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# COMPARATIVE ANALYSIS OF BENTONITE AND LOCAL CLAY AS VISCOSITY CONTROL ADDITIVES OF DRILLING FLUID

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**Abstract -** This study focused on comparing bentonite and local clay as viscosity control additives of drilling fluids. Samples of bentonite and clay, both before and after treatment, were processed and characterized. Next, employing clay and bentonite as viscosifiers, fluids (muds) with oil and water bases were created. The rheological and related parameters of the drilling muds were then characterized. Considering the process variables, the effects of clay or bentonite dosage (5w% - 13wt%), temperature (303K – 343K), and mixing time (20min – 40min) on the viscosity of each produced mud were determined. Analyzing the results, Si-O bond stretching was found in untreated clay, treated clay, and bentonite. Changes in the functional groups were revealed in the untreated and treated clay samples. Also, heteroatoms were present in the samples, which indicates that the clay/bentonite will be suitable for the viscosity control function. Viscosity, pH, weight of the mud, and other related parameters are all within the American Petroleum Institute Standard. Water-based mud (WBM) and oil-based mud (OBM) have values of mud weight between 8.65 and 9.60 pounds per gallon. This is an indication that the muds possess the required capacity for lifting drilling cuttings from the drilling borehole. The viscosity of each mud with clay additive has higher values of apparent viscosity (AV) and plastic viscosity (PV) than OBM. This means that mud with clay additive is more viscous than that of bentonite additive. Viscosity-associated properties (yield point (YP) and YP/PV ratio) have values that reveal that the formulated muds are suitable for drilling operations. In both WBM and OBM, the viscosity increased with the rise in clay/bentonite dosage and time till the optimum (maximum) point was reached at 9wt% dosage. On the contrary, the viscosity decreased with an increase in temperature. Comparatively, the treated clay competed favorably with bentonite and should be applied as an alternative to the imported bentonite in the formulation of drilling mud.
**Keywords: Bentonite, Local Clay, Viscosity Control Additives, Drilling Fluid**

## 1. Introduction

Bentonite is a kind of clay composed especially of montmorillonite, a mineral belonging to the smectite group (Olatunde, et al, 2021). It is usually utilized in drilling mud because of its excessive swelling capacity, excessive viscosity, and cap potential to form a seal in the wellbore. The key factor influencing bentonite's efficacy as an extender is its montmorillonite content. Depending on the predominant exchangeable cation, bentonite is classified as either sodium or calcium. Sodium bentonite is more reactive than calcium bentonite in clean water. According to Okologume and Akinwumi (2016), bentonite is categorized as having "excessive yield" (sodium bentonite) or "low yield" (calcium bentonite) in terms of overall performance. Bentonite clays are in high demand in industry because of their amazing thixotropic, swelling, and absorption qualities. The best bentonite typically accessible for use in drilling fluid applications is Wyoming bentonite.

The majority of clay minerals are found in fine-grained materials with particle sizes of less than 0.002 mm. Despite clay's abundance and wide range of applications, certain property requirements must be satisfied by both raw and refined clay. The geotechnical characteristics of natural clays are typically altered by refining, which may boost the industrial potential of the clays. The raw materials used to make mud are often chosen based on clays that have a significant amount of montmorillonite and are evaluated based on how they behave in water. Their applicability is determined by several factors, including filtering characteristics, volumetric yield of the specified clay, and viscosity. Bentonite clay is the raw material that satisfies the greatest number of drilling requirements. Bentonite is manufactured through the weathering of volcanic ash. The complex process of weathering that produces clay minerals from their parent minerals involves several factors, but climate, topography, vegetation, and exposure period are crucial ones. Regardless of its geological origin, bentonite is widely used for any polymeric, colloidal, and swelling clay. These clays fgrequently contain a significant amount of montmorillonite group minerals. According to Nweke et al. (2015), bentonite is clay that expands more frequently when wet.

