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Analysis Of The Potentials Of Locally Sourced Bentonite As A Replacement For Imported Bentonite In Water-Based Mud Formulation

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***Abstract*—The Nigerian Government regulated the importation and use of foreign bentonite clays in 2003 in order to tap into the large amounts of local bentonite found in nation soil. Notwithstanding this law, there are few or no documented instances of local bentonite clays being used in drilling fluid formulation, therefore the oil and gas sector has not yet fully embraced their use for this purpose. The majority of the foreign bentonites utilized are frequently smuggled into the nation by international corporations. Hence, research into the usage of local clays for drilling mud formulation in the oil and gas industry cannot overemphasized. The analysis of locally sourced bentonite as a replacement for imported bentonite in water-based mud formulation was successfully carried out. The imported sample and local sample of Bentonite were mixed in the following ratio: 100:0, 75:25, 50:50, 25:75, 0:100. The resulting mixtures of the samples were used to formulate drilling mud, and a complete mud check was carried out to determine the flow and fluid loss properties of the formulated mud. The results proved that the local bentonite impacted a poor rheological properties and fluid loss properties compared to the imported bentonite. 600rpm viscosity decreases to 55, 50, 40, and 35 cP when 25%, 50%, 75%, and 100% of local bentonite were used, respectively. However, the cost benefit analysis indicated that the use of local bentonite is more cost effective - as the percentage of local bentonite increased from 0 to 100%, the percentage cost saved also increases from 0 to 36.34% respectively.**

Keywords*—Nigeria, Bentonite, analysis, drilling fluid, potential, Replacement, cost

Introduction

The global practices of exploration and drilling for crude oil discoveries in uncharted regions and deeper formations are being driven by the continuously increasing demand for oil and gas. In order to achieve the desired depth during oil drilling while sustaining the hydrostatic pressure, cooling the drill bit as well as provide wellbore stability and suspend the formation cuttings, drilling fluids are utilized in the drilling operation (Alcheikh, 2017). In drilling operations, the characteristics and formulation of the drilling fluids are crucial (Khodja et al., 2010). Complex drilling fluids account for about 15% to 18% of the overall cost of drilling a petroleum well. Accidental scenarios involving hydrocarbon spills and blowouts occasionally occurs during drilling operations. However, by using blowout preventers to seal the well and adjusting ~~altering~~ the physical characteristics of the drilling fluid, these incidents are curtained to a large extent (Prasad, 2014).

Majority of wells are drilled using clear water for faster rate of penetration until certain depth are attained, then because of difficult hole circumstances, the need for a formulated and conditioned fluid with particular qualities. Drilling fluids constitute a fundamental requirement in all drilling operations (Dankwa, 2018). In deeper formations, enhancing chemicals including dispersants for viscosity control, viscosifying agents, and clay as filtrate reducers are introduced to the drilling fluids. Every ~~Any~~ drilling fluid must be able to carry cuttings from the hole to the surface as its primary function, but how effectively it can do so depends heavily upon its viscosity (Neff, 2005). Again, to achieve the objectives for which the mud was intended, it is crucial to regularly track and adjust the viscosity of the mud while drilling (Okumo and Isehunwa, 2007). Aside from removing cuttings from the well, the mud should be capable of forming a thin seal preventing fluid from and to the formation that causes stuck pipe and loss of circulation, an influx that may graduate into a blowout, and formation damage (Igbani, 2015). Commonly used drilling fluids contain a minimum number of additives that maintains the essential properties of the drilling fluid. Generally, for consistent optimum performance of drilling fluid, static filtration tests are utilized to determine the filter cake thickness and filtrate loss of volume for a drilling mud (Amoco, 2006). The two main types of difficulties attributed to filtration include filtrate invasion and filter cake deposition (Kanna, et al., 2017). Filtration occurs whenever a permeable formation contacts the drilling mud at a pressure greater than the reservoir pressure. Furthermore, the kinds, amounts and level of interactions of the solids as well as the well's temperature and pressure impacts significantly on the filtration characteristics (Amoco, 2006). Active clay such as bentonite, attapulgite and polymers such as starch, and polyanionic cellulose are mostly used as fluid loss additives in drilling fluid formulations.

