Investigating Nigeria Local Clay for its Marsh Funnel Viscosity and Gel Strength: A Study of Irhodo Bentonite

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Abstract
Due to the daily increasing demand for crude oil fuel for its various capacities of energy production and utilizations, a twin respond of exploration for more hydrocarbon reserves and drilling activities was accompanied. As a result, rate and cost of importing drilling clay (Wyoming Bentonite), a major raw material in drilling mud becomes so high that hundreds of millions of dollar is incurred on company budget (Arinkoola, *et al.,* 2020). Thus, the Federal Government of the federal republic of Nigeria, on sensing the benefits of local content development, then clamour for its use as drilling mud. This therefore becomes the bed-rock which this paper is belt on to investigate local clay for some its properties, like viscosity-gel strength. This paper also reviews the formulation of an equivalent one barrel of a laboratory drilling mud using Irhodo bentonite. This paper report two methods and devices used to determine viscosities; the marsh funnel viscosity method using Marsh Funnel and Fann Viscosity-Gel method using the Rheometer. The result of the experiment for the determination of viscosity using marsh funnel apparatus, for both local and bentonite drilling mud, and show 27.12 and 37.17sec/qt (seconds per quart). And when additives, CMC and guar-gum were added, 27.23sec/qt, 29.47sec/qt and 23.19sec/qt and 29.47sec/qt respectively obtained.

Keywords: Viscosity-Gel Strength, Local Clay, Drilling mud, Fann V-G Meter and Marsh Funnel.

Introduction

Nigeria economy is heavily bet on the earnings from crude oil. Therefore, embarking on substantial drilling activities covering all terrains, formations and depth becomes inevitable [Zhangi, et al., 2020]. The drilling process is the most complicated operation in the oil and gas industries [Wang, 2009]. And, of more crucial to successful drilling, is the drilling mud which required clay of very special qualities like; hydrophilic, swelling and plasticity [Kaffyalullah et al., 2021. and Murtaza, et al., 2020]. The clays that possess these qualities are called bentonite clay.

The Niger Delta region, apart from being the vacuum accumulator of hydrocarbon, is also a hub for drilling clay [Igwilo, et al., 2021; Ameloko, et al., 2020; Afolabi, et al., 2017 and Emofuriata, 2001].

Clay remain indispensable as its use is dated back to the creation of man and when man came into existence, uses clay for monument, means of water preserving, and as body coolant from heat. And this go on to makings of various clay pots, beads, bricks for building as stated by Karnland, et al., 2006 and now, in more enterprising areas like; pharmaceutical industry, ceramic, Arts, bottling company, construction industries, paint, paper and drilling companies for water, and oil and gas well [Igwilo, 2021, Moses, O.E. et al., 2021 and Udie, 2016].

This paper is concerned about the evaluation of clay that posses the aforementioned qualities to reduce importation which engulf millions of dollars every year, create jobs, reduce overall company expenditure and ensure more foreign earnings for both operating company and its host country [Afolabi et al., 2017, Omole et al., 2013, Samson and Saheed, 2020, Ameloko, et al., 2020]. The drilling mud (fluid) is a mixture of clay, water and additives [Afolabi, et al., 2017]. During drilling, drilling mud transverse along with bottom hole equipment through different bed rocks and fluids with contaminants that influences the efficacy of the drilling mud.

The drilling mud have several properties, and for it to perform its primary functions (providing a desirable mud density/weight to subdue formation pore pressure, removal of cuttings from wellbore, prevention of water loss, well bore stabilization and e.t.c.) effectively, the properties are being tested on routinely bases for loss of quality and modify anytime the drilling operation would last [Alsabaa, et al., 2020; Institute of Petroleum Engineering, 2005].

This study then will focus on of these properties of Nigeria local clay (Irhodo clay deposits) like the marsh funnel viscosity and10 seconds and 10 minutes Gel strength properties and compare with Wyoming clay as API standard for specification.

