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ORIGINAL RESEARCH ARTICLE

POTENTIAL OF JESSE CLAY AS DRILLING MUD

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ABSTRACT

The high bottom hole pressure normally encountered during drilling, poses serious challenges during drilling operations of oil and gas wells. The unavoidable quest for crude oil source of energy by man, required for running its home and industries, makes the high risk pose by the underground hole pressure a risk-worth taking for new discovery of oil and gas reserve. The fear of encountered formation pressure is conquered by the use of drilling fluid (drilling mud). The drilling mud is a mixture of clay, water and chemicals. The drilling clay possesses certain properties that distinguished, and earmarked it as a drilling fluid, highest economy clay that is highly sorted/hunted for, either as purely for export for economic purpose by countries where it is found but have no oil or for oil and gas exploration activities in countries where hydrocarbon exploration takes pace. Nigeria as a country is a practical scenario of the above case the drill-mud–clay is being imported for the exploration of its large oil and gas reserve. Therefore, this paper seeks address the lingering unresolved challenges of the inability to establish Nigeria's local drilling mud-clay with properties comparable with the existing imported drilling mud-clay through laboratory analysis of Nigeria clay. In searching for suitable Nigerian clay for to be used as drilling mud, two properties (mud density and sand content) of local clay extracted from Jesse, in Ethiope-West local government area of Delta State was analyzed and the results were recorded and compared with those of imported foreign clay. For their densities, the result was recorded as 8.41kg/m^3, 8.50kg/m^3, 8.50kg/m^3 and 8.67 kg/m^3 for local clay, and 8.60 kg/m^3, 8.66 kg/m^3, 8.67 kg/m^3 and 8.83 kg/m^3 for foreign /imported Bentonite. The percentage of sand content in both the local and imported foreign drilling mud after analysis, were recorded as 0.1%, 0.1%, 0.2%, 0.2% and1%, 1.5 %, 1.5 % and 2% respectively. The little differences noticed between the sand value of in the drilling mud prepared with local clay and imported clay, indicates that the local drilling mud can be at its best as drilling mud like the conventional drilling mud, which is in accordance with the API recommended value range of between 0.25% -1.2% if the experimented properties are further enhanced.

1.0 Introduction

The drilling mud remains the most valuable and inevitable fluid to abandon during drilling operations of oil and gas in the life of a well. This is as a result of its support for the safety of life and ease in drilling that anchor on the general success of the drilling operation. These two components; safety and ease in drilling is made possible due to the properties of the drilling mud that is on adequately routine checking and maintaining to carry out its functions like subduing formation pore pressure and removal of sand in drilling mud (Alsabaa *et al*., 2020).

The drilling mud is composed of clay, water, and additives (Rajesh *et al*., 2017). The clay is the major component of drilling mud and is normally identified by its high cation exchange capacity in water (Apugo *et al*., 2011; Zhang *et al*., 2020; Mobeen *et al*., 2020; Moses *et al*., 2021). This was also reported in the work of Moses *et al*., 2021, Richard *et al*., 2017, Jun *et al*., 2020 and Arabi *el al*., 2017. The likes of this clay possess a swelling behavior when in contact with water and the colloid formed is plasticity in nature. This mixture of clay and water is referred to as drilling mud (Rajest *et al*., 2017). The drilling mud is the heartbeat of the drilling operations. The clay with these characteristic are called Bentonite clays respective of the region that is found (Apugo *et al*., 2011).

These special characteristics of the clay make it difficult to be found in every region, even when there is an abundance of clay in every square of the earth's surface. Thus, the clay is continually being imported either as raw or as the mixture called drilling mud (Kaffayalullah *et al*., 2021). The clay is imported from overseas and cost is in millions of dollars as reported in Moses *et al*. (2021), Omole *et al*. (2013), Ameloko *et al*. (2020) and Arinkoola (2020), and this increases the financial burden of the company and thus, reduces the foreign earning of the host country and ushers in economic crush and high unemployment rate, thus, leading to national crisis.