Bentonite is one of the major components (or ingredients) used in the formulation of water base mud. It is a clay that swells significantly and also has potential to increase its volume by up to an 8-fold factor due its water absorbing capacity (Achadu and Osadolor, 2022). The amount of either sodium or calcium cations present in a bentonite sample as well as the swelling index and pH are the indices used to classify bentonite (Nweke, 2015). Natural sodium, calcium bentonite and activated calcium bentonite are the main categories. It swelling capacity enables it to optimizes the function of drilling fluid by improving the rheology properties, reducing filtrate loss to the formation, and formation of thin filter cake. Nigeria is bestowed with large amount of bentonite resources that if properly harnessed, will replace imported bentonite and specialized drilling mud. There have been reports of significant bentonite clay deposits in many region of Nigeria. Nigeria is reported to have bentonite reserve of over 700 million metric tons (Aigbedion and Iyayi, 2007a, Aigbedion and Iyayi, 2007b, James et al., 2008, Omole et al., 2013, Bilal et al., 2015) which are majorly found in Afuze, Edo State and estimated at about 70-80 million metric ton (Nweke et al., 2015, Nweke, 2015). Hence, the Federal Government of Nigeria banned by legislation the importation of foreign bentonite clays in 2003 to allow the country tap into the large amounts of bentonite deposit in the nation soil. Nonetheless this law, there are visibly no documented instances of the application of local bentonite clays for drilling fluid formulation. The oil and gas sector therefore has not fully embraced the use of the local bentonite. The majority of the foreign bentonites that are currently in use are smuggled into the country by the international corporations. Hence, research into the usage of local clays for drilling mud formulation in the oil and gas industry need to be expedited. Several researchers (Igwilo, et al., 2020, and Afolabi, et al., 2023) have reported that the local bentonite in its raw state impacts poor rheological properties and high rate of fluid loss due to the presence of calcium ions. However, after beneficiation with Sodium salt, it promises great outcome. Hence, this study therefore aimed at analysing the potentials of locally sourced bentonite as a replacement for foreign bentonite in water-based mud formulation.

2.0 Materials and Method

2.1Materials

The main materials used for this study include bentonite, barite, calcium carbonate ($CaCO_3$), biocide, soda ash,

2.2Methods

2.2.1Bentonite Sample Preparation

Foreign and local bentonite samples were mixed together in the following ratio; 100:0, 75:25, 50:50, 25:75, 0:100 and labelled as samples A - E. The resulting mixtures of the samples were used to formulate drilling mud, and a complete mud check was carried out to determine the properties of each of the formulated mud.

2.2. Sample Preparation

Drilling fluid was formulated and contaminated with equal amount of water and clay (similar to the location).

2.3. Determination of mud weight, emulsion stability, rheological properties, gel strength, fluid loss and oil- water ratio

The formulation of the drilling mud were carried out based on the API drilling testing standards. The base fluid (fresh water) and various raw materials were placed in a mud mixing cup (measured in grams using a graduated cylinder and electronic weighing balance). The raw materials were added in a mixing order at intervals of 5 minutes in the mixer cup except barite with a mixing time of 30 minutes. The introduction of the various raw materials were carried out in descending order as presented in Table 1. The procedure for the determination of mud weight, emulsion stability, rheological properties, gel strength, fluid loss and oil- water ratio followed those methods specified in the study conducted by Achadu et al., (2023).

S/N	Chemicals Used	Unit	Amount Used	Function
1	15 PPB Bentonite	BBL	0.889	Viscosifier
2	Soda Ash	PPB	0.25	Shale Inhibition
3	Caustic Soda	PPB	0.25	pH Adjuster
4	Calcium Carbonate (Coarse, Medium, Fine)	PPB	10	Bridging Agent
5	Biocide	PPB	0.5	Bacteria Inhibition
6	Barite	PPB	150	Weighting Agent

Table 1: Components of Water-Based Drilling Mud Formulation System

Result and Discussion

3.1 Results

The results of the investigation are presented in tables and graphs. Tables 2, 3 and 4 represent the bentonite quality, effect of varying the percentage of imported and local bentonite on drilling fluid properties and bentonite cost benefit analysis respectively. Figures 1, 2, and 3 are the plots of API fluid loss against percentage of local bentonite, rheology properties against percentage of local bentonite and Percentage of cost saved against percentage of local bentonite.

3.1 Bentonite Quality

The result of the analysis of the bentonite quality is presented in Table 2.

Table 2: Bentonite Quality

Unit of Measurement	Test Result		API Specification
	Foreign	Local	
600 rpm (N/m^2)	36	25	Minimum 30
YP/PV	2	6	Maximum 3
Filtrate Volume	15.6	20	Maximum 15

The result in Table 2 showed that rheological property (600 rpm) of 36 N/m^2 and 25 N/m^2 were recorded for imported and locally sourced bentonite samples respectively. The 600 rpm value for the locally sourced bentonite was less than the threshold value of 30 N/m^2 and this implied a negative influence in the performance capacity of any drilling fluid formulated with such low quality bentonite. Also, the value of the ratio of plastic viscosity to yield point of the locally sourced bentonite was higher than the API recommended maximum value of 3. The value of the imported bentonite was 2 while that of the local bentonite was 6. Furthermore, the result of the Filtrate Volume for the two bentonite samples were 15.6 and 20 for imported and local bentonite respectively. Though, the values for this parameter was higher than the API compliance value in both cases, the value for the local bentonite was significantly at variance with the API value.