Viscosity:

The viscosity can be inferred as a practical/apparent resistance to fluid flow. Viscous fluid like drilling mud are classified as Non Newtonian fluid which do not exhibit direct proportionality between shear stress and shear rate unlike the Non-Newtonian fluids like water, light oil etc, that exhibit direct proportionality between shear stress and shear rate and its graph passes through the origin and the slope from the straight line graph is called viscosity, and the numerical value is unity no matter the shearing stress. This is in revise for Non-Newtonian fluid whose graph-slope intersected at a point above the origin. This mean Non-Newtonian fluid must be sheared to deform before fluidity occur.

This, clearly show that Non-Newtonian fluids are thixotropics and developed internal structure that build up gelation strength while at rest and which broke-down when shear stress is applied. Therefore, the shear stress- shear rate relationship completely governed fluid viscosity which are highly influenced by the reaction between there particles and liquid phase.

In the rig, there are two equipment and, also the methods, used for measurement of viscosity and are; marsh funnel and rotational viscometer.

Marsh funnel:

The marsh funnel was invented by Hallen N Marsh of Los Angeles in 1931 [Mohmad et al., 2020]. The device has two sectional parts; Funnel and Cup [Faleh, et al., 2014].

Funnel:

Generally, the marsh funnel device required little equipment, easy or simple to operate and quick or fast in measurement of drilling fluid viscosity [Chandan, 2013, Fann Instrument Company, 2013, Friedrich, 1941; Delikesheva, et al., 2020]

The funnel is made of break-resistant plastic and has a permanent outlet or orifice with quantify diameter (Friedrich, 1941) and have two sectional design; cone and tube. The marsh funnel simple measure the viscosity of drilling mud by taking record of time it flow from the cone and through the orifice tube (1500ml) into a graduated cup capacity of 946 cubic centimeters and recorded in seconds as a measure of viscosity of mud.

Cone Section:

The cone section measure 12 inches (30.5cm) long and 6 inches (15.2cm) in diameter and have a wire sieve on one side of the upper open session of the cone [Faleh, *et al.,* 2014, Mohmad, *et al.,* 2020]. The top open screen mesh wire session restrained large particles from entering the funnel and blocking the orifice or outlet [Mohmad, *et al.,* 2020].

Tube Section:

The tube section, is 2inches (5cm) long and 3/16inches (0.475cm) in diameter. The fluid capacity of marsh funnel to the level of inscription "Mud Here" is 1500 milliliters.

Marsh Cup:

The marsh cup has a capacity volume of 946cubic centimeter to a Mud Here level or mark inscription which is equivalent of one quart of fluid be tested. The cup is 135mm (5.31inches) long and a diameter of 130mm (5.12 inches) [Luetert, 1941]. The flow time of funnel viscosity is the ratio of the *SPEED* of the mud sample as it flow out the orifice/outlet tube (shear rate) to the *AMOUNT/DENSITY/WEIGHT* of mud that is causing the mud to flow (shear stress) [Friedrich, 1941].

The drilling mud is on routine checking for the deterioration of its properties [Darley and Gray, 1988; Bougonyne, et al., 1991]. The viscosity is recorded in figure of seconds required for an equivalent of one quart (946cc) of mud to flow out of a full marsh funnel (1500ml) and is frequently use to monitoring the relative changes in the progression of drilling mud [Marsh, 1931; Friedrich, 1941].

As reported in API standard test for calculating the viscosity of drilling mud in a marsh funnel, the time for one quart of mud was achieved is substituted in the formula given by M.J Pitt, (2000) as;

$$\mu_{eff} = \rho(t - 25) \ [3] \ \dots\dots\dots\dots\dots\dots 1$$

Where,
μ_{eff} = **effective viscosity (cp)**
ρ = **Density (gm/cc)**
t = **time (sec)**

For record purposes, the viscosity of water using marsh funnel is 26 seconds per quart (sec/qt), and is the lower limit of viscosity a drilling mud would attain [Kelly, 2018]. The experimental rang for clay minerals are from 30 to 50 seconds per quart [Kelly, 2018].