Realizing this huge loss, Nigeria as a country, initiated a local content development to curb importation to boost external reserve, generate employment, and kick-start rural area industrialization, and urban-rural area drift and development (Omole *et al*., 2013). To ensure the drilling mud continue to perform its primary functions, a consistent routine check of sand volume, and mud density is conducted to avert abrasion of drilling hose and/or bottom hole equipment, and balancing of formation pore pressure, for safe and economical of drilling operations (Rajest *et al*., 2017). Thus, it is important to measure the properties that make up the drilling mud which controls the ability to perform these functions.

This research work aimed at substituting the imported conventional clay/drilling mud with the local Nigeria clay. This, if achieved would not only stop the importation of the drilling clay (Bentonite clay), but would also boost foreign exchange earnings and as well start rural area industrial development. To this end, two properties; sand content and mud density of drilling mud is investigated to a certain their suitability as drilling mud when compare with the conventional drilling mud.

1.1 Sand Content

Clay-solids and those mixed-up while drilling (as it has been), at some volume, can be permitted and may be beneficial and at some other, if not removed will undergo continuous grinding into smaller size particles and are more difficult to remove from the drilling mud. The small particles have a greater effect on drilling mud properties than larger particles and would be intricate to remove and lead to problems like; dilution cost for mud chemicals and barite, disposal cost for mud hauled away, reducing drilling rate, reduced bit life, excessive abrasion of the pump, mud line, swivel, guns, thick filter cake and pipe stuck (Faruk, 2000 and Apugo-Nwuso *et al*., 2011). The drill solids are insoluble in drilling mud systems and the quantities and types present in drilling mud systems played a major role in its properties (ASME, 2005). Therefore, the development of a solid control program in drilling mud is important to aid improve the performance of the mud's basic functions.

Sand is defined as a particle whose size is larger than 74m (microns). The sand content in the drilling mud is measured wih the aid of a mesh sieve of 200 capacity and a glass tube called sand content set (Bourgoyne, 1991).

A concentration of solids (from Bentonite or those incorporated while drilling or the low gravity inevitable solids) in mud is the main cause of mud problems (Standard Procedure Manual, 2003 and Wolfgang, 2016).

Therefore, its then important to check the volume of sand in drilling mud by routine measurement, with the aid of sand content set and a mesh sieve of 200 capacity (Institute of Petroleum Engineering, 2005).

The drill solids are insoluble in drilling mud systems and the quantities and types present in drilling mud systems played a major role in its properties (ASME, 2005). Therefore, the development of a solid control program in drilling mud is also an important factor to aid improve the performance of the drilling mud's basic functions.

1.2 Mud Density

One primary function of drilling mud is to control the subsurface pore pressure and formation fluid into the well, which is the force exerted by a mud column, and it depends on the mud density and true vertical depth (TVD) (Akpoturi *et al*., 2017; Rajesh *et al*., 2017). The buildup hydrostatic pressure of the mud is usually a little/a bit higher than the subsurface pore pressure to avoid an inflow of fluids into the well (kick), and if urgent attention is taken to stop it, results in a blow-out, and lives and equipment are a loss.

When planning for pressure control, the control of mud density is the first thing that comes to mind. The weight of a column of mud in the hole necessary to balance formation pressure is the base point from which all pressure control calculations are based. The required weight of the mud column establishes the density of the mud for any specific case.

1.3 Established Areas of Bentonite Location in Nigeria

Studies on local clay in the Niger Delta reviewed the existence of high swollen clay (Bentonite) as well as non-swollen clay of Kaolinite origin (Ameloko, *et al*., 2020; Igwilo *et al*., 2021). The reason being the Niger Delta region is opened to the continental shelf of brine seawater and so, the formation is enriched with sodium. Some of the areas where Bentonite are found are shown Table 1:

Table 1: Localities where local Bentonites are found in Nigeria

S/N	State	Locations	Estimated Reserve	Comments
1	Abia	Arochukwu, Umuahia, Bende, Isiukwuatolkwuano	A proven/inferred reserve is 5.8-7.5 mil. tons	Most deposits require further investigation
2	Adamawa/Taraba	Gujba (Mutai)	Not yet quantified	Deposits in River channel
3	Akwa-Ibom	Itu		
4	Anambra	Awka	Not yet quantified	Need investigation.
5	Borno	Gamboru, Marte, Ngala, Dikwa, Monguno	700 million	Product of clay of quaternary and tertiary
6	Cross River	Ogurude		Need further investigation
7	Delta	Abbi, Amai Edeje-Irhodo, Jesse	Not yet quantified.	
8	Ebonyi	Ohaozara		Asu River Group Shale.
9	Edo	Akoko-Edo, Afuze, Okpebhio, Esan, Owan, Etsako.		
10	Gombe	Akko, Gombe, Yamaltu-Deba		
11	Imo	Orlu, Isu, Oru, Okigwe	Inferred reserve estimates are 5.8-7.5 million tons	Mining activities are on in some of the locations.
12	Kebbi	Jega	Not yet quantified	Found in Benin formation
13	Yobe	Ngala, Marte, Mongunu, Damboa		Black cotton

Source: Okologume C. Wilfred and Akinwumi E. Aknade. (2016). International Journal of Engineering, Vol. 8. pp 6.

2.0 Materials and Methods

The local and foreign materials used in the experimental work are shown in Table 2:

Table 2: Thee Local and foreign Materials in use.

	Materials	Functions
Local	Clay Sample	For preparation of mud sample to be analyzed
	Tap Water	For watching and preparation of mud sampleto be tested.
	Rag	For cleaning
Foreign	Clay Sample	For preparation of drilling mud to be used as comparison.

Table 3: Equipment use, and their Source and Functions

Equipment	Source	Functions
Sand content set (US mesh sieve size, 200 microns)	OFITE, Houston	To determine the volume percent of sand-size particles in the drilling fluid.
Mesh Sieve (74 microns)	U.S.A Standard test sieve	For sieving to talc size
Mud Balance + box	Baroid Division, Taxas	To determine mud weight
Multi mixer and Cups	Gallenkamp, England	For mixing.
Measuring Cylinder	Pyrex, England	For measuring water
Spatula and Stirrers	Pyrex, England	For taking sample from container
Local Sieve of un-quantified mesh size	Locally fabricated, Nigeria	For sieving prior to standard mesh sieve of 74μm
Weighing Balance	Ohaus, London	For weighing of materials
Electronic Drier Box	OFITE Roller Oven, USA	Aid in effect of temperature on drilling mud.
Thermometer	England	To determine the degree cool and hotness
Sample Cans	Local, Nigeria.	For keeping of samples
Masking Paper Tape	Purchase in Bookshop, Nigeria.	For labeling of clays local and Foreign and mud samples

2.1 Location and Geology of Study Area.

The selected area for this work is Edeje, a village that is located in Ethiope West Local Government Area of Delta State, south-south Nigeria. It lies on longitude 5.870° N and latitude 5.750° E. It is 290 kilometers (180 miles) southeast of Lagos. It has a common boundary with Edo state in the west, River Ethiope in the east and south, and Mosogar in the northern part. This area is characterized by annual heavy rainfall, thick forest vegetation, and terrestrial animals. Edeje is also discretized by Benin, Agbada, and Akata formation. It is a sedimentary region with flat topography which is characterized by fine reddish, and brown topsoil underlain by shale formation.

2.1.1. Sample collection, Processing and Experimental Procedure/Method

Clay samples were collected from Edeje was dried under the sun with the aid of a locally fabricated wired mesh-garri processing filter and then later dried under moderate temperature in a drying oven. It was then pulverized with the aid of a local mortal and were sieved with 200 mesh to obtain a fine clay powder sample. This powdered sample was then collected in a sample can and was labeled accordingly using paper tape. A 24.5g, 22.0g 21.0g, and 17.5g respectively of the different clay powder samples (Wyoming and local) were weighed out using Ohaus chemical weighing balance. Afterward, a 350ml of tap water was measured with a 500ml of glass measuring cylinder, and poured into the mud mixer cup and the pH were tasted. Then a 0.5ml of sodium hydroxide was measured and poured into the mud cup containing the water. The multi-mixer mud cup was then clamped to the high speed Hamilton beach multi-mixer, and “on button” set on and allowed to stirred for two minutes, for proper mixing of water and sodium hydroxide before the pH was tested. This was followed by pouring a particular clay concentration, bit-by-bit to eliminate clogs/cake that would prevent proper mixing of the mixture before the "on-button" was switched off. The pH of the final mixture (drilling mud) was tested before it was allowed to age for 24 hours.