3.2Characteristics of formulated drilling fluid using local and imported bentonite.

The characteristics of formulated drilling fluid using local and imported bentonite are presented in Table 3.

Table 3: Effect of Foreign and Local Bentonite on Drilling Fluid Properties

Mud Property	Bentonite Ratio (Imported: Local)				
	A	B	C	D	E
SG	4.10	4.10	4.10	4.10	4.10
Density (Ppg)	9.6	9.6	9.6	9.6	9.6
pH	9.5	9.5	9.5	9.5	9.5
API Fluid Loss (ml)	10	12	15.5	18	20
Water (%Volume)	58	58	58	58	58
Solids (%Volume)	42	42	42	42	42
600	57	55	50	40	35
300	39	35	31	28	25
200	31	28	21	18	15
100	22	20	17	12	10
6	7	6	5	4	3
3	6	5	4	2	1
PV	18	20	19	12	10
YP(Lbs/100ft^2)	21	15	12	16	15
10secs Gel	9	5	3	1	0.5
10min Gel	19	18	17	12	11

A=100:0, B = 75:25, C = 50:50, D = 25:75, E = 0:100. A, B, C, D and E is imported and local bentonite ratio.

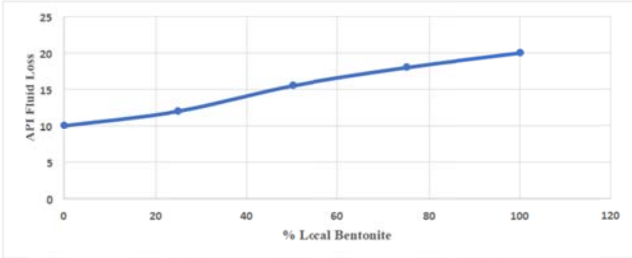

Figure 1: API Fluid Loss vs % Local Bentonite

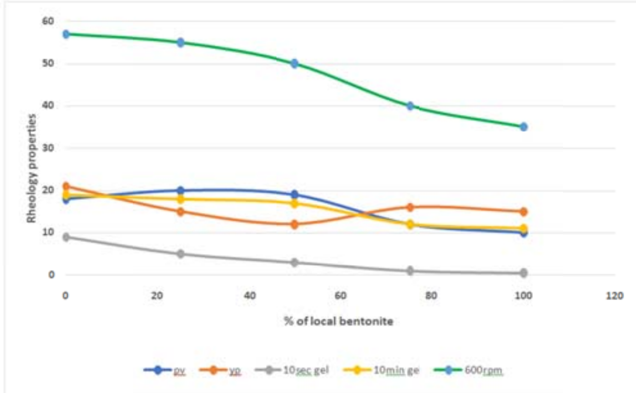

Figure 2: Rheology Properties vs % Local Bentonite

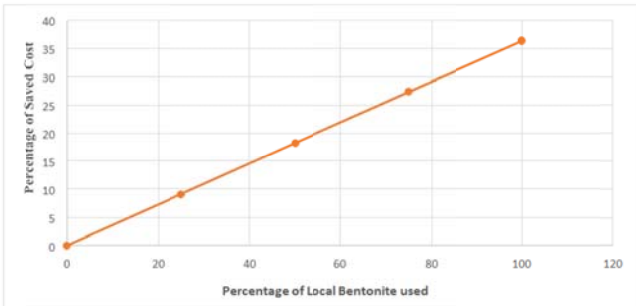

Figure 3: Percentage of Saved Cost vs Percentage of Local Bentonite

3.2 Discussion

The results in Tables 2 showed obviously that the local bentonite did not meet the API requirements. It is therefore evident that foreign bentonites are preferable to local bentonite from the values of the fluid loss recorded. The result is also consistent with that of Igwilo, et al., (2020) who investigated the economic viability of using periwinkle shell and mucuna solannie for beneficiating Nigerian bentonite. Again, due to its chemical makeup, local bentonite recorded poor fluid loss quality. In contrast to imported bentonite with acclaimed sodium basis, local bentonite has a calcium base. The most common forms of bentonites, which are three-layer swelling clays with calcium and sodium as their main constituents, are used to viscosify and regulate fluid loss in drilling fluids (Yu et al., 2022; Kanna et al., 2017; Mahmoud, 2022). Sodium based bentonite possess higher hydrational capacity than calcium based bentonite, Hence, sodium bentonite which is presently abundant in the northwest region of USA is the desirable and sought for type of bentonite. It is regarded as "premium bentonite" (ADCO, 2005; Amoco, 2006).