ROTATIONAL RHEOMENTER (Fann V-G or Multi rate Viscometer):

The most common and accurate device used in determining a gel strength (10 seconds initial gel and 10 minutes' final gel), is the rotational viscometer. There are common types; manually operated and electronic. The manual operating rheometer has two gears (300rpm and 600rpm) while the electronic types have six gears (3rpm, 6rpm, 12rpm, 100rpm, 300rpm and 600rpm). In the field, the two gear rheometer is most use as they are proficient to measure the needed properties of drilling fluid required.

GEL STRENGTH: (10 seconds initial gel and 10 minutes final gel)

The gel strength is measured with an instrument called viscometer. Gelation strength (gel sth.) of drilling mud is an off-shoot of drilling mud deforming properties, which describe the attractive forces of the drilling mud quiescent time [Okon, *et al.,* 2014]. There are two main functions of gel strength testing which are determined at difference time space accord to their functions. The different time and functions are; 10 seconds for the quick gelation of the drilling mud and 10 minutes gelling strength for its ability for suspension of drilling mud. The 10 seconds and 10 minutes' gel strength determination is usually done at a retort revolution speed of 3rpm. The drilling mud is thixotropic which is the ability of the drilling mud to thicken when at quiescent time and becomes fluidic when agitated. This characteristic is proportionally depended on the quantities and types of solid, temperature, brine formation and time [Max, R.A, Martin, V.S., 1996].

The measurement of shear stress of drilling mud at low shearing rate after drilling

mud have been static for a quiescent time, is referred to as gel strength. Thus, gel strength examine the gelling characteristic of drilling mud to ascertain its ability to perform its primary functions of quick gelling (10 sec or initial gel) and suspension of cuttings (10 minutes gel). The gel strength is reported in Ibf/1000ft^2.

Geomorphology of the Area.

The selected area for this work is Irhodo, a village that is located in Ethiope-West local Government Area of Delta State, south-south region of Nigeria and lies on longitude 5.870°N and latitude 5.750°E and at a distance of 290 kilometers (180 miles) south east of Lagos. It has a common boundary with Edo state in the west, River Ethiope in the east and south, and Mosogar

at the northern part. This area is characterized with annual heavy rain fall, thick forest vegetation, and terrestrial animals. Irhodo is also discretized by Benin, Agbada and Akata formation. It is a sedimentary region with flat topography which characterized by fine reddish top soil underlain by shale formation.

METHODOLOGY
Procedure for experiments: Experiment 1

Aim: To formulate one barrel of laboratory mud of local Nigeria clay and Montmorillonite (Wyoming) bentonite with a known initial P^H 7 of water.

Materials for the analysis:

Table i: Local Nigeria and foreign materials used in experiment 1

S/N	Materials	Place	Purpose
1	Local Nigeria Clay	Irhodo, Jesse	For formulation of local mud sample
2	Wyoming/ Bentonite Foreign Clay	USA	For formulation of foreign mud
3	Fresh Water	Nigeria	For formulation of mud (Continuous phase of mud mixture) and Washing.
4	Rags	Nigeria	For cleaning

Table ii: Apparatus used for the analysis in experiment 1.

S/N	Apparatus	Place	Purpose
1	High Speed Hamilton Beach multi-mixer	Gallenkamp, England	For stirring/agitation of mud.
2	Sample Can	Nigeria Market	For storage of mud samples
3	Thermometer	England	To determine the degree of cool and hot .
4	Triple beam Balance	Ohaus, London	For weighing of materials
5	Spatula	Pyrex, England	For adding or removing clay sample during measurement, as well for manual stirring of mud.

