Analysis of Effects of Foreign Clay and Local Clay Additives on Viscosity of Water Based Drilling Mud

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

This research compared the viscosity and other allied rheological properties of formulated water based drilling mud using local clay (that is modified with cheap and available additives) and foreign clay. These additives (such as xanthum gum, high viscosity polyanionic cellulose (PAC-R), modified natural polyanionic cellulose (PAC-L), potassium hydroxide (KOH), sodium carbonate (Na_2CO_3), and barite) are added to enhance/control the rheological properties (such as density, viscosity, yield point and gel strength) of the drilling mud. In this work, the viscosity and other allied rheological properties of water based mud were improved by the use of locally sourced clay from Awgu in Enugu State. The local clay was beneficiated/treated with hydrochloric acid (HCl) and characterized using x-ray fluorescence (XRF) spectrometer. The results of the characterization revealed that the local clay is more of silica which is typical of a kaolinitic clay. Local clay was examined as a possible replacement for foreign bentonite by comparing the rheological properties of water based mud (WBM) with bentonite and WBM with clay. Plastic viscosities (PV) of WBM with bentonite and WBM with clay were found to be 11.7 and 12.3 cP respectively. Other allied properties such as yield point, gel strength, pH and mud weight of WBM with bentonite and WBM with clay adequately compared closely. Laboratory analyses on the effects of three process variables (such as temperature, aging time and dosage of clay/ bentonite) on the viscosity of the formulated muds were investigated. The laboratory results show

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that the readily available additives added to the local clay improved its viscosity and other allied rheological properties for effective drilling of oil and gas well when compared with foreign bentonite.

1. INTRODUCTION

Nigeria is recognized as the largest producer of oil and gas in sub-Saharan Africa, as she (Nigeria) has abundant reserves of petroleum hydrocarbons. However, these petroleum hydrocarbons could only be exploited and brought to the earth's surface for conversion into useful end products by means of drilling. The numerous drilling and petroleum industries operating within the shores of Nigeria have been consuming and are still consuming huge quantities of clay for their drilling operations, all of which are imported, yet there are large reserves of clay scattered everywhere in Nigeria. Presently, the consumption of foreign clay (bentonite) for drilling operations in Nigeria is well over fifty thousand (50,000) tons a year and all of it is imported from USA [1]. Consequently, the foreign exchange involved and the high cost of drilling fluid materials constitute an economic burden for the petroleum and other drilling industries in Nigeria. Hence, it has become very necessary to source, harness, study and analyze the potential of local clay in Awgu Local Government Area of Enugu, Nigeria for drilling operations. Research has shown that clay deposit is everywhere across the entire six geo-political zones in Nigeria, although their properties differ from one site to another on account of geological differences [2].

Drilling muds are essential to drilling success. They are usually formulated to meet certain properties in order to carry out the basic intended functions. Some of the functions of drilling muds include, hole cleaning, suspension of cuttings, prevention of caving, ensuring tightness of the well wall, maximizing recovery, cooling the drill bit, maintaining wellbore stability, minimizing the amount of time it takes to achieve first oil, aiding in collection and interpretation of data available through drill cuttings, cores and electrical logs [3] and [4]. The most common drilling mud is a liquid-based mud typically composed of a base fluid (such as water, diesel oil, mineral oil or a synthetic compound) [5]. Muds are classified into three major types as, water based mud (WBM), oil based mud (OBM), and synthetic based mud (SBM). Although, WBM and OBM are the most common drilling fluids currently used, WBM has the advantages of higher shear thinning, high true yield strength, good bit hydraulics and reduced circulation pressure losses, environmental friendliness, over other types. It also improves borehole stability [6]. WBM usually consists of clay (foreign or local) and other additives to enhance the rheological properties of the mud. Local clay is beneficiated in order to improve its economic value. Hence, clay beneficiation is any process that the raw clay needs to pass through before it can be used for drilling mud formulations or for other purposes. A very important reason for beneficiation according to [7] is to obtain partly dissolved material of increased specific area, porosity and surface acidity. Acids are usually used for the beneficiation process. Some of the acids used include, hydrochloric acid (HCl), tetraoxosulphate (vi) acid (H_2SO_4) and trioxonitrate (v) acid, (HNO_3).