Drilling mud is a flowing fluid used in rotary drilling to accomplish one or more tasks during the process. It typically consists of clay, weight compounds, water or oil, and a few different chemical additions. Its viscosity and ability to hold and preserve water are its two most important physical qualities. It is well known that the effectiveness and value of the drilling process heavily depend on the drilling fluid utilized. Drilling mud travels in a circle, starting from the construction platform, where it is forced into the formation device by entering the drill string and then raised to the surface by the drill bit. For the ideal result, the fluid properties, which include temperature and density, must be regularly monitored. Drilling fluids are commonly identified by their gel or thixotropic properties, which allow them to reversibly change from having an excessive to a low viscosity state while under stress or strain (Dolz et al., 2007). These variations shatter the well's microstructure, but they can be gradually restored when the fluid is at rest (Azar and Samuel, 2007). Wells' commercial functionality is typically compromised by complex interactions between fluid and rock that reduce permeability to gas and oil. Drilling mud must therefore be continuously modified to reduce these undesirable consequences (Nascimento et al., 2013). The major factors determining which type of mud is most significant are the wellbore's depth, strain, and mechanical and effect resistance.

There is a lack of comprehensive studies comparing the rheological properties, filtration characteristics, and other performance of drilling mud containing bentonite and local clay additives, and there are no such studies to inform drilling mud formulation and optimization. The effectiveness of local clay as a drilling mud additive may be influenced by processing methods, particle size distribution, and other factors and there is a need to investigate these factors in order to optimize the performance of drilling mud containing local additives.

## 2 Materials, Chemicals, and Equipment Used

The following tools were used to complete this task: a single-spindle mixer (Hamilton Beach, HMD200), a manual grinder, test sieves, mixing bowls, beakers, spatulas, sample trays, stopwatch, laboratory mortar and pestle, electronic weighing balance, graduated (measuring) cylinders, flat bottom flasks, funnels, heating mantle (TYPE - 981B-00050, Chemland Instrument), water bath (HH-4), filter papers, conical flasks, wash bottles, blue litmus papers, sample bottles, and Fourier-transform infrared (FTIR) spectrometer (Cary 630, Agilent Technologies USA), drilling mud balance (Model 140 - FANN), pH meter (PH400, Apera Instruments), and viscometer (Model 35 - FANN). The clay sample was obtained from Agbani in Nkanu West Local Government Area of Enugu State Nigeria and was treated with 98% pure sulfuric acid ($H_2SO_4$), which has a specific gravity of 1.84. High-viscosity polyanionic cellulose, diesel, water, and xanthan gum biopolymer are some of the additional ingredients utilized to formulate the drilling muds.

**2.1 Experimental Procedures**

In this work, the following experiments are conducted: clay treatment, bentonite, clay sample characterization, drilling mud formulation, and rheological property assessment of the formulated drilling muds. These studies were conducted following API-suggested standards, as stated in API RP 13D (2017).

**2.1.1Treatment of the kaolin**

According to Apugo-Nwosu et al. (2011), the raw clay was treated via crushing, screening, forming slurry (with water added), dewatering, drying, crushing, sieving, and packaging. After being manually ground into lumps, the clay sample was filtered through a 2 mm sieve to get rid of big debris and stones. The screened clay was placed in a mixing bowl, and air bubbles that had been entrained were removed by thoroughly mixing the distilled water with a spatula. This created an aqueous slurry that was highly homogenized. After the resulting slurry was spread out and scooped little by little into a sample tray for easy drying, it was allowed to air dry for 24 hours. Once dry, the clay was ground using a laboratory mortar and pestle by the API standard for clay particles and screened with a 74μm sieve to remove any remaining solid or oversized materials, yielding 900g of fine clay powder. Following preparation, the clay was allowed to leach, and during this process, 1.0M $H_2SO_4$ was used to treat the clay. To prepare 1.0M $H_2SO_4$, 700 ml of distilled water and 54.35 ml of $H_2SO_4$ were combined in a 1-liter measuring cylinder. Distilled water was then added to the solution to bring it up to a 1-liter volume. 50g of the fine clay sample was put into a flask with a flat bottom for the leaching procedure. 250ml of 1.0M $H_2SO_4$ was then added, and the flask was gently agitated. After one hour of heating at 95 degrees Celsius on a heating mantle, the mixture was allowed to cool in a water bath. Following cooling, the leached clay mixture was filtered and repeatedly cleaned with distilled water to eliminate all traces of the acid; blue litmus paper was periodically used to test the filtrate to determine whether the acid had been completely washed out. The residue was air-dried for 48 hours, ground and screened to finally obtain treated clay, and then packaged in sample bottles. The treatment procedure above was therefore repeated to get a mass of 680g of the treated clay.

