Effect of Cashew Nut Shell Liquid Esters on KCL/Polymer/Glycol Drilling Fluid Flow Property

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ABSTRACT**: Drilling to target depth at minimal cost with less environmental impact mud systems have been the major issues during drilling operation. Especially with the advent of novel technologies and techniques such as deviated well, high-pressure-high-temperature (HPHT) and extended reach wells. The uses of more complex additives in formulating mud systems for such operations have shown successes but have inherent environmental issues. They are often petroleum based sources, thus, are toxic, non-biodegradable and costly. Within the formation, flow and property of the mud is affected by changing temperatures thereby weakening their active ingredients and distorting their ability to perform effectively. Most of these additives are phenolic compound with low carbon chain structure and molecular weight hence they degrade at slight changes in temperatures. This study investigates the effects of composition of novel additives (esters) synthesized from Cashew nut shell liquid (CNSL) on the flow properties of drilling fluid. The results obtained shows that the esters were compatible with other mud additives utilized in the formulation. The plastic viscosity values obtained for all samples ranges from 14-17cp with sample E having the highest value with reference to based mud. All the samples had PV values within API range (8-35cp). Yield point for samples were between 15 and 24 (Ib/100ft^2), sample F was highest with 24(Ib/100ft^2) while D and G values 16 and 15 (Ib/100ft^2) respectively were lower compared to the standard mud value. The gel strength values for all mud samples were between 3and 4(Ib/100ft^2) for10sec and 10minrespectively except sample D with 1Ib/100ft^{2}10 seconds gel. However, YP and Gel values for all samples were within API acceptable range ((YP=5 and ≤ 3(PV); Gel: 10sec (2-5) and 10 min (2-35))except sample D with lower10 seconds gel value. The results proved that the formulation can actually sustain the cuttings with minimal pump pressure required to further initiate flow after circulation is stopped. It is therefore proposed that the esters could serve as potential multi-purpose additives in water based mud formulations. This will help to reduce the cost and environmental toxic impacts of using synthetic oilfield additives.

Keywords: *CNSL, Natural Esters, Drilling Fluid, Additives, Properties*

I. Introduction

In spite of numerous calls for other alternative energy sources, the world's energy usage still borders on the use of oil and gas and will continue to be in the nearest future. The energy council estimated continuous energy demand due to raising population of the world (OECD/IEA, 2005). However, there is rapid decline of the reserves to satisfy these demands even with the rise in crude oil price globally. To remedy the shortfall between demand and supply, exploring from alternative resources in an unexplored area and deeper formations have evolved. Such drives are made possible by the numerous advances in technology (Shah et al., 2010).They opined that satisfying the future energy demand goes beyond discovering untapped resources but advances in

developing and application of novel technology. The use of inclined, horizontal and extended reach wells techniques etc have all evolved and opened up new frontiers in the design of fluids or mud for drilling operation. Applying these techniques and technologies requires special consideration in terms of cost and environment (Shah et al., 2010). One area of interest is to understand the impact of additives on the properties of drilling fluids in order to develop and design fluids that are eco-friendly, cheap, and able to sustain its properties under varying conditions of temperatures and pressures while trying to overcome different technical challenges during drilling operations.
Drilling operations has to do with excavation of the earth in order to get out the natural resources (hydrocarbons). The cost of drilling a well has been estimated between $34,000 and $42,000million (USA Dollar) for stable wells (Amorin, et al., 2015; Fitzgerald et.al, 2000). This could be more than double the cost for wells with varying challenges especially in deeper and inclined wells (Amorin, et al., 2015). Drilling successfully to target depth requires design of a suitable drilling fluid with the right additives to achieve well stability. Rotary drilling operates by circulating drilling fluid down the geological formation through a drilling bit. Drilling mud is a complex fluid and has been defined by different researchers (Fakharany et.al, 2017; Dosunmu and Ogwurindu 2010; Amanullah, 2005). It is composed of water/solids and oil or solids with varying amount of other chemicals called additives. Drilling fluid formulated with the right additives expected to maintain wellbore stability by performing the functions outlined by (Ibrahim et.al, 2017). Drilling fluids have been classified into three main types; water based mud, oil based and synthetic based mud (Irawan, 2009). The selection of the mud type for formulation is premised on trend of the well condition, safety of personnel, cost, logistics, environment (Okoro et al., 2015). Usually muds are evaluated based on their capacity to effectively discharge these functions which depends on the flow properties to achieve a stable borehole (Fakharany et.al. 2017). Because of this, additives are incorporated into the formulation to give it the desired flow properties. Technically, drilling to desired depth at a reduced cost with less environmental impact have been the major issues especially with inclined and extended reach wells. This has opened up a new chapter in the choice and nature of additives used in the design of a mud system. Some additives exist in the literature, but contribute to the high cost of drilling fluids because of transportation and import charges. Again, their sources of synthesis are petroleum based. Petro-base additives contains relatively large amount of aromatics and other dangerous materials which may be harmful to animal or plant when these fluids are disposed to the environment (Dardir et.al 2013; Mckee, 1995). A way to curb this is by the use of biodegradable materials to synthesize cheap and eco-friendly additives that will have minimal impact when the drilling mud is dispose to the environment. Such sources include the use of edible and non-edible vegetable oils from plants and agro- wastes containing natural liquids. This research focuses on the agro-waste sources. The study investigates the effects of agro-waste liquid and its derived compounds on some properties of drilling fluid. Water based mud is the mud of interest because it is cheap and eco-friendly, therefore, the aim is to optimize water based drilling fluid to perform specific functions relative to oil and synthetic based mud.