This study is limited to the comparison of foreign clay (bentonite) and local clay (Awgu clay) additives on the rheological properties of formulated water based mud. The rheological properties considered include; apparent viscosity, plastic viscosity and yield point. According to previous studies by [8-10], the drilling fluid viscosity can be expressed as either relative or absolute measurements. The relative measurements are the funnel viscosity and the apparent viscosity. The absolute measurements are the quantitative values of the non-Newtonian characteristics namely: Plastic viscosity (PV), Yield point (YP) and Gel strength. Other associated properties (such as mud weight and pH) of the formulated muds were also considered. Plastic viscosity – the internal resistance offered by a fluid to flow, is the rheological property of interest as it is the most important rheological flow property on account of its ability to hold formation chip at the bottom [8]. The values of these parameters were compared in terms of muds produced with bentonite and those produced with Awgu clay. Considering one factor at a time, effects of dosage of bentonite/clay, temperature and aging time on the viscosity of each of the formulated muds were determined. Several studies have been

carried out on the comparative effects of foreign bentonite and local clay additives with special attention on viscosity [1], [11], [12] and [13]. From the review of previous works, there is need to improve the rheological properties of WBM using Awgu clay as no report was found on the use of Awgu clay for drilling mud purposes.

2. MATERIALS AND METHODS

2.1 Equipment and Raw Materials

The equipment used in this work include; graduated measuring cylinder, beakers, electronic weighing balance, mixer, viscometer, drilling mud balance, water bath, pH meter, and stop watch. The raw materials used in the formulation of the water based drilling fluids using bentonite and Awgu clay are presented in Table 1.

2.2 Experimental Procedure

2.2.1 Beneficiation of the clay

The local clay obtained from Awgu in Enugu State was beneficiation through the following treatment steps as shown in Fig. 1, until a mass of 500g of the beneficiated clay was got [9]:

Table 1. The raw materials used for the formulation of the drilling mud samples

| Raw materials	Functions	Quantity
Water	Base fluid	240ml
Bentonite/Clay	Viscosity and filtration control	9.0g
Xanthum Gum biopolymer (XCD)	Viscosity and fluid-loss control in low solid muds	0.6g
High viscosity Polyanionic Cellulose (PAC-R)	Fluid loss control and viscosifier	0.5g
Modified natural polyanionic cellulose (PAC-L)	Fluid loss control and viscosifier	0.3g
Potassium hydroxide (KOH)	Potassium source for inhibitive purpose	0.2g
Sodium carbonate (Na_2CO_3)	Calcium precipitant	6.0g
Barite	Weighing agent	13.0g
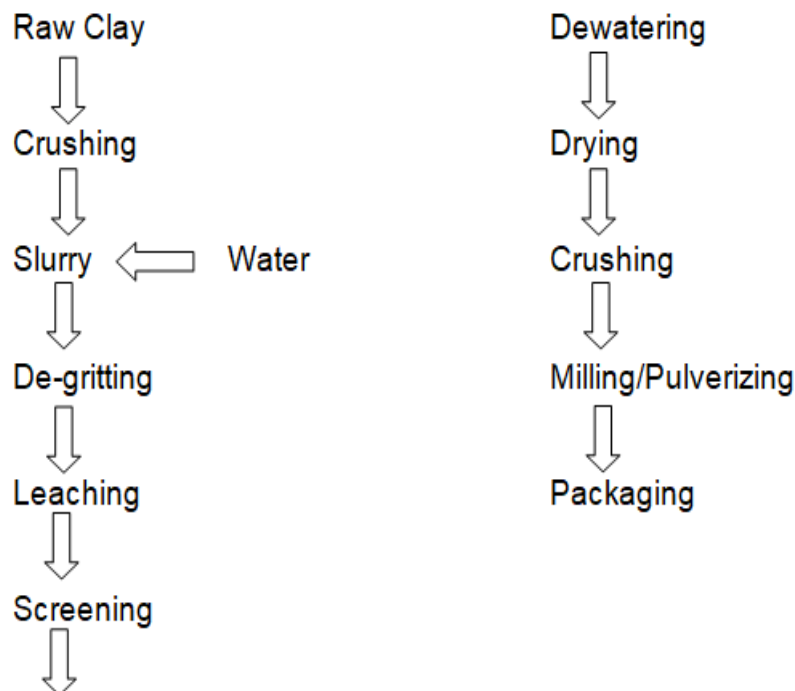
Fig. 1. Flow chart of clay beneficiation