Procedures for experiment:

The formulations of the mud samples begin by measuring 22.0 grams of clay samples (local and foreign) with a triple beam balance (as shown in table 3 above) and pour into different sample can holder. A 500ml graduated measuring cylinder was then used to measure 350ml of water with known p^H of 7 and poured into separate mud mixer cups. The mud cup is clamped firmly to the multi-mixer and the clay sample is gradually poured bit-by-bit avoiding clogs and allowed for

3 to 4 minutes for homogeneous mixture of clay and water. This prepared 1 barrel equivalent laboratory mud samples were allow for 24 hours for proper hydration (Aging) and after which is re-agitated whenever for further experimental analysis.

Experiment 2
Aim: To determine viscosity of local Nigeria and Foreign bentonite using a Marsh Funnel with cup.

Table iii: Materials used for the analysis of mud viscosity of Local and Bentonite clay.

S/N	Materials	Place	Purpose
1	Agitated drilling mud samples:		
	---- Local Clay	Irhodo Village, Jesse.	Sample to be analyzed
	---- Bentonite Clay	USA	For Comparison
2	Fresh Water	Nigeria	For Washing
3	Rag	Nigeria Market	To Clean and Dry

Table iv: Apparatus used for the analysis of mud viscosity of Local and Bentonite clay.

S/N	Apparatus	Place	Purpose
1	Marsh Funnel (1500ml)	OFITE, Houston	To analyze mud viscosity
2	Marsh Funnel Cup (1quart=946cc)	OFITE, Houston	To quantify exact point of mud
3	High Speed Hamilton Beach multi-mixer	Gallen kamp, England	For mixing.
4	Sample Can	Nigeria Market	For storage of mud samples
5	Thermometer	England	For determine the degree of cool and hot
6	Spatula	Pyrex, England	For adding or removing clay sample during measurement, as well for stirring of mud.

The marsh funnel is positioned vertically with its 2-inches long tube over the graduated mud cup as the orifice is covered with a finger. The re-agitated prepared mud sample were poured into the mesh funnel through a wire mesh screen located on top-one-side to the inscribe mark 1500ml (to reach the bottom of the wire mesh screen). Remove finger simultaneously with the starting of the timing device and stop when the mud level reaches one quart (1 qt) mark on the viscosity cup and record the value in second per quart (sec/qt) as marsh funnel viscosity.

Experiment 3
Aim: To determine the gel strength of local Nigeria and Foreign bentonite Clay Using the Fann Viscosity-Gel Meter.

Table v: Materials used for determination of gel strength of both local and foreign mud.

S/N	Materials	Place	Purpose
1	Agitated drilling mud samples:		
	---- Local Clay	Irhodo Village, Jesse.	Samlpe to be analyzed
	---- Bentonite Clay	USA	for Comparison
2	Fresh Water	Nigeria	For washing
2	Rag	Nigeria Market	To Clean and Dry

Table vi: Apparatus used for determination of gel strength of both local and foreign mud.

S/N	Apparatus	Place	Purpose
1	Fann Viscosity-Gel Strength Meter with Cup	OFITE, Houston	For determination of drilling fluid viscosity.
2	High Speed Hamilton Beach multi-mixer	Gallenkamp, England	For mixing/agitation of drilling mud.
3	Sample Can	Nigeria Market	For storage of mud samples
4	Thermometer	England	For determine the degree of cool and hot
5	Spatula	Pyrex, England	For adding or removing clay sample during measurement, as well for manual stirring of mud.

The gel strength (10 sec and 10 min) is obtained from the maximum dial reading (max. dial deflection) after mud is allowed for finite period of time while at low rotor speed of 3revolution per minutes (3rpm). The time at which the drilling mud is allowed to be at rest,

decide the gel strength type (that is whether 10sec or 10 min gel) to be obtained.

Initial gel strength (10 seconds gel strength or Zero quiescent time):

For the initial gel strength (10 sec), stir mud at high rotor speed of 600 revolutions per minute for 10 to 15 seconds, then turned gear at low rotor speed of 3 revolutions per minute and switch off the machine and allow mud for 10 seconds quiescent time. After which turn gear at low rotor speed (3rpm) then observe maximum dial deflection and record reading as 10 seconds gel strength in 100Ibf/100ft^3.