**2.1.2 Determination of the Functional groups of the clay samples**

Using Fourier-transform infrared (FTIR) spectroscopy, the functional groups of the untreated clay, treated clay, and bentonite samples were determined. Finding and identifying the functional groupings of the corresponding samples was the goal of the analysis.

**2.1.3 Formulation of the drilling muds**

Muds with an oil and water base were made independently. Tables 1 and 2 display the contents of the water- and oil-based muds, respectively. The formulations were made in compliance with API RP 13D, 2017 regulations for drilling mud manufacturing.

**Table 1: Water-based mud composition**

| S/No. | Raw material | Function(s) | Quantity |
|---|---|---|---|
| i. | Water | Base fluid | 220ml |
| ii. | Clay or bentonite | Viscosity control | 9g |
| iii. | Xanthan gum biopolymer | Viscosity and fluid-loss control | 1.2g |
| iv. | High-viscosity polyanionic cellulose (PAC) | Viscosity and fluid-loss control | 1g |
| v. | Barite | Weighing agent | 12.0g |

**Table 2: Oil-based mud composition**

| S/No. | Raw material | Function(s) | Quantity |
|---|---|---|---|
| i. | Diesel | Base fluid | 220ml |
| ii. | Clay or bentonite | Viscosity control | 9g |
| iii. | Xanthan gum biopolymer | Viscosity and fluid-loss control | 1.2g |
| iv. | High-viscosity polyanionic cellulose (PAC) | Viscosity and fluid-loss control | 1g |
| v. | Barite | Weighing agent | 12.0g |

The different amounts of the raw materials were measured using graduated cylinders and an electronic weighing balance. They were then poured into the steel cup of the single-spindle mixer, which was held in place, one after the other (in descending order as listed in Tables 1 and 2, within a 5-minute interval), while the mixer was powered on and the spindle rotated, mixing them thoroughly. After all the ingredients had been added to the mixer, it was stirred for 30 minutes to ensure complete consistency and produce finely blended drilling muds with a brownish appearance. The formulation process was performed again, and the materials in the steel cup were stirred and left for 15, 20, 25, and 35 minutes, respectively. The formulated mud's rheological characteristics were suitably assessed.

**2.2 Rheological characterization of the formulated drilling muds**

Following the guidelines provided by API suggested standard methods (API RP 13B-1, 2019; API RP 13B-2, 2014; API RP 13I, 2020), the formed muds were analyzed and their rheological parameters were ascertained as follows:

**1. Determination of mud weight**

A level, flat surface served as the foundation stand for the mud balance, which had been properly calibrated. The dirt sample was placed into the dry, clean cup, and any trapped air was gently shaken free by tapping the cup's lid several times. The surplus dirt was then allowed to escape through the lid's vent hole, which will also aid in clearing the sample of any trapped air, and the lid was positioned on the cup by slowly pressing down and rotating until it was securely seated. A finger was used to cover the vent hole and the muck from the exterior of the cup and lid was wiped away. The assembly was leveled by sliding the weight rider down the balancing arm's knife-edge, which was fitted into the fulcrum, until the level bubble oscillated equally on each side of the center line. The rider's indicator was used to record the mud weight reading, which was measured from the side closest to the balancing cup—that is, the rider's left edge—to the closest scale division in pounds per gallon.

**2. Determination of pH**

After correctly calibrating the pH meter, the electrode was cleaned with distilled water and wiped dry. After adding a mud sample to a beaker and immersing the electrode in it, the measure button was hit. A short while later, the digital reading stabilized, allowing the pH of the mud to be determined.

