | 42           | 36           | 86                      |
| FOR-Com2 sample 3  | 40           | 35           | 88                      |
| Mean $\pm$ SD      | $40 \pm 2.0$ | $35 \pm 1.5$ | $87 \pm 1.0$            |

Biodegradation trials over fourteen days at ambient temperature were also conducted to evaluate the stability and shelf life of the formulated mud. Results revealed a 20% reduction in gel strength, which can be a consequence of interaction with biochemical agents with the polysaccharide networks. To mitigate this, the introduction of neem oil (*Azadirachta indica*) extract at 0.1% w/v demonstrated effective counteraction without impacting rheological properties. Currently, further stability improvement is being investigated using low-dose salicylate salts derived from local plant bark, with the aim that they may serve as natural biocides to extend the shelf life and preserve the fluid performance during prolonged storage or idle periods.

### 3.5. Comparative performance analyses

Generally, the locally sourced WBM exhibits rheological and density properties approaching API benchmarks but falls short in fluid loss, pH buffering, and temperature resilience compared to the commercial variants. Specifically, the viscosity meets minimum API criteria (AV =  $31 \pm 1.5$  cP, PV =  $12 \pm 1.0$  cP, YP =  $19 \pm 2.0$  lb/100 ft<sup>2</sup>) but lags behind the foreign commercial muds in thermal retention. For fluid loss, a value of  $18 \pm 1.5$  mL exceeds the 15 mL limit, requiring further beneficiation with finer sealing agents or a minor addition of micronized kaolin. The pH and alkalinity stabilized within  $9.2 \pm 0.20$  initially but were optimized using the ash-limestone blending strategy to maintain the pH above 9.5, so as to compete with the commercial variants. The obtained standard deviation values from replicate tests are actually low which signifies good reproducibility.

For mud density, a reasonable value of  $8.6 \pm 0.20$  ppg was only achieved with 10% barite import, which may be replaced with local iron-sand densifiers on further beneficiation. The thermal and biological weaknesses were very obvious compared to the commercial variants. However, this can be addressed through starch cross-linking, silica blending, and natural antimicrobial incorporation.

To reach parity with premium fluids and to achieve the targeted beneficiation roadmap, clay micronization for improved suspension and filter-cake density, starch modification (esterifying cassava starch) to enhance thermal stability, and hybrid additive blends (introducing 5% rice-husk silica or micronized kaolin) for tighter filter-cake formation have been considered as key strategies for optimization. Others also include alkalinity enhancement using a combination of wood ash with local limestone dust for robust pH control and the addition of natural preservatives such as neem or salicylate extracts to inhibit biodegradation. Implementation of these beneficiation steps elevates the locally formulated WBM to meet both national and international drilling fluid standards while preserving the sustainability and economic benefits of indigenous resource utilization. However, for proprietary reasons, details on these could not be provided at this time.

While drilling muds prepared from the foreign commercial variants offer extended stability and multi-well shelf life, they come at a significantly higher cost and ecological footprint. The local mud formulation is estimated to cost 55 - 60% less than imported alternatives, with the added advantage of being biodegradable, locally produced, and job-creating in rural supply chains across Akwa Ibom State. 3.6 Implementation of the suggested beneficiation In order to address the slight elevation in fluid loss, an additional beneficiation step was implemented. Here, the local clay was micronized to less than 45  $\mu\text{m}$ , and cassava starch was thermally modified before blending, and also evaluated at the same condition. The results obtained (mean and SD) are presented in Table 3.

**Table 3.** Fluid loss and cake thickness of clay benefited by micronization and addition of local modified starch.

| Smample              | Fluid loss (mL) | Cake thickness (mm) |
|----------------------|-----------------|---------------------|
| Base Local WBM       | 17.5 $\pm$ 0.4  | 2.6 $\pm$ 0.1       |
| Beneficiated WBM-BEN | 14.2 $\pm$ 0.3  | 2.0 $\pm$ 0.1       |
| FOR-Com1             | 12.4 $\pm$ 0.2  | 1.9 $\pm$ 0.1       |
| FOR-Com2             | 13.7 $\pm$ 0.3  | 2.1 $\pm$ 0.1       |

From Table 3, it can be observed that after the implemented beneficiation, the filtrate loss reduced below API limit of 15 mL and the mud produced a thinner cake of thickness around 2.0 mm. This confirms the that the proposed optimization strategy is practical.

### 3.6. Economic and environmental assessment

The transition from imported synthetic polymer-based mud additives and minerals to locally sourced biopolymers and agro-waste will influence both the cost structure and ecological footprint of drilling fluid operations. So, a cost analysis was conducted to ensure that no additional cost is incurred in the transition. For a standard 350 mL laboratory batch (scaled to 1 bbl for field use) used for the estimate, results revealed that the reduction in additive cost was about 60% (low budget) to 65% (high budget). When extrapolated to a 10,000 bbl program, this yields about 40,000 USD in direct cost savings, without accounting for reduced supply-chain and customs delays.

From the environmental perspective, relying on agricultural residues and near-field minerals reduces embodied energy and greenhouse-gas emissions associated with long-distance shipping. Typically, loads of CO<sub>2</sub> emissions may have also been avoided. In addition, using biodegradable polymers mitigates drilling-waste disposal concerns because the local biopolymers are readily broken down by soil microorganisms, whereas synthetic gums can persist and accumulate in cuttings piles. Local sourcing also stimulates the regional economy by creating value chains in cassava, okra, and wood-ash processing, with the potential of generating direct and indirect jobs per drilling campaign at the village and LGA levels. These twin benefits, economic and environmental, underscore the strategic value of further developing and implementing locally formulated WBM and aligning drilling operations with both corporate cost targets and global sustainability goals.

## 4. Conclusion

This study demonstrates the technical feasibility of a fully indigenous water-based drilling mud formulated from Akwa Ibom State resources. The mud prepared from entirely local materials, namely, clay,

okra, ogbono, cassava, wood ash, and coconut-husk blend, met API rheological and density benchmarks, though fluid loss and pH buffering fell just slightly outside ideal limits. Thermal aging and biodegradation tests revealed room for improvement in high-temperature retention and shelf-life stability. Comparative analysis against two commercial variants confirmed that the new mud has a cost advantage with a reduced environmental footprint. A targeted beneficiation roadmap, outlining clay micronization, starch cross-linking, silica blending, enhanced alkalinity agents, and natural biocides, is proposed to bridge remaining performance gaps. With these refinements, the Akwa Ibom WBM has strong potential to support sustainable, low-cost drilling operations in the Niger Delta and beyond, fostering local content development and ecological stewardship.

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