II. Materials and Method

The locally synthesized compounds used in this study were obtained from chemistry research laboratory, department of chemistry, University of Port Harcourt. The compounds were extracted, synthesized and characterized from agro-waste material from eastern part of Nigeria. And the products found to satisfy the requirement as potential additive to replace petro-based additive for drilling operation. Industrial grades chemicals for drilling fluid formulation were used, while standard 8-speed Fann viscometer model 800 for testing drilling fluids theology was utilized. The equipment was provided and experiment carried out at MI SAWACO drilling fluid laboratory, Port Harcourt.

2.1 Mud preparation

Potassium chloride/ polymer/glycol fresh water based mud system was formulated using the composition in Tables1 and 2. The formulation followed procedure adopted from (Ikodiya et.al, 2016; Nmegbu and Bakee 2014) and was carried out in accordance with the standard procedure of the American Petroleum Institute-API - 13B-1 (2014) which provides recommended standard test procedure for testing drilling fluids. Seven (7) mud samples were formulated using 350ml to be an equivalent to one lab barrel(350ml= 1lab barrel). And, was designated as; sample A, B, C, D, E, F. G. The additives were added into the mud samples slowly at different mixing times (table1), for better hydration while, stirring and mixing was done with Hamilton beach mixer and allowed to mix for 30 to 40mins to achieve homogeneity (Okorie, et al.,2015; Dardir, 2013).Equal concentration of 2gms per synthesized compound were introduced into the mud samples B, C,D, E, F while, sample A and G, served as "blank or control" in order to investigate the effect of each of the compound on their properties.

2.2 Rheological property test

The rheological property testing of the formulated mud samples was done using 8- speed Fan viscometer model 800. For this study, plastic viscosity, apparent viscosity, yield points were considered and determined by correlating shear rate and shear stress relationship equation 1-4 (Putri et.al, 2015; Okorie, 2015).The determination is important in order to ascertain the suitability and compatibility of the agro-waste liquid derived compound as additives in formulating mud and to check for their sustainability level in maintaining mud flow properties under the study temperature. The testing followed standard laboratory procedure (Ekeinde et.al, 2018; Putri et.al, 2015; Okorie et.al, 2014; MI- SWACO drilling fluid manual).

$$Shear\ rate(s-1) = Speed(rpm) \times 1.7034 \qquad (1)$$

$$Plastic\ Viscosity, PV\ (cp) = 600rpm - 300rpm \qquad (2)$$

$$Yield\ Point, YP\left({}^{lb}/_{100ft^2}\right) = (300\ rpm\ reading) - (Plastic\ Viscosity) \qquad (3)$$

$$Apparent\ Viscosity\ (AV) = {}^{600}/_{2} \qquad (4)$$

Where:

Rpm= viscometer rotor speed

1.703= viscometer sleeve and bob geometry factor

Determination of the gel strength of the mud was also done using the same procedureabove.In this case, the readings were taken after10seconds and 10minutes respectively after due shearing of the fluids, (Hafiz and Abdou, 2003).

Table1:Potassium Chloride/ Polymer/Glycol fresh Water- Based Mud System Composition

Component	**Quantity**	**Function**	**Mixing Time (sec.)**	**Unit**	**Specification for Kcl/polymer/glycol mud**
Fresh water	309.66	Continuous medium as the base fluid		Bbl	
Barite	54.9	Weighting Agent	8	Ppb	
Potassium Chloride	16.3	Shale stabilizers (inhibitor)	5	Ppb	5%
Soda Ash	0.025	Hardness controller	5	Ppb	

Caustic-Soda (NaOH)	0.25	pH Control Agent	5	Ppb	
Poly-Pac-R	1.5	Viscosifier and fluid loss agent	7	Ppb	
Xanthan Gum	1.75	Viscosifier and fluid control	5	Ppb	
Glycol	1.75		5	Ppb	5% v/v

Table 2: Composition of the Locally Synthesized Compound

Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Standard mud	Standard+Cnsl+DEA (1:1)	Standard+Cnsl+DEA (2:1)	Standard + Cnsl + TEA (3:1)	Standard+Cnsl+ TEA (2:1)	Standard+Cnsl+ TEA (1:1)	Standard + lube 156