**3. Determination of apparent viscosity, plastic viscosity, and yield point**

After filling the viscometer cup with mud to the meniscus line, the viscometer was adjusted so that the rotating sleeve was submerged in the cup and the mud's surface contacted the scribed mark on the sleeve. The viscometer was then set on its stand. After that, the sample was mixed for 10 to 15 seconds on the "STIR" setting of the viscometer. After that, the rotor speed was adjusted to 600 rpm, and the reading on the dial was recorded once it steadied. The rotor speed was then adjusted to 300 rpm, and when this reading was reached, a stabilized dial reading was noted. The dial readings obtained were used to evaluate the apparent viscosity, plastic viscosity, and yield point of the mud using Equations 1, 2, and 3 respectively (Omotioma et al., 2014).

$$\text{Apparent viscosity (cP)} = \text{600rpm dial reading} \div 2 \qquad (1)$$

Plastic viscosity (cP) = 600rpm dial reading – 300rpm dial reading (2)

Yield point (lb/100 $ft^2$) = 300rpm reading – Plastic viscosity (3)

**4. Determination of gel strength**

After mixing the mud sample in the viscometer cup for ten to fifteen seconds on the "STIR" setting, the viscometer was turned off. The rotor speed knob was turned to the 3 rpm setting, also referred to as the "GEL" setting, while the dial deflection was monitored. The mud was left still for 10 seconds after the rotor sleeve had stopped moving. The 10 seconds of gel strength was determined by recording the maximum dial reading before the gel breaking. These procedures were carried out twice more, allowing the mud to stand still for ten and thirty minutes, respectively, giving the mud its various gel strengths. The units of measurement were lb/100ft2.

**2.3 Determination of effects of process variables on the viscosity and yield point of the mud**

The effects of temperature, mixing time, and bentonite or clay dosage on the viscosity of the corresponding prepared muds were determined, taking one component at a time.

## 3 Results and Discussion

### 3.1 Characteristics of Clay and Bentonite

FTIR spectra of the untreated Agbani clay, treated Agbani clay, and bentonite are presented in Figures 1, 2, and 3 respectively. Each spectrum showcases transmittance versus wavenumber plot, and peaks of the plot represent the functional groups. An infrared chart was used to recognize the functional groups of the clay and bentonite samples. The functional groups are presented in Tables 3– 5. There are changes in the functional groups of the untreated and treated clay. This may be attributed to the treatment process that beneficiated the clay. Si-O bond stretching was found in untreated clay, treated clay, and bentonite. Also, heteroatoms were present in the samples, which indicates that the clay/bentonite will be suitable for the viscosity control function.

