Performance Evaluation of Abia Clay with Natural Polymers in Water-Based Drilling Fluid Development

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Abstract-
The quest for local content in the oil and gas industry for sustainability of materials and resources has necessitated further research on the use of Nigerian clays and locally sourced materials as additives in drilling fluid formulation to substitute the imported bentonite and synthetic additives currently used in natural oil and gas exploration. In this study, Uturu clay was treated using NaOH, NaHCO₃, KOH and NaCO₃ to improve its suitability for drilling fluid formulation. The clay sample was characterized using particle size analyzer (for particle size distribution), X-ray diffraction (for purity and crystallographic patterns), Fourier Transform infrared for surface chemistry. Water-based drilling fluid was developed using the characterized Uturu clay as the main composition and other four locally source natural polymer namely cassava starch, breadfruit starch, bush mango seed and corn fibre as rheology modifiers. It was found that clay treatment did not have significant effect on spud mud rheology. Clay characterization reveals that the untreated clay consists mainly of montmorillonite with traces of kaolinite and quartz. Preliminary drilling fluid formulation shows that rheological properties were significantly improved with the addition of the natural polymers. In addition, the rheological data were best described using power law model. Further optimization study is required to achieve optimum formulation comparable to the American Petroleum Institute recommendations and this investigation is ongoing in our lab and results will be communicated in another article.

Key words: Abia clay, natural polymer, rheology, drilling fluid

1. Introduction
The success of drilling operation depends extensively on the functionality and properties of drilling fluid. Drilling fluids are can be oil based, water based or gas; water based being the most extensively used due to its environment friendliness and cost effectiveness. Water-based drilling fluid is primarily clay and water to which chemical additives are added for improved rheological and filtration properties. Drilling fluids are developed to perform specific tasks which include transporting the drill cuttings to the surface, cooling of the drill bit, balancing the formation and hydraulic pressure, prevention of fluid loss to and from the formation by forming low permeable filter cake, lubrication of the drill bit among others [1-4].

Clays are the primary active solid in water-based drilling fluid. The most commonly used is bentonite which usually contains about 70% montmorillonite [5]. Several clay reserves were confirmed to exist across Nigeria; however, studies have shown that most of these clays require
treatment before they can be used effectively for drilling fluid formulation [4], [6]. Harsh conditions encountered in deep wells have necessitated further beneficiation of bentonite suspension using different additives [7].

Due to high cost of synthetic additives especially polymers, the use of natural additives has recently gained attention of researchers. The cost of drilling increases exponentially with depth, therefore it is imperative to investigate the suitability of cheap and environment friendly local resources that are abundantly available for drilling fluid development as substitute for synthetic imported additives. Some of the previously investigated natural polymers include cassava starch [8-10], sweet potato starch [10], corn starch [11], cellulose generated from groundnut husk [12], Achi [4] and food gum [13].

Despite the success achieved by these researchers, there use of these natural biopolymers for drilling fluid development by natural oil and gas exploration industries has not gain popularity. Therefore, further investigations are still required to ascertain and establish the suitability of the abundantly available natural additives in water-based drilling fluid development. This study therefore aimed at developing a novel water-based drilling fluid using composite biopolymers. The developed drilling fluid was characterized for rheological properties and flow behaviour of the fluid was also investigated.

2. Methodology

2.1 Materials and Sample Preparation

Clay sample was sourced from a clay site in Uturu (5° 78’ N / 7° 43’ E), Abia state at a depth of 2.5m below the surface. Impurities in the clay sample were removed through wet sieving in distilled water. Sieved clay was air dried to reduce the moisture content and later oven dried at 50 °C to constant weight [14]. Pregelatinized starches were processed from cassava roots and breadfruit following the method of [15]. Bush mango seeds and corn fibre were obtained from local markets. The processed clay and additives (cassava starch, breadfruit starch, bush mango seed and corn fibre) were ground using electric grinder and ball milled for further size reduction.

2.2 Clay Treatment

The clay sample was treated using NaOH, Na2CO3, NaHCO3, and KOH for possible cation exchange and improved suitability for drilling fluid development. Experiment was designed for the pretreatment experiment using Central Composite Design (CCD) in Response Surface Methodology (RSM) of design expert software. Concentration and treatment time was varied between 1.1-5 M and 60-80 minutes [4].

2.3 Clay Characterization

Particle size distribution of the ball milled clay sample was done using Malvern Master Sizer (MS 2000). Clay sample was analyzed for mineral composition using XRD apparatus X’Pert PRO PW3040/60 (PANalytical) diffractometer equipped with a Cu-Kα radiation source. The test was run at 40 kV and 40 mA. A continuous mode was used for collecting the data in the 2 theta range from 3 to 80 degree at a scanning speed of 2s count time per step. The acquired data were analyzed using X’Pert high score software works with PDF-2 database. An infra-red spectrum was obtained using Perkin Elmer Spectrometer (Spectrum Two- UATR).
2.4 Drilling Fluid Development
Drilling fluid was prepared by adding 24.5 g of clay in 350 ml of water under continuous stirring for 10 minutes. Additives were added (Table 1) to the clay-water mixture before ageing it for 24 hours for proper hydration (Rheological properties were determined using Antar Paar rheometer (Rheolab QC).