Final gel strength (10 minutes' gel strength or Ten minutes' quiescent time):

The procedure used for the 10 seconds gel strength is repeated for the final gel strength (10-minute gel strength), except that mud was allowed to remain at static for a period of 10 minutes instead of 10 seconds to record its value of maximum dial reading (or deflection).

RESULTS AND DISCUSSION
Table of Results:

Table vii: Show the result of marsh funnel viscosity of local and foreign mud beneficiated with additives (CMC & Guar-gum).

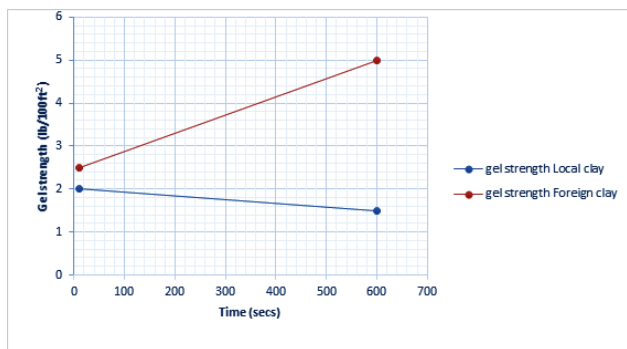| Sample	Marsh funnel readings in sec/qt	Volume of mud used	Types of Viscosifying Agent used		
			Conc. in grams	CMC in sec/qt	Guar-gum in sec /qt
Local	27.12	5bbl	10	27.23	29.47
			25	23.19	29.47
Foreign	37.17		No beneficiation of foreign clay except modification of local mud to meet value of 37.17 of foreign mud.		

Note: All graph/figure are prepared with GIF

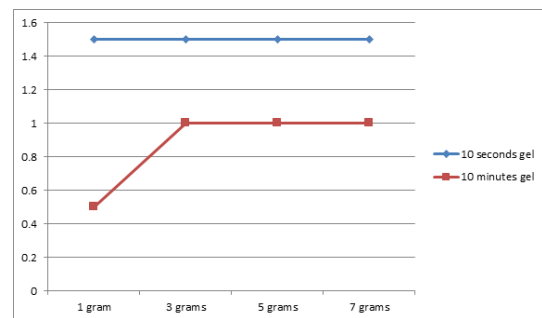**Figure i:** Show results of drilling mud gel sth of local and foreign clay without beneficiation.

Figure ii: Show the result of 10sec and 10min gel strength of both local and foreign drilling mud beneficiated with CMC as additive.

Figure iii Show the results of 10sec and 10min gel strength of both local and foreign drilling mud beneficiated with Guargum as additive.
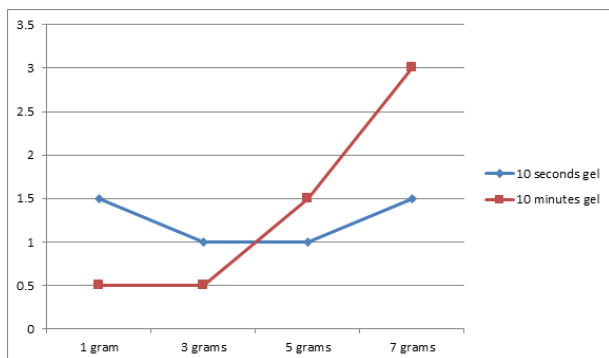
Discussion of Results

From table vii, the marsh funnel viscosity for both mud of local and bentonite clay are respectively 27.12second per quart (sec/qt) and 37.17sec/qt. This value of bentonite mud will be used as reference base for this analysis. It was also observed after beneficiating with carboxyl methyl cellulose (CMC) and guar-gum, result show low values as compared to the value obtained from bentonite drilling mud, and display a characteristic of having a uniform value afterward even with further beneficiation.