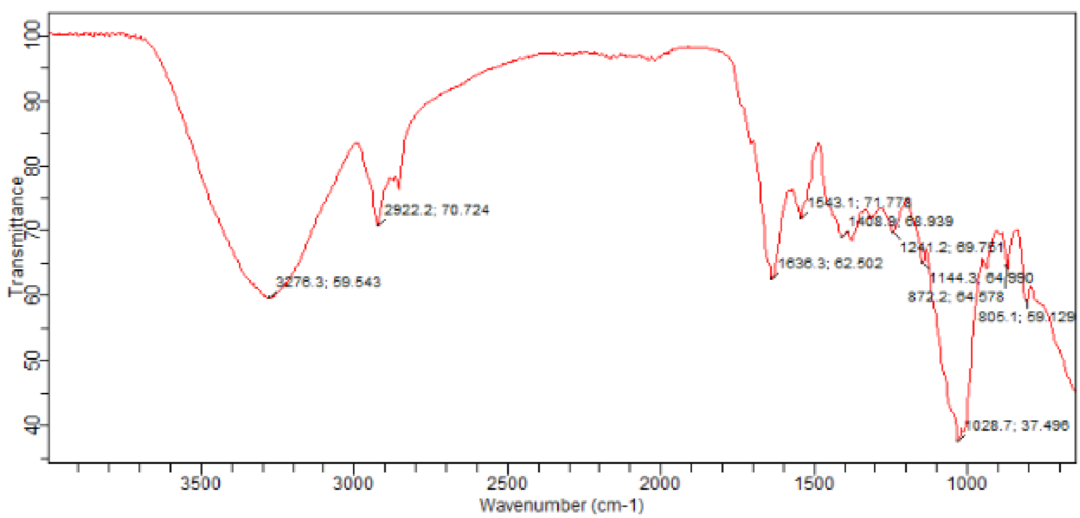


**Figure 1: FTIR spectrum of the untreated Agbani clay**

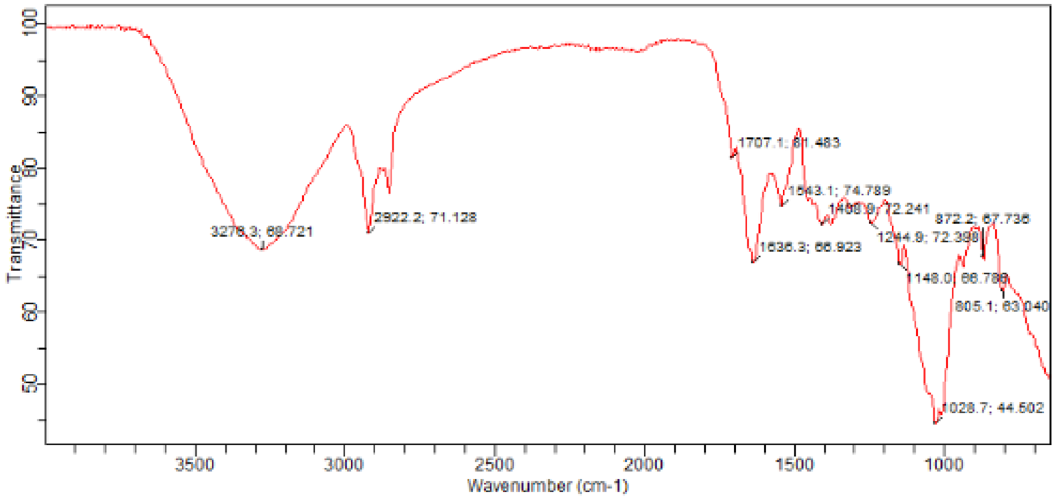


**Figure 2: FTIR spectrum of the treated Agbani clay**

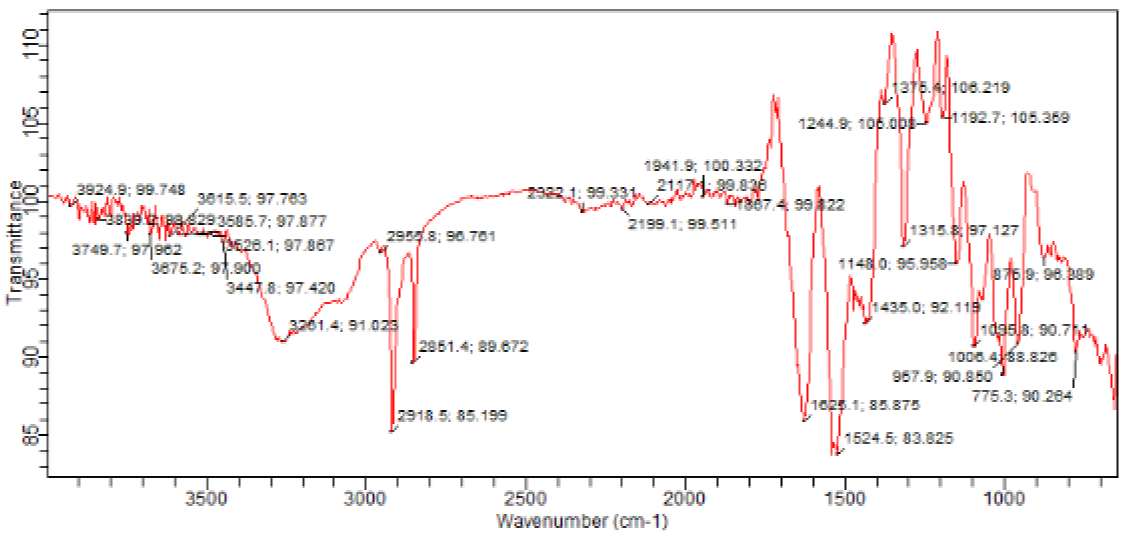


**Figure 3: FTIR spectrum of the bentonite**

**Table 3: Functional groups of the untreated Agbani clay**

| Peak | Functional Group | Class of Compounds |
|---|---|---|
| 3278.3 | ≡C-H Stretch | Alkynes |
| 2922.2 | C-H Stretch | Alkanes and Alkyls |
| 1638.3 | Bond | Amides |
| 1543.1 | N-H Bond | Amides |
| 1241.2 | C-F Stretch | Alkyl halides |
| 1144.3 | Si-O bond stretching, C-O stretch | Silicate, Alcohols |
| 805.1 | C-H Bond | Aromatic Compounds |
| 1028.7 | C-H Bond | Alkyl halides |

**Table 4: Functional groups of the treated Agbani clay**

| Peak | Functional Group | Class of Compounds |
|---|---|---|
| 3278.3 | O-H Stretch | Carboxylic acid |
| 2922.2 | C-H Stretch | Alkanes and Alkyls |
| 1244.9 | C-F Stretch | Alkyl halides |
| 1148.0 | Si-O bond stretching, C-O stretch | Silicate, Alcohols |
| 1028.7 | C-H Bond | Alkyl halides |

**Table 5: Functional groups of the untreated Agbani clay**

| Peaks | Functional Group | Class of Compounds |
|---|---|---|
| 3447.8 | N-H Symmetric & asym. Stretch | Amines |
| 3201.4 | N-H Symmetric & asym. Stretch | Amides |
| 2955.8 | C-H Stretch | Alkanes and Alkyls |