III. Results and Discussions

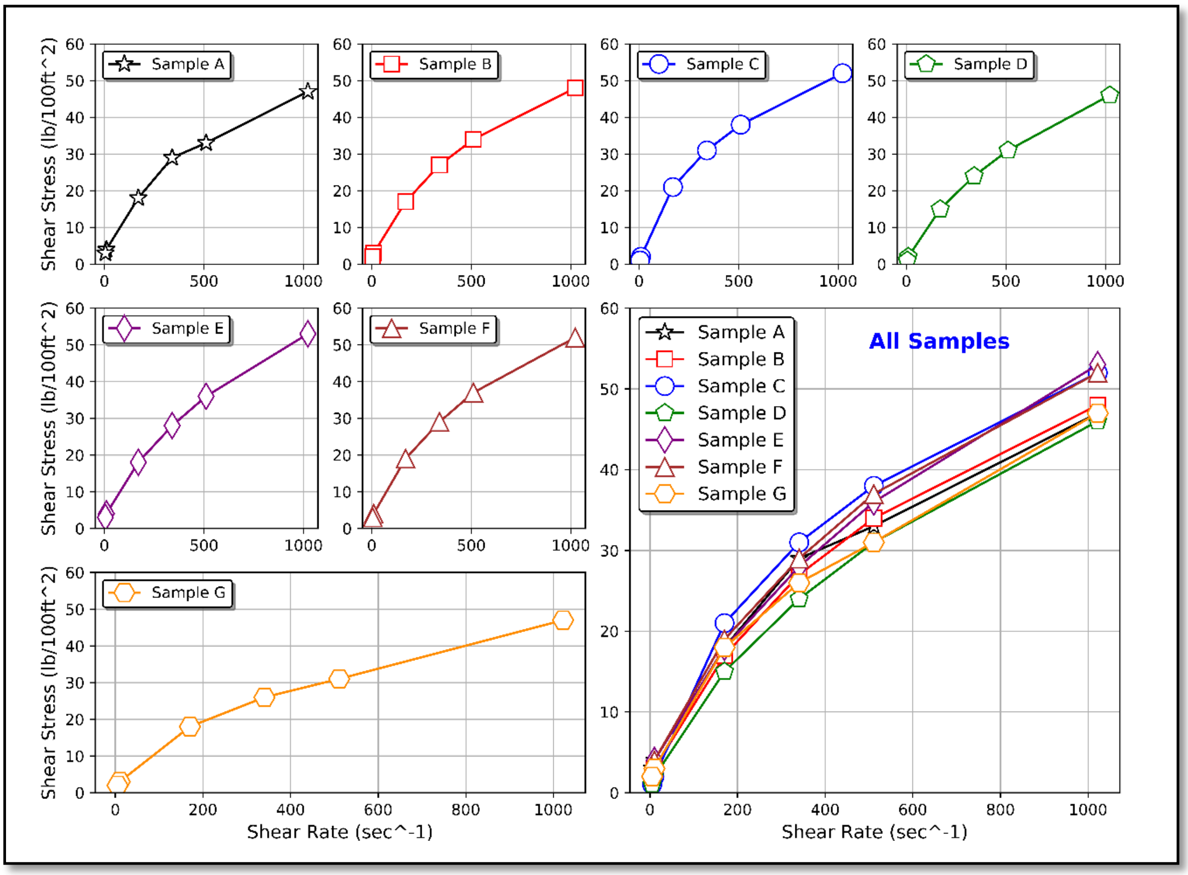

Figure 1: Shear Stress versus Shear Rate for the entire sample at 120°F

From the rheological property test, sample A represents the standard Kcl/Polymer/Glycol mud formulation which served as control for other mud samples formulated with the synthesised compound (table1and 2).The rheological properties were measured at temperature of 120°F using 2g of each of the derived compound to determine their impact on the viscosity of the fluid. The result in table (A1) shows the dial (shear stress) and dial readings for rpm of 600, 300, 200,100, 6 and 3 respectively.

Figure 2 represents plots of plastic and apparent viscosity against composition of different mud samples. The blank sample was observed to have plastic viscosity of 14cp and used as yardstick for other samples. Samples B and C also have the same value of PV (14cp) respectively. Relative differences in the PV were observed with sample D and F with PV of 15cp respectively. Sample E had a PV of 17cp and sample G with PV equal to 16cp.The result showed a good PV values for all samples relative to the blank with slight increase in sample D, E, F, G. at the temperature of interest. The slight increase could be attributed to the chemical content of the compound used as additive in formulating the fluid. Also, the PV values for all samples relative to the reference are an indication of the compatibility of the compounds with the viscosifying agents used in the formulation. The dotted red line in figure 2 served as boundary to show API acceptable and unstable ranges for PV values. Every PV value below 7.5 are not within the acceptable range hence would not be used as drilling fluid whiles, PV values above 7.5 indicate fluid whose PV values were within API acceptable range. All samples used in the study had PV within API acceptable range of 8-35cp at the temperature investigated (Amosa et al., 2010). The moderate viscosity values obtained in the study implies that the drilling a well with a fluid that has the same viscosity behaviour under the study condition of 120°F will continue to flow with minimal pressure, energy losses, and can hold the cuttings to the surface. The result is in agreement