Table 1: Drilling Fluid Formulation

| Additive            | Quantity |
|---------------------|----------|
| Water               | 350 ml   |
| Clay                | 24.50 g  |
| Barite              | 6.00 g   |
| Caustic Potash      | 2.00 g   |
| BFS                 | 4.50 g   |
| BMS                 | 4.50 g   |
| CS                  | 4.50 g   |
| CF                  | 1.13 g   |

BFS = Bread Fruit Starch, BMS = Bush Mango Seed, CS = Cassava Starch and CF = Corn fibre

3. Result and discussions
3.1 Rheological properties of untreated and treated clay
The rheological and physical properties of spud mud prepared using untreated and treated clay samples are shown in Table 2. Dial readings of all the spud samples increases with increasing shear rate. Surprisingly, pre-treatment did not have any significant effect on the viscosity of all the treated samples. Viscosities of the Na₂CO₃ treated clays are ranges between 3 and 4 cp, which is lower than viscosity of the untreated clay (4.5 cp). Similar trend was observed for NaOH treated clay. Run 1 (KOH treated clay), run 1 and 6 (NaHCO₃) gave viscosity of 4.5 cp which is the same for the untreated clay. In the same vein, mud weight and gel strength were not improved via pre-treatment. However, pH values were significantly improved and the obtained values are within the API stipulation. It can therefore, be concluded that the investigated clay sample did not require chemical pre-treatment prior to its use for drilling fluid formulation since pre-treatment did not significantly improve the rheological properties.

Table 2: Dial reading and physical properties of Uturu Na₂CO₃
|       | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | Untreated |
|-------|------|------|------|------|------|------|------|------|------|-----------|
| **AC (M)** | 5.5  | 1.1  | 0.19 | 3.3  | 5.5  | 3.3  | 1.1  | 6.4  | 3.3  | -         |
| **AT (mins)** | 80   | 60   | 70   | 55.86| 60   | 84.14| 80   | 70   | 70   | -         |
| **600 rpm (cp)** | 3.5  | 3    | 4    | 3.5  | 4    | 4    | 3    | 3    | 4.5  |           |
| **300 rpm (cp)** | 2.5  | 2    | 3    | 2    | 3    | 2.5  | 2.5  | 2    | 2    | 3.5       |
| **200 rpm (cp)** | 1    | 1.5  | 2.5  | 1.5  | 2.5  | 2.5  | 2    | 2    | 1.5  | 2.5       |
| **100 rpm (cp)** | 1.5  | 1    | 2    | 1    | 2    | 2    | 2    | 1    | 2    | 2.5       |
| **MW (lb/gal)** | 8.7  | 8.7  | 8.7  | 8.75 | 8.7  | 8.7  | 8.7  | 8.7  | 8.75 | 8.7       |
| **pH (fresh)** | 11.03| 10.83| 9.66 | 10.65| 11.15| 10.79| 10.6 | 11.1 | 10.87| 7.87      |
| **pH (hydrated)** | 10.89| 10.63| 9.55 | 10.49| 10.95| 10.71| 10.6 | 11.03| 10.68| 7.81      |
| **GS (10 secs)** | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1         |
| **GS (10 mins)** | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1         |
| **KOH** |       |      |      |      |      |      |      |      |      |           |
| **600 rpm (cp)** | 4.5  | 3    | 4    | 4    | 4    | 4    | 3    | 3    | 4    | 4.5       |
| **300 rpm (cp)** | 3    | 2    | 3    | 3    | 2    | 3    | 2    | 3    | 2    | 3.5       |
| **200 rpm (cp)** | 2.5  | 1.5  | 2.5  | 1.5  | 2    | 1.5  | 2    | 1.5  | 2    | 2.5       |
| **100 rpm (cp)** | 2    | 1.5  | 2    | 1    | 2    | 1    | 2    | 1    | 2    | 2.5       |
| **MW (lb/gal)** | 8.7  | 8.75 | 8.7  | 8.7  | 8.7  | 8.7  | 8.7  | 8.7  | 8.7  | 8.7       |
| **pH (fresh)** | 10.82| 10.19| 9.12 | 8.76 | 11.3 | 10.08| 9.16 | 10.66| 10.73| 7.87      |
| **pH (hydrated)** | 10.66| 10.03| 9.01 | 8.69 | 10.96| 9.97 | 9.05 | 10.53| 10.6  | 7.81      |
| **GS (10 secs)** | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1         |
| **GS (10 mins)** | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1         |
| **NaOH** |       |      |      |      |      |      |      |      |      |           |
| **600 rpm (cp)** | 4    | 4    | 3.5  | 3.5  | 4    | 4    | 4    | 3.5  | 3.5  | 4.5       |
| **300 rpm (cp)** | 3    | 3    | 2.5  | 2.5  | 3    | 3    | 3    | 2.5  | 2    | 3.5       |
| **200 rpm (cp)** | 2    | 2.5  | 2    | 2    | 2.5  | 2.5  | 2    | 2    | 1.5  | 2.5       |
| **100 rpm (cp)** | 2    | 2    | 1.5  | 2    | 2    | 2    | 1.5  | 1    | 2    | 2.5       |
| **MW (lb/gal)** | 8.7  | 8.7  | 8.7  | 8.75 | 8.7  | 8.7  | 8.7  | 8.7  | 8.7  | 8.7       |
| **pH (fresh)** | 10.2 | 10.14| 9.91 | 10.41| 10.72| 10.75| 9.95 | 10.09| 10.45| 7.87      |
| **pH (hydrated)** | 10.15| 10.01| 9.82 | 10.33| 10.59| 10.61| 9.83 | 9.94 | 10.37| 7.81      |
| **GS (10 secs)** | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1         |
| **GS (10 mins)** | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1         |
| **NaHCO3** |       |      |      |      |      |      |      |      |      |           |
| **600 rpm (cp)** | 4.5  | 4    | 3.5  | 4    | 4    | 4.5  | 4    | 4    | 3    | 4.5       |
| **300 rpm (cp)** | 3.5  | 3    | 2    | 3    | 3    | 3.5  | 3    | 3    | 2    | 3.5       |
| **200 rpm (cp)** | 2.5  | 2.5  | 1.5  | 2.5  | 2    | 2.5  | 2.5  | 2    | 2    | 2.5       |
| **100 rpm (cp)** | 2    | 2    | 1    | 2    | 1    | 2    | 1    | 2    | 1.5  | 2.5       |
| **MW (lb/gal)** | 8.7  | 8.7  | 8.7  | 8.7  | 8.7  | 8.7  | 8.7  | 8.7  | 8.75 | 8.7       |
| **pH (fresh)** | 10.05| 10.05| 9.62 | 10.48| 10.38| 10.37| 10.2 | 9.83 | 9.52 | 7.87      |
| **pH (hydrated)** | 9.94 | 9.92 | 9.57 | 10.39| 10.29| 10.19| 10   | 9.71 | 9.38 | 7.81      |
| **GS (10 secs)** | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1         |
| **GS (10 mins)** | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1    | 1         |
MW = Mud weight; GS = Gel strength