| 2851.4 | C-H Stretch | Alkanes and Alkyls |
| 2918.5 | C-H Stretch | Alkanes and Alkyls |
| 2922.1 | O-H Stretch | Carboxylic Acids |
| 2117.1 | C ≡C-H Stretch | Alkynes |
| 1244.9 | C-F Stretch | Alkyl halides |
| 1375.4 | $CH_3$C-H Bond | Alkanes and Alkyls |
| 1192.7 | Si-O bond stretching, C-O stretch | Silicate, Alcohols |
| 1095.8 | C-F Stretch | Alkyl halides |
| 1000.4 | C-F Stretch | Alkyl halides |
| 967.9 | C-H Bond | Alkanes |
| 1025.1 | C-F Stretch | Alkyl halides |
| 1524.5 | N-H Bond | Amides |

### 3.2 Rheological Characterization of the Drilling Fluids

The rheological characteristics of the mud are displayed in Table 6. Recorded mud weight, pH, viscosity, and allied properties are within the American Petroleum Institute Standard (API, 2006). Values of the mud weight of water-based mud (WBM) and oil-based mud (OBM) fall within the range of 8.65 lb/gal – 9.60 lb/gal. This is an indication that the muds possess the required capacity for lifting drilling cuttings from the drilling borehole (Omotioma et al, 2015; Rana et al, 2020). The pH values are greater than 7, showing that the formulated muds are in alkaline form (Anthony et al, 2020; Azinta et al, 2021). WBM has a higher pH value than OBM. Also clay additive has higher pH than the bentonite additive in both WBM and OBM. It shows that WBM is more alkaline than OBM.