Furthermore, as the percentage of local bentonite increases, the fluid loss increases, and the filter cake also increases in thickness. Pure local bentonite (100%) has the highest fluid loss volume of 20ml. This is undesirable because according to Samavati, et al., (2014), a good drilling fluid should have a low fluid loss volume and a thin filter cake. Additionally, Figure 1 showed that the fluid loss increased gradually when the percentage of the local bentonite was 25%. The increase in fluid loss becomes excess as the percentage of the local bentonite increases to 100%. This was noticed on the steepness of the curve near 100% local bentonite. Hence, the imported bentonite has a better fluid loss property than the local bentonite. Rheological properties measured with a rotational viscometer are commonly employed to indicate solids build-ups flocculation, lifting and suspension capabilities, and estimation of drilling fluid hydraulics (Amoco, 2006).

Figure 2 showed that the viscosity of the fluid decreases as the percentage of local bentonite increases and that of imported bentonite decreases. Plastic viscosity (PV) which represents the flow resistance produced by friction between the solid particles in drilling fluids and fluid layers (Ali et al., 2021) are measured by the viscosity of the mud system. This implied that higher PV arises from an increase in the amount of solid content in drilling fluids and is undesirable because of its drilling speed reduction capacities (Dankwa, et al., 2018; Ali, et al., 2021). Tables 2 and 3 also showed that barite and $CaCO_3$ variation had little or no effect on the PV of the drilling fluid because of the absence of changes in the number of solids present in the fluid. The values obtained corroborated the works of Akinlabi, et al., (2019) and V.udaya, (2022). On the other hand, bentonite variation significantly affects plastic viscosity. The variation leads to a change in plastic viscosity because of the effects of bentonite on viscosity of drilling fluid. The values of the plastic viscosity recorded in Table 3 are 18, 20 19, 12, and 10. The 75:25 ratio of imported bentonite to local bentonite gave the highest plastic viscosity. This Irregularity could be linked to temperature because plastic viscosity is a function of the base fluid, solid content, and temperature.

Yield Point (YP) is used to measure the degree of non-Newtonian behavior of drilling fluids. YP is the measure of the drilling fluid to keep drill cuttings suspended in the wellbore while cycling in and out of the annulus (Amoco, 2006; Ali, et al., 2021; V.udaya, 2022). As a result, drilling issues such as differential sticking can be avoided (Ali, et al., 2021). Comparative analysis of the yield point obtained in Table 3 depicts pure imported bentonite showing the highest yield point (21) while the local bentonite has a yield point of 15. The lowest YP was recorded when equal percentage of foreign and local bentonites were used and this owing to the indirect relationship between YP and size of solid additives (rise in YP results in reduction in the size of the solid additive particles and attraction forces between solid particles increase) (Mahmoud, 2022). Again, as reported earlier, the Nigerian and foreign bentonites are calcium and sodium based respectively. The Calcium atom has a higher volume than the Sodium atom. Hence, as the amount of local bentonite increases, the volume of solids in the fluid also increases leading to low YP. More so, the attractive forces between sodium ions and water molecules are higher than that of calcium and water molecules (Amoco, 2006; Mahmoud, 2022). Therefore, the imported bentonite gives a better YP than the local bentonite.

Gel Strength is a measure of the capacity of drilling mud to suspend drill cuttings while at rest. It is reported that when the mud is static, the rheological properties should prevent solids (weighting material and drilled formation solids) from settling. This property is the drilling mud’s gel strength (V.udaya, 2022; Nguyen, 1996). V.udaya, (2022) reported that a 10 minutes gel strength of 30-35 Ibs/100 ft^2 should be considered as a maximum for all muds under all conditions.

The 10 seconds/10 minutes gel strength values recorded in Table 3 decreases progressively (9/19, 5/18, 3/17, 1/12, and 0.5/11) as the percentage of local bentonite increased from 0% to 100%. The highest gel strength was noted in mud formulated with 100% imported bentonite and the lowest gel strength was observed in the mud formulated with 100% Nigerian bentonite. This could be associated with the active forces between the different components making up the mud system (clay particles, polymer radicals, or emulsion droplets) that forms a semi rigid structure called gel. Also, the 10 seconds gel strength was obtained by the concentration of the particles while the other

(10 minutes gel) is dependent on the rigidity of the resulting interparticle structure (V.udaya, 2022). In clay dominated mud system, the interparticle structures are strong and are reflected in progressive gel development in such muds. However, the bonds between polymers are weak and often results in “flat” gels in polymer muds. (Werner, 2017).