3.2 Clay Characterization

3.2.1 Particle Size Analysis

Particle-size distribution (PSD) is one of the most important physical characteristics that can be measured in clay minerals. It affects nearly all soil characteristics and behavior including porosity, permeability, chemistry, mineralogy, and structure and bulk density directly or in indirectly (Parry et al., 2011). The PSD plot is characterized with multiple peaks indicating the presence of particles of different sizes. As shown in Figure 2, 10% of the clay particles, \( d (0.1) \) have diameters less than 0.1 μm (100 nm), 50% of the clay particles, \( d (0.5) \) have diameters less than 3.215 μm while 90% of the particles, \( d (0.9) \) have diameters less than 16.14 μm.

![Figure 1: Particle Size distribution of clay sample](image)

3.2.2 Mineralogical composition

The phase identification using X’pert High Score software revealed that the clay samples contain complex mixtures of clay minerals. XRD pattern show the clay sample has layered crystalline structures. Untreated Uturu clay is predominantly montmorillonite with mixture of quartz and minor amounts of kaolinite. Prominent montmorillonite and kaolinite peaks were observed to co-exist at 2θ values of 19.70°, 24.76°, 36.07, 61.96° at corresponding d-spacing of 4.50, 3.59, 2.46 and 1.49 Å respectively. XRD reflections of quartz were observed at 2θ = 26.60 (d-spacing = 3.35 Å). Similar results of montmorillonite XRD reflection observed at 2θ = 5.94, 17.54, 19.72, 29.52, 34.98 and 36.04°) and substantial amounts of admixture of quartz (2θ = 21.84, 26.66, 35.98, 39.42 and 42.40º) was reported by Ikhitikova et al. (2012). XRD reflection of kaolin appeared at 2θ = 12.23° (d-spacing =7.24 Å). This deflection angle is typical of kaolinite as reported by [16].
3.2.3 Surface Chemistry

OH stretching of kaolinite was observed at 3619 and 3686 cm\(^{-1}\) in the untreated clay sample. The band at 1000 cm\(^{-1}\) is attributed to Si-O stretching due to the overlapping character of the different type of silicate mineral [17]. The band at 911 cm\(^{-1}\) is attributed to Al-OH-Al bending [18]. The band at 795 cm\(^{-1}\) is attributed to Al-O-Si inner surface vibration [19]. The band around 637 cm\(^{-1}\) shows the coupled Al-O and Si-O out of plane vibration which is common to montmorillonite according to [20]. The tetrahedral bending mode of Si-O-Al occurred at 530 cm\(^{-1}\). The bands in FTIR analysis confirm the presence of montmorillonite, kaolinite, and silica oxide as shown in the XRD analysis.