The sand content set was used for the analysis of the volume of sand in the drilling mud. The component parts of the content set are; 200 mesh sieve of 2½ inch in diameter funnel and a conspicuous glass tube graduated in percentage from 0 to 20% (Rajesh *et al*., 2017)

The procedure for determining sand content begins with ensuring the sand content glass tube is dried and dust-free. Then is held upward, and the funnel containing filter screen is fitted onto its mouth/opening and was filled with the freshly prepared mud sample to the mark "*Mud to Here*" (Rajesh, et al., 2017). Then water was added to the mark "*Water to Here*" and with the funnel removed, the mouth was firmly and completely covered with thumb and shaken vigorously. Afterward, the funnel was replaced and the mixture of mud and water was allowed to flow out through the screen. And then, was placed under running tap water, and prudently remove sand particles clinching around the wall of the conspicuous graduated glass tube by backwashing. This process continued till the mud was completely washed out. Then the fitted filter screen was slowly inverted onto the funnel on the mouth of the glass tube for the sand particles to settle to the bottom of the tube and the quantity was then read and recorded as the volume percent of sand content in the drilling mud (Apugo-Nwosu *et al*., 2011).

3. Results and Discussion

The results obtained from the experimental analysis of mud densities of the drilling muds prepared with the local Nigeria clay and imported foreign clay, and their sand content, are presented in a graphical form in Figures 1 to 4.

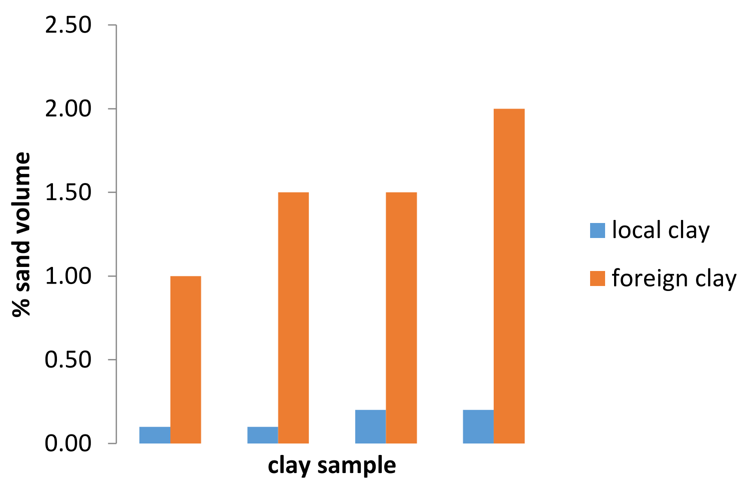

Figure 1: Shwing the Comparison of the Percentage Volume of Sand in Local Clay-mud and Foreign Clay-Mud.

The Figure 2 shows the percentage volume of sand of both locally prepared drilling mud and its foreign Bentonite. The experimental results of both local and foreign percentage sand volume are 0.1%, 0.1, 0.2%, 0.2% and 1.0%, 1.5%, 1.5%, and 2.0%. The low percentage sand volume recorded in local-clay drilling mud, was due to the large void between the inter-particles of clay which causes weakness in bonding, and low aggregation of particles. Thus, lead to poor interactions with water molecules, and eventually becomes less viscous. As a result of this, cannot suspend sand particles in the drilling mud as the foreign to avert borehole sand problems. This therefore cannot meet the API specification of 1% to 2% recommendation of sand volume in drilling mud (Nmegbu, 2014) (Nmegbu, 2014). However, if the local-clay drilling mud is beneficiated, could meet the percentage of sand in the foreign bentonite and the recommended API percentage of sand volume in drilling mud. In conclusion, large sand-size particles in the drilling mud causes problems like abrasion on drilling equipment such as hose, mud pump, drilling string and down hole equipment (Apugo-Nwosu *et al*., 2011). The low percentage volume of sand recorded in the local drilling mud is because of the large void between inter-particles of clay which caused weak bonding and low aggregation of clay particles leading to poor interaction with water molecules and eventual lack of viscosity. Viscosity in drilling fluid is responsible for holding back sand particles in the drilling mud and then causes it to become viscous. Thus, the local clay with a very low viscosity; cannot retain a large quantity of sand as with the foreign mud, and therefore cannot meet the API standard specification of 1 % to 2 % of volume percentage in drilling mud (Nmegbu, 2014).