2.2.2 Formulation of the muds

The various quantities of the raw materials were measured using a graduated cylinder and electronic weighing balance. The raw materials were then poured, one after the other, with an interval of 5 minutes into the steel cup of the single spindle mixer in a descending order as arranged in Table 1 above. As each material is being put into the mixer, the mixer is powered to cause the spindle to rotate and mix the contents inside the steel cup being held at a fixed position. As the materials have been completely applied into the mixer steel cup, it was allowed to age for 30 minutes, under stirring condition, for a total uniformity of the materials to give finely formulated water-based drilling mud whose colour appears brownish. The production methods and determination of the rheological and allied properties of the drilling muds were carried out based on the American Petroleum Institute (API) drilling mud production standards [14]. The mixing method used by [15] was adopted. Drilling mud balance was used to measure the density of the mud. Viscometer was used for the measurement of rheological properties of the formulated drilling mud. The rheological readings, API Testing, 600 RPM (revolution per minutes), 300 RPM, 6 RPM and 3 RPM, were recorded. Also,10 seconds, 10 minutes and 30 minutes gel strength values were recorded. The plastic viscosity and yield point values were appropriately evaluated. The pH meter was used to measure the pH of the formulated drilling mud. This procedure is carried out in triplicate, and average value for each parameter was obtained. Bentonite mud was formulated first, then followed by Awgu clay mud.

3. RESULTS AND DISCUSSION

3.1 Experimental Result

The characterization results of the treated and untreated clay samples for some selected dominant cations (Al^{3+}, K^+, Si^{4+} and Fe^{3+}) using X-Ray fluorescence, Philips PW 2400 XRF spectrometer are shown in Table 2. It shows that the untreated and treated Awgu clay samples contain exchangeable cations (aluminum (Al^{3+}) and potassium ion (K^+)) and essential metal (iron (iii) ion (Fe^{3+})) [16] and [17]. The exchangeable ions in the treated clay were largely reduced compared to the untreated clay. The high percentages of SiO_2 (64.26% and 68.54%) for the untreated and treated clay samples respectively, indicate that the clay samples are more of silica

(quartz) which is typical of kaolinitic clay. The Si^{4+} cation is not removed, but increased from 64.26% to 68.54% with acid treatment. This increase is as a result of depletion of the cation from the interlayer and octahedral sheet of the clay, which is in agreement with the findings of [12]. The metal, Fe^{3+} present in the untreated clay sample also increased from 12.54 % to 13.36% in the treated clay sample. This increase is due to the increase in surface area of the clay which brought out the metal and made it easier for leaching [13].

The results of the properties of the formulated WBM with bentonite and WBM with clay at the optimum operating conditions of 9wt% bentonite/clay dosage, 30 minutes aging time and 313K temperature, including their dial readings are presented in Tables 3 to 6.

The mud weight and pH result of the formulated WBM with bentonite and WBM with clay are presented in Table 3. The table shows that the values of mud weight of WBM with Bentonite and WBM with Clay are close and the muds are in alkaline state [10] from the pH values. These results between WBM with Bentonite and WBM with Clay are close, indicating that the local clay can serve as a substitute for imported clay in terms of mud weight and pH [10].

The gel strength result of WBM with Bentonite and WBM with Clay are presented in Table 4. The results as shown in the table are close and within the required range [10]. It was further noted by [10] that very high gel strength values will require high pump pressure to keep the mud in circulation once again, and this high pump pressure may create a lot of problems, example lost circulation. The observed close values of the mud gel strengths imply that the local clay can compete appreciably with foreign clay.

The Dial reading results of the formulated water-based muds with bentonite and clay are presented in Table 5. These results were instrumental in calculating the values of Plastic viscosity, yield point and apparent viscosity of the formulated water-based muds [14].

The Plastic viscosity, yield point and apparent viscosity of the formulated water-based muds were calculated using Equations (1), (2) and (3) respectively [14]:

$$\text{Plastic Viscosity (PV), cP} = 600\text{RPM reading} - 300\text{RPM reading} \quad (1)$$

$$\text{Yield Point (YP)}, \text{lb}/100\text{ft}^2 = 300\text{RPM reading} - \text{PV} \quad (2)$$

$$\text{Apparent Viscosity (AV)}, \text{cP} = 600\text{RPM reading}/2 \quad (3)$$

The Plastic viscosity, yield point and apparent viscosity results of the formulated water-based muds are presented in Table 6. The additives used improved the rheological properties of the local clay mud significantly [10].