The reason for this low value gotten from drilling mud formulated with local clay is as a

result of its low ions exchangeable capacity between clay particles and clay and water molecules which, resulted in low plastic viscosity and gel strength. Consequently, the local drill mud possessed low mud weight and therefore runs out from the marsh funnel faster with less time (27.12sec/qt) than bentonite mud (37.17sec/qt).

This literally means that further beneficiation, will only resulted to values inch-away from the readings gotten and which is still insignificant to the reference base reading (37.17sec/qt) from bentonite mud. Thus, it is uneconomical and not advisable for company to venture for business.

In figure ii, studies reviewed the readings of bentonite mud and local mud at 10 sec and 10 minutes gelling strength was 2.5 Ibs/100ft^2 and 5.0Ibs/100ft^2, and 1.5Ib/100ft^2 and 2.0Ib/100ft^2 respectively.

The low value from local mud, is resulted from low hydration of clay particles in water, and thus, leading to low gelling and viscosity unlike bentonite mud which possesses quick gelling tendency at a 10 seconds (secs) gelling strength (gel strength) value of 2.5Ibs/100ft^2 and mud suspension, for at a high value of 5.0Ibs/100ft^2, 10 minutes' gel strength.

Therefore, the mud formulated from local clay, lack quick gelling properties and ability to suspension cutting as met to do or functioned. From figure iii the outcome is being aimed at ensuring the gel strength of local mud is equivalent to that of bentonite mud. Hence, after beneficiated with CMC, at different clay concentrations (1g, 3g, 5g, and 7g), the value obtained for both 10sec and 10minute gelling strength were constant except at 1gram and 3gram concentration of local clay where the lowest value of 0.5 Ibs/100ft^{2}for each at 10-minute gelling strength.

This was due to the quiescent time of 10minutes of drilling mud when the shear stress-shear rates were directly proportional (Newtonian fluid).

In all, the gel strength values (10sec: 1.5, 1.0, 1.0, 1.5 and 10 minute: 0.5, 0.5, 1.5 and 3.0) of local clay do not meet the values of 2.5Ibs/100ft^{2}and 5.0Ibs/100ft^{2}of bentonite mud, considered as base reference value for the10sec, 10minute gelling strength analysis.

Therefore, is not suitable as drilling mud due to its low weight that culminates into lack of

quick gelation and ability to suspend cuttings when drilling operations is on hold.

From figure iv after beneficiating with guar-gum, an additive to increase local mud viscosity, and, at a step-wise addition of clay concentrations of 1g, 2g, 3g, 5g and 7g, a constant uniform value of 1.5Ibs/100ft^2 was observed for 10 sec gel strength. While at 10 minutes gel strength, apart from the value obtained for 1g of clay concentration, a progressive constant value of 1.0Ibs/100ft^2 was observed.

Also, was observed that further beneficiation will be fruitless as long the viscosity remains constant.

This result is poor and is attributed to low inter-particle interaction in local mud, which resulted in a very low ions exchangeable capacity between clay particles and water molecules. As a result, mud weight becomes low and less viscous.

Consequently, the local mud would not able to perform its primary functions of 10seconds gelling to commence drilling in-situ and the 10minutes gel to suspend cuttings when circulation of drilling mud is stopped, may be due to reasons like; community disturbance, government policy, and others.

And also, the local drilling mud would not be able to circulate cuttings from the wellbore to the surface and, this, causes drill-hole problems like; mud hydration, mud cake, sticking bottom-hole equipment, and excess usage of power for mud circulation.

Conclusion

From the result of analysis of the experiment, the drilling mud gel strength and marsh funnel viscosity of local Nigeria clay obtained from Irhodo village in Jesse, were very weak compare to foreign Wyoming clay. This, by application can be used to drill low pressure wells (shallow wells) and not deep wells (high pressure well).

Note: The reference section was in line with the journal format.

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