Figure 1 showed the impact of the Nigerian bentonite on the rheological characteristics of the mud. API pegs the threshold viscosity for clay meant for drilling operations at 30 cP for at 600 rpm. The result showed that 600rpm viscosity decreases to 55, 50, 40, and 35 cP with 25%, 50%, 75%, and 100% of local bentonite respectively.

The minimum viscosity value recorded was 35 cp and was obtained when 100% of local bentonite was used. In addition, Figure 3 pictured that decreasing the percentage of imported bentonite reduces the rheological parameters of the mud. The 10-s and 10-

min gel strengths decreased from 9 to 0.5 1b/100 ft^2 and 19 to 11 1b/100 ft^2 respectively when 0% to 100% of the local bentonite were employed. Also, the plastic viscosity and yield point decreased with an increment in the percentage of local bentonite. This decrease in the rheological properties could be attributed to the increase in the amount of local bentonite used. Local bentonite is a calcium-based bentonite clay with poor swelling capacity. Hence, the local bentonite is not fit for drilling fluid application in it raw state.

Emofurieta (2001) reported that a certain mine in Edo State estimated 4 billion tons of bentonite reserves in Nigeria. The study as noted that the present usage of bentonite in the country today stands at 50,000 tons per annum and virtually all are sourced from oversea especially north America. This figure is however at variance with the values reported by the Raw Materials Research and Development Council (RMRDC) in 2010 but are reportedly still imported into the country. The average cost of imported bentonite in Nigeria is $550 per metric tonne while of that of local bentonite is $300 per metric tonne. Hence, Nigeria spends more than $27 million on bentonite importation.

Bentonite Cost Benefit Analysis

Table 4 detailed the cost benefit analysis of applying local bentonite in place of imported bentonite. The table showed that as the percentage of local bentonite increases from 0% to 100%, the cost of bentonite used decreases from $3.742 to $2.382.

Table 4: Bentonite Cost Benefit Analysis

Ratio (Imported: Local)	Bentonite Ratio (Imported: Local) and Cost				
	A	B	C	D	E
Mass Concentration of Mixture Used	15	15	15	15	15
Cost of Mixture Used (USD)	3.742	3.402	3.062	2.722	2.382
Cost Saved (USD)	0	0.34	0.682	1.022	1.360
% Cost Saved	0	9.09	18.23	27.31	36.34

A=100:0, B = 75:25, C = 50:50, D = 25:75, E = 0:100. A, B, C, D and E is imported and local bentonite ratio.

It is evidenced therefore from the data in Table 4 that it is cheaper to formulate drilling fluid with local bentonite. About $1.360 could be saved when the drilling fluids were formulated with pure local bentonite. However, local bentonite offers very poor rheological properties compared to the imported bentonite. In light of optimum performance and cost effectiveness, formulating drilling fluid with local bentonite will fall short of the required optimum drilling fluid performance. Although, the cost of sourcing local bentonite might be cheaper, using it to formulate drilling fluid is not desirable because of its poor rheological and filtration properties which will lead to other mud problems, such as poor hole cleaning, low rate of penetration, loss circulation, excessive fluid loss to the formation, formation fluid invasion, etc. This may generally increase the overall cost of drilling activities. Also, Figure 2 showed that as the percentage of local bentonite increased from 0 to 100%, the percentage cost saved also increases from 0 to 36.34 respectively. Therefore, beneficiating local bentonite would be necessary for its drilling fluid formulation. Igwilo, et al., (2020) and Yu, et al., (2022) opined that it is more economical to use beneficiated local bentonite for drilling fluid formulation than to use imported bentonite.

CONCLUSION

Analysis of the locally sourced bentonite as a possible replacement for the imported bentonite in water based mud formulation was successfully carried out. It is therefore imperative from the from the findings that imported bentonite has better filtration and rheology properties than raw local bentonite though it is more economical to formulate drilling fluid using locally sourced bentonite. The foreign bentonite possess better quality and performance capacity. However, beneficiation of local bentonite can improve its filtration and rheology properties, hence, the need to beneficiate the local bentonite prior to application for drilling fluid application. Local bentonite may serve for drilling water boreholes and shallow wells.

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