3.3 Rheological properties of drilling fluid
Rheological properties of the developed drilling fluid are illustrated in Table 3. Results indicated that rheological properties were significantly improved by the addition of processed natural polymers. Dial readings at 300 and 600 rpm are 8.86 and 16.92 cp respectively. American Petroleum Institute (API) recommendation for dial reading at 600 rpm is 30 cp minimum, hence the formulation still requires further optimization to meet the standard. PV and YP were estimated to 8.06 cp and 0.08 lb/100ft² respectively. The value of PV is within the API recommendations of 8 cp minimum. A relatively low value of YP (0.08 lb/100ft²) was obtained for the fluid.

Table 3: Rheological Properties of drilling fluid

| Parameter                        | Values |
|----------------------------------|--------|
| Dial reading at 300 rpm (cp)     | 8.86   |
| Dial reading at 600 rpm (cp)     | 16.92  |
| Plastic viscosity (cp)           | 8.06   |
| Apparent viscosity (cp)          | 8.46   |
| Yield point (lb/100ft²)          | 0.08   |
| pH                               | 8.7    |

Rheograms of Experimental data and fitted rheological flow models are illustrated in Figure 4. Viscosity as a function shear rate was plotted on the secondary vertical axis (Fig. 4) while Flow model parameters and their statistics are summarized in Table 4. The fitted rheological flow models are Bingham, Power law (PL) and Herschel Bulkley (HB) flow models. Viscosity of the developed DF increases almost linearly at higher shear rate. The rheogram of the experimental data reveals the non-Newtonian behaviour of the DF, indicating the dependence of viscosity on shear rate. Both Power law and Herschel Bulkley model excellently describe the rheological data of the DF with correlation coefficients of 0.9965 and 0.9976 respectively at 95% confidence interval. Rheological behavior of drilling fluids has been well described by power law and HB models [5,21,22].

The yield stress (YP), which is the stress require in order to move the drilling fluid is extremely diminutive, hence could not be captured by Bingham and HB model. The developed fluid can therefore be regarded as power law fluid due to absence of yield stress. Kelessidis et al. reported that YP is an important rheological parameter which directly affects the pumptability and ability of drilling fluid to transport and suspend drill cuttings [5]. When YP is too high, it may be impossible to restart the drilling process; however, YP is needed to prevent settling of large particles when drilling is paused. Therefore, extremely low YP obtained in this study is not desirable, hence the need for further optimization of the rheological properties to achieve a YP sufficient enough to suspend drill cuttings.

Flow index (n) and consistency index are rheological properties that are both related to shear dilution and shearing force, respectively [7]. Consistency index (n) greater than 1 indicates a shear thickening behaviour (dilatant fluid) which may be desirable when the viscosity of drilling fluid is not that high as obtained in this study.
Figure 4: Rheograms of fitted rheological models
Exp. = Experimental, PL = Power law model, BM = Bingham model, HB = Herschel Bulkley model

Table 4: Model and Statistical parameters of the developed drilling fluid

| Flow model       | Parameter | \( R^2 \) | MSSE  |
|------------------|-----------|-----------|-------|
| Bingham          | \( \tau_y = 0 \) | 0.9459 | 2.5024 |
|                  | \( \mu_p = 12.85 \text{ cp} \) |       |       |
| Power law        | \( n = 1.710 \) | 0.9965 | 0.0880 |
|                  | \( k = 0.0001 \) |       |       |
| Herschel Bulkley | \( \tau_y = 0 \) | 0.9976 | 0.0700 |
|                  | \( n = 1.783 \) |       |       |
|                  | \( k = 7.09 \times 10^{-5} \) |       |       |

4. Conclusions
Uturu clay was pre-treated using NaOH, NaHCO\(_3\), Na\(_2\)CO\(_3\), and KOH. Rheological properties of the treated clay revealed that pre-treatment did not have significant effect on the clay except on the pH. Drilling fluid was therefore developed using untreated clay sample. Addition of biopolymers significantly improves the rheological properties but the obtained results are still below API recommendations. Rheogram plots indicate the developed fluid is non-Newtonian, dilatant and is best described by power law model. However, further optimization is required to meet the API recommendations.

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