3.1.1 Effect of dosage on viscosity

The effects of dosage of bentonite/clay on the viscosity of the formulated WBM with bentonite and with clay at constant optimum conditions of aging time of 30 minutes and temperature of 313K are presented in Fig. 2. The figure shows a parabolic curve with optimum viscosities of the mud at the mid-point of the considered process factor (9wt% dosage of bentonite/clay). Also, this implies that higher dosages were unfavorable for enhancing the viscosity beyond the optimal dosage (mid-point) [15].

3.1.2 Effect of temperature on viscosity

The effects of temperature on the viscosity of the formulated WBM with bentonite and with clay at constant optimum conditions of aging time of 30 minutes and bentonite/clay dosage of 9wt% are presented in Fig. 3. The viscosity of the muds decreased steadily, and then gradually with increase in temperature. This effect can be explained according to the investigation carried out by [16]. They quoted an author to have stated, "The viscosity of most muds is decreased on heating, but the interesting thing is that the degree of flocculation is also increased on heating." In addition, the reduction in viscosity of drilling muds with increasing temperatures is an indication of thermal degradation [18].

Table 2. XRF results of untreated and treated clay samples

Properties (Oxides)	Untreated Clay (%)	Treated Clay (%)
Al_2O_3 (Al^{3+})	21.4249	14.4592
K_2O (K^+)	0.1932	0.0503
SiO_2 (Si^{4+})	64.2628	68.5437
Fe_2O_3 (Fe^{3+})	12.5420	13.3643

Table 3. Mud weight and pH of the formulated water based muds

Properties	WBM with Bentonite	WBM with Clay
Mud weight (lb/gal)	9.36	9.43
pH	10.10	10.30

Table 4. Gel strength result of the formulated water based muds

Properties	WBM with Bentonite	WBM with Clay
Gel Strength (10sec), lb/100ft^2	4.0	4.3
Gel strength (10min), lb/100ft^2	6.8	7.7
Gel strength (30min), lb/100ft^2	7.7	9.1

Table 5. Dial readings result of the formulated water based muds

Properties	WBM with Bentonite	WBM with Clay
600rpm	34.8	37.2
300rpm	23.1	24.9
6rpm	9.9	9.1
3rpm	6.2	5.7

RPM (Revolution per minute)

Table 6. Plastic and apparent viscosities and yield point result of the formulated water based muds

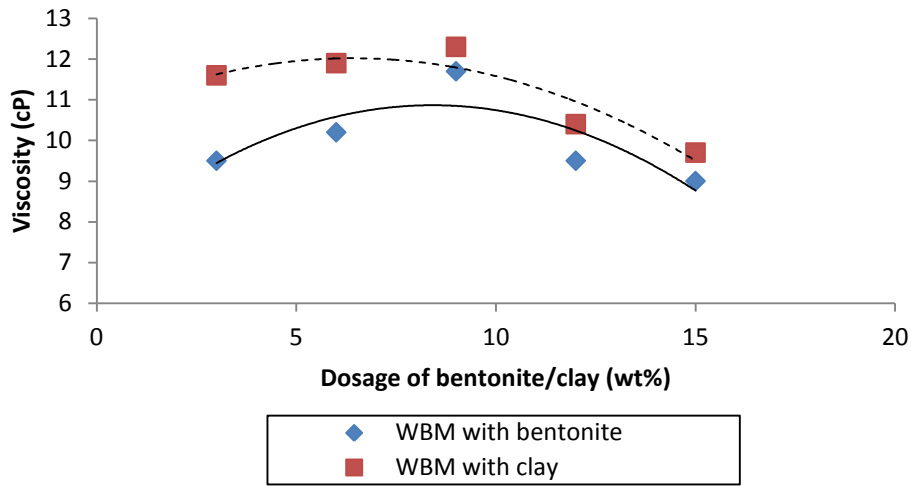| Properties	WBM with Bentonite	WBM with Clay
Plastic viscosity	11.7	12.3
Apparent viscosity	17.4	18.6
Yield point	11.4	12.6