On the viscosity of each mud, mud with clay additive has higher values of apparent viscosity (AV) and plastic viscosity (PV) than OBM. It means that mud with clay additive is more viscous than that of bentonite additive. Viscosity-associated properties (yield point (YP) and YP/PV ratio) have values revealed that the formulated muds are suitable for drilling operations (Dankwa et al, 2018, Azinta et al, 2021). Recorded gel strength values are within the API standard. This shows that muds have the lifting capacity of bringing the cuttings to the outer surface

**Table 6: Rheological properties of the muds**

| Properties | | WBM with Agbani Clay | WBM with bentonite | OBM with Agbani Clay | OBM with Bentonite | API Standard |
|---|---|---|---|---|---|---|
| Mud weight (lb/gal) | | 9.08 | 9.23 | 9.51 | 9.17 | 8.65 – 9.60 |
| Ph | | 10.17 | 9.91 | 9.69 | 9.54 | 9.50 – 12.50 |
| Viscometer reading (cP) | 600 RPM | 49.38 | 48.37 | 60.51 | 60.72 | > 30.0 |
| | 300 RPM | 36.36 | 36.22 | 43.28 | 43.93 | > 23.0 |
| Apparent viscosity (cP) | | 24.69 | 24.19 | 30.26 | 30.36 | 12.0 – 35.0 |
| Plastic viscosity (cP) | | 13.02 | 12.15 | 17.23 | 16.79 | 6.0 – 65.0 |
| Yield point (lb/100ft$^2$) | | 23.34 | 24.07 | 26.05 | 27.14 | 15.0 – 50.0 |
| YP/PV ratio | | 1.793 | 1.981 | 1.512 | 1.616 | ≤ 3.00 |
| Gel strength (lb/100ft$^2$) | | 12.65 | 12.04 | 11.81 | 11.04 | 3 – 20 |
| | | 13.21 | 12.97 | 14.23 | 13.99 | 8 – 30 |
| | | 15.37 | 14.68 | 16.84 | 16.50 | – |

**3.3 Effect of Process Variables on the Viscosity of the Muds**

Figures 4, 5, and 6 show the effects of bentonite or clay dosage, mixing time, and temperature (process factors) on the viscosity of the mud, respectively. In both WBM and OBM, the viscosity increased with the increase in clay/bentonite dosage till the optimum (maximum) point was reached at 9wt% dosage. Beyond the maximum point, the viscosity declined slightly in all the cases. This may be attributed to the weakening of the inter-molecular forces (occasioned by excess clay/bentonite dosage) in the drilling mud mixture (Omotioma et al, 2014; Arinkoola et al, 2022; Nlemedim et al, 2023). A similar trend is shown in the relationship between viscosity and mixing time in Figure 5. On the contrary, the viscosity decreased with an increase in temperature, Figure 6. The temperature rise weakens the bonding forces of the mud, there decreasing the opposing forces of the mud flow.

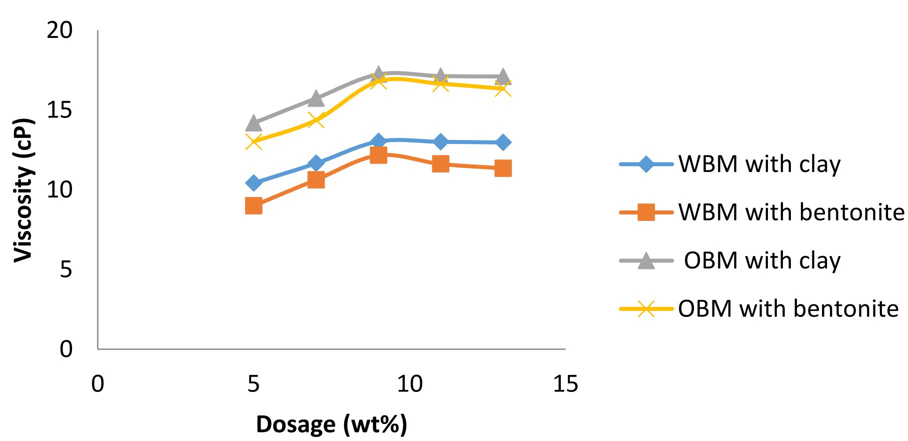


**Figure 4: Effect of dosage on the viscosity of the muds**

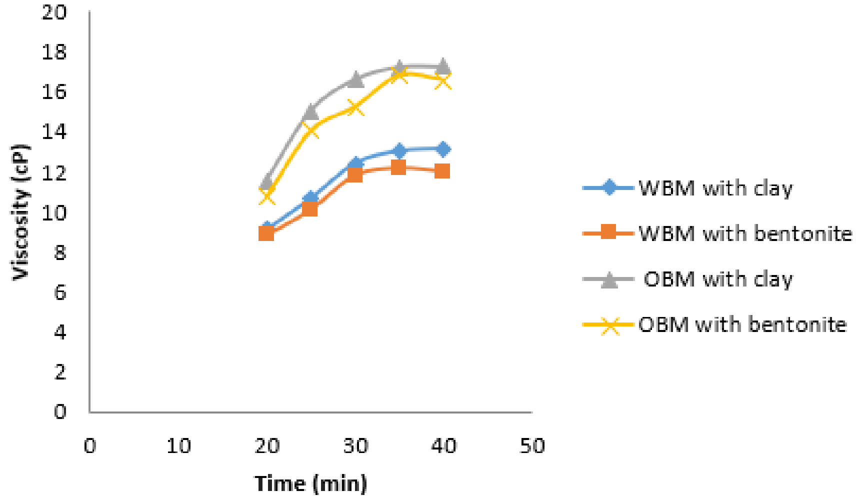


**Figure 5: Effect of time on the viscosity of the muds**

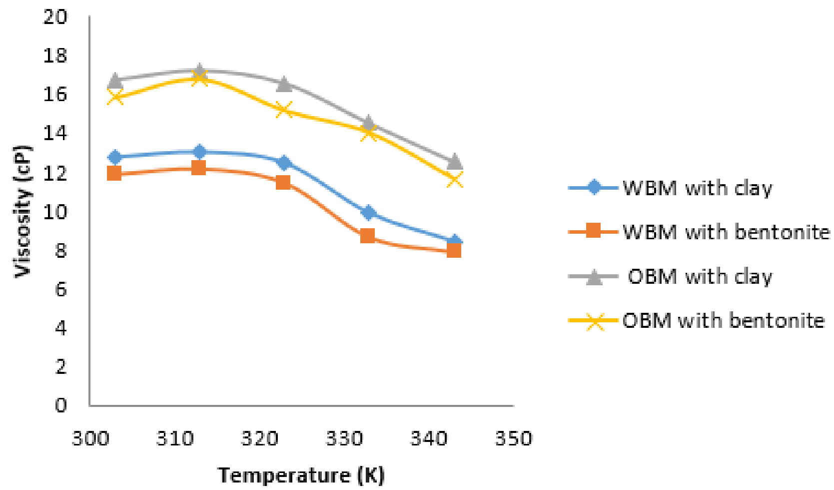


**Figure 6: Effect of temperature on the viscosity of the mud**

## Conclusion

The evaluations of the experimental data led to the following deductions.

Si-O bond stretching was found in untreated Agbani clay, treated Agbani clay, and bentonite. Changes in the functional groups were revealed in the untreated and treated Agbani clay samples. The beneficiation of the clay enhanced its functional groups. Also, heteroatoms were present in the samples, which indicates that the clay/bentonite will be suitable for the viscosity control function. The American Petroleum Institute Standard is met by the recorded mud weight, pH, viscosity, and related parameters. The mud weight values of oil-based mud (OBM) and water-based mud (WBM) are between 8.65 and 9.60 pounds per gallon. This suggests that the muds are capable of lifting drilling cuttings out of the drilling borehole. In terms of viscosity, mud-containing clay additive is more viscous than OBM in terms of both apparent viscosity (AV) and plastic viscosity (PV). It indicates that mud with a clay additive has a higher viscosity than mud using a bentonite additive. The yield point (YP) and PV ratio—two parameters related to viscosity—have values that indicate the formulated muds are appropriate for drilling operations. The viscosity rose in both WBM and OBM as the dosage of clay/bentonite and the mixing period were increased, reaching an optimum (highest) value at 9wt% dose. Conversely, as the temperature rose, the viscosity decreased. Bentonite and the treated clay have a favorable competition.

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