To determine the density of drilling mud (local and foreign), the baroid mud balance was used. The experiment begins by ensuring the apparatus was dried, clean, and dust-free, then the mud cup was filled to the brim/mouth with the agitated mud sample and the side of the cup was tapped gently to allow mud to settle down in areas occupied by air bubbles. Then the cover/lid was turned slowly until it was firmly tight on the cover of the mud cup. Then with the thumb covering the hole/vent on the cover, mud spills were washed with water from the exterior of the mud cup and dried with a rag. The balance arm attached to the mud cup was then placed on the pivot with knife edges. This reading was taken at a balanced of the riding weight on the graduated arm of the mud balance and the densities were read in the four units as kg/m^3, kpa/m and Specific Gravity (S.G) and recorded according to the mud type (local and foreign). Finally, the mud is poured out from the mud balance cup into the sample can for future use, and the apparatus was then washed with water and dried with a rag before it was kept properly to avoid being damaged to prevent it from giving erroneous readings when is in use in the future.

The variation of the foreign clay-mud density with clay concentration is presented in Figure 2.

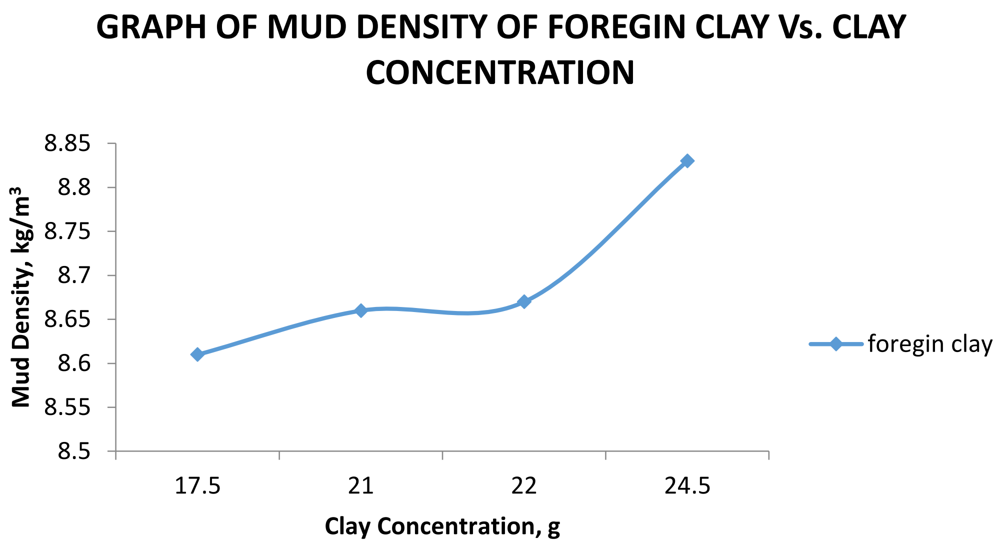

Figure 2: Foregin Clay Mud Density Vs. Clay Concentration.

From Figure 3, there's a progressive and consistent increase in the mud density values of foreign clay which ranging from 8.61 kg/m^3, 8.66 kg/m^3, 8.67 kg/m^3 to 8.83 kg/m^3, and with a progressively corresponding increment in clay the concentrations from 17.5 kg, 21.0 kg, 22.0 kg to 24.5 kg.

This is due to the high interaction between particles in the drilling mud and water. The hydrophilic character of the foreign clay for water almost instantaneously increases the rate of water absorption and a consequential change in physical size, and eventually becomes thick, viscous, and plasticity leading to plastic viscosity and Gel strength and consequently, resulting in high internal resistance buildup in the fluid and become weighty.

The weight is referred to as hydrostatic mud weight or pressure. The hydrostatic mud pressure performs functions such as stabilization of formation pressure during the drilling, preventing inflow of fluids into the wellbore (Apugo-Nwuso *et al.*, 2011)

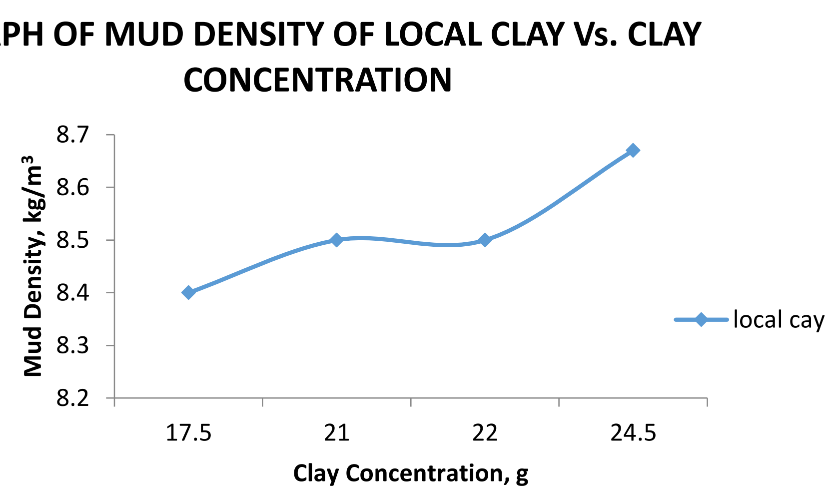

Figure 3: Local clay Mud Density Vs. Clay Concentration

In Figure 4, there is a conspicuous display of lack of consistency in the incremental values of mud weight of 8.40 kg/m^3, 8.50 kg/m^3, 8.50 kg/m^3, and 8.67kg/m^3. as observed in the local Nigeria clay, and also, against the corresponding increasing clay concentrations of 17.5 kg, 21.0 kg, 22.0 kg, and 24.5 kg. The constant values of 8.50 kg/m^{3}l of mud weight with a corresponding progressive incremental value of clay concentrations of 21.0 kg and 22.0 kg, is a strong indication of the high phobic nature of the local clay-minerals with water molecules. This is due to the distance between particles and inter-particles in the local clay minerals that are far apart and weaken the bonding of clay particles and water molecules and become less reactive. The preceded sudden increase in mud weight value of 8.67 kg is as resulting from the thick accumulation of clay particles from the previously witnessed constant of mud densities but yet on incremental clay concentrations of 21.0 kg and 22.0 kg.

The local clay-mud has a very viscosity due to its inability to absorbed water and swell to become viscous which is a required mud density of any drilling mud.

These characteristics depict the local clay having low mud weight and in turn having a lower mud pressure and/or hydrostatic pressure and not being able to perform its primary duties as drilling mud for drilling of oil and gas well operations. However, there is a visible sight that further increases clay concentration, would enhance clay-minerals and reduce the distance between clay particles and increase bonding and reaction for an increased viscosity, and mud weight and hydrostatic pressure (mud pressure), and then, can be used as complimenting foreign clay-mud.

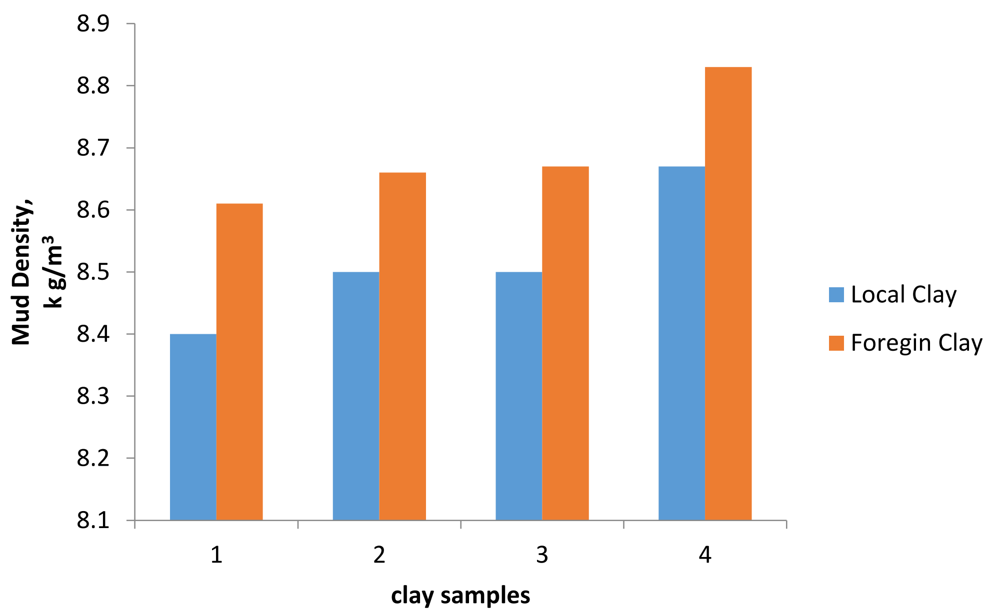

Fig 4: Chart of Local Clay and Foregin Clay-Mud Density.

From the figure 4, the result of the local clay-mud densities are 8.4 kg/m^3, 8.5 kg/m^3, 8.5 kg/m^3 and 8.67 kg/m^3 while that of the foreign clay-mud densities are 8.61 kg/m^3, 8.66 kg/m^3, 8.67 kg/m^3 and 8.83 kg/m^3. The graph shows clearly the superior property in the foreign clay-mud to the local clay-mud. The local clay-mud at the beginning of contacting water molecules, lack viscosity, but started developing viscosity with increasing clay concentrations. The viscosity was sustained at equilibrium for between a density value of 8.5 kg/m^3 and of clay concentration of 21.0 kg and

8.5 kg/m^3 of a clay concentration of 22.0 kg before the sharp increase in density of 24.5 kg/m^3. However, like the local clay-mud density, a uniform thickness viscous mud was noticed in the foreign clay-mud, and was constant before before the sudden increased after an increment in clay concentration. In general, the local clay-mud can be used as a complimentary drilling mud with the conventional imported drilling cay-mud if these properties been analyzed are further enhanced.

However, is also observed that further modification (beneficiation) of local clay, will bring closer the particles in the drilling mud to cause high interaction and increased plastic viscosity and Gel strength and, will then lead to high viscosity and mud weight. In all, the local clay mud has low mud weight and a characteristic that if beneficiated, will enhance the quality and complement the conventional drilling mud, as it will aggregate to meet those of foreign clay and consequently, the API standard values of mud weight/density of between 8.65kg/m^3 to 9.60 kg/m^3, and there-after stop the huge loss to the importation of drilling mud-clay (Nmegbu, 2014).

4. Conclusion

In general conclusion, the local clay-mud densities exhibit this same graphical trend as the foreign clay-mud densities with equilibrium constant values at the same sand concentration values of 21.0 kg and 22.0 kg. This is an indication that the local clay-mud, can either be used as an independent drilling mud or as complimentary the foreign imported drilling clay-mud in the drilling operations of an oil and gas wells if these the properties analyzed are further enhanced. The percentage sand volume observed in the local clay-mud is nearly almost equal the value of the percentage volume of sand content in the foreign clay-mud and as such, can be treated to conform to the minimum acceptable volume of sand content in drilling mud.

References

Akpoturi, PE., Idudje, EH. and Okologume, CW. 2017. Drilling Fluid Properties and Treatment of some Nigeria Clays. International Journal of Advance Academic Research/Science, Technology and Engineering, 2(9): 16-27.

Arinkoola**,** AO., Salam, KK., Salawudeen, TO., Abidemi, GO., Hamed, JO., Jimoh, MO., Olufauyo, OA. And Aladeitan, YM. 2020. Improvement of filtration Properties of Treated Nigeria Bentonite Clay Using Locally Sourced Bio-Materials. LAUTECH Journal of Civil and Environmental Studies, 5: 114.

Alsabaa, A., Hany, G., Salaheldin, E. and Abdulazeez, A. 2020. Real Time Prediction of Rheological Properties of Invert Emulsion Mud Using Additive Neuro-Fuzzy Inference System. Sensors MDPI, 20(1): 1-21.

Amoco Production Company, 2001. Amco Production Drilling Fluids Manual. Palmer Publishers, Los Angeles, Revision 6/9, 224: 5-26.

Ameloko, AA., Ogologo, CE., Daramola, OC. and Babalola, AO. 2020. Assessment of Clay Materials for Suitability in Drilling Mud Formulation from Part of Ondo State, South-West Nigeria. Journal of Petroleum Exploration and Production, 10: 2815-2816.

Apugo-Nwuso, TU., Mohaad-Dabo, IA., Ahmed, AS., Abubakar, IG., Alkal, AS. and Ayilara, SI. 2011. Studies on the Suitability of Ubakala Betonitic Clay for Oil Well Drilling Mud Formulation. British Journal of Applied Science and Technology, 1(4): 155-156.

ASME Shale Shaker Committee, 2005.Drilling Fluids Processing Handbook. Gulf Professional Publishing Company. An Imprint of Elsevier, 30 Corporate Drive, Suite 400, Burlington, MA 01803, USA. Linacre House, Jordan Hill, Oxford OX2 8DP, UK, 15.

Bourgoyne, AT Jr., Chenevert, ME., Millheim, KK. and Young, FS Jr. 1991.SPE Textbook Series, Society of Petroleum Engineers, Richardson, TX. 58.

Wolfgang, DF**.** 2016. Drilling Engineering. Curtin University of Technology, Department of Petroleum Engineering, Australian. 155.

Faruk**,** C. 2000. Reservoir Formation Damage. Gulf Publishing Company. An Imprint of Elsevier, Book Division. Houston, Texas, 5310-20: 648.

Igwilo, KC., Uwaezuoke, N., Ukaka CM., Amaefule CV. 2021. Evaluation of Rheoogical and Fluid Loss Properties of Bentonite Using Periwinko and Nucuna Solannie. ISSN: Journal home page: https://www.tandfonline.com/loi/oaen20. (8): 2.

Institute of Petroleum Engineering, Heriot Watt University 2009. Drilling Engineering. Edinburgh, Scotland, United Kindom UK, 371.

Kaffayalullah, K., Shaukat, AK., Muhammad, US. and Muhammad, A. 2021. Improvement of Locally Available Raw Bentonite for use as Drilling Mud. Open Construction and Building Journal, (15): 1.

Rejesh, K., Bhavani, Y., Hussain, A., Junaid, T., Nidhim, M. and Shiva, GK.2017. Determing Sand Content Set in Various Compositions of Drill Mud. International Refereed Journal of Engineering and Science (IRJES), 6(6): 13-16.

Mobeen, M., Hafiz, MA., Muhammad, SK. and Syed, MSH. Mohamed, M. and Shirish P. 2020.Evaluation of Clay Hydration and Swelling Inhibition Using Quaternary Ammonium Dicatonic Surfactant with Phenl Linker. MDPI, Molecules, 4333, (25): 2, 1-20.

Mosese, OE., Christopher, O. and Joy, CI. 2021. A Synoptic Review of Mineralogical and Chemical Characteristic of Clay in the Southern Part of Nigeria. Research in Ecology, 3(2):33.

Nmegbu, CGJ.2014. Laboratory Investigation of Rivers State Clay Samples for Drilling Mud Preparation. International Journal of Engineering Research and Application, 46(4): 1.

Omole, O., James, O., Adeleye, O., Malomo, S. and Oyedeji, OA. 2013. Investigation into the Rheological and filtration properties of drilling mud Formulated with Clay from North Nigeria. Journal of Petroleum and Gas Engineering, 4(1): 1.

Standard Procedure Manual,2003. Drilling Fluid, ENI Agip Oil Company, Italy, 2.

Zhang, JR., Meng, DX., Christidis, GE. and Chun, HZ. 2020. Clay Minerals in Drilling Fluids: Functions and Challenges. Cambridge University Press, (10): 1