Fig. 2. Effect of dosage on viscosity of WBM with Bentonite and WBM with Clay
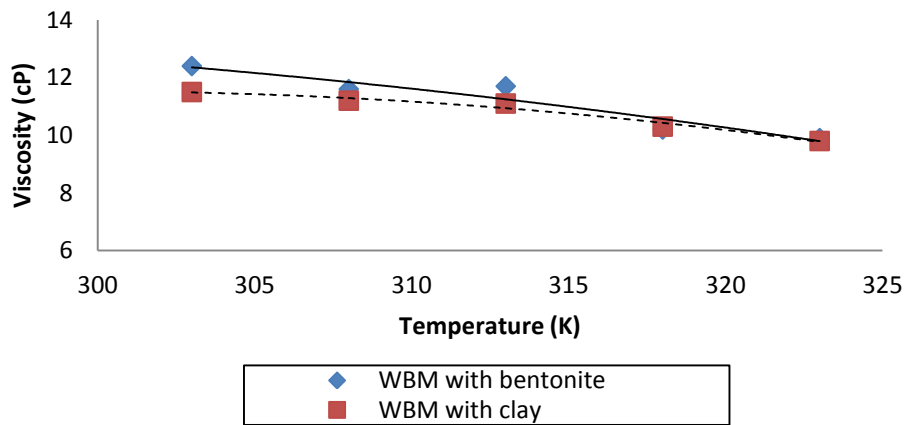

Fig. 3. Effect of temperature on viscosity of WBM with Bentonite and WBM with Clay
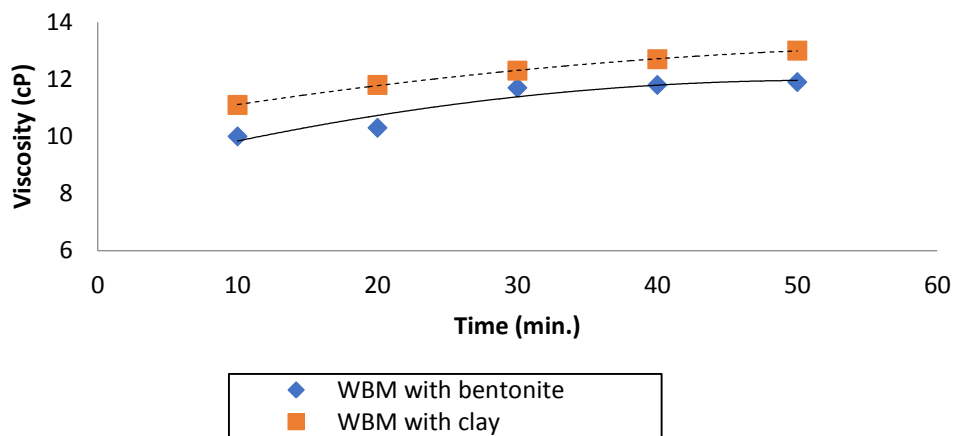

Fig. 4. Effect of time on viscosity of WBM with Bentonite and WBM with Clay

3.1.3 Effect of time on viscosity

The effects of time on the viscosity of the formulated WBM with bentonite and with clay at constant optimum conditions of temperature of 313K and bentonite/clay dosage of 9wt% are presented in Fig. 4. The viscosity of the muds increased gradually but steadily with increasing aging time of mixture. This might be explained from the fact that the degree of dispersion and flocculation increased when the mud was aged statically [19].

4. CONCLUSION

From the analyses of the experimental results the following conclusions were made:

i. Clay additives used improved the rheological properties of the local clay mud significantly and hence compete favorably with the commercial bentonite mud.
ii. The viscosity values of WBM with bentonite and WBM with clay are 11.7cP and 12.3cP respectively.
iii. The viscosities of WBM with bentonite and WBM with clay showed a parabolic curve with optimum viscosity at the mid-point of the considered process factor (9wt% dosage of bentonite/clay) as the dosage of bentonite/clay increases.
iv. The viscosities of WBM with bentonite and clay respectively decreased with increase in temperature, but increased with increase in time.
v. Other rheological properties (such as gel strength, yield point, pH and mud weight) of WMB with bentonite and WBM with clay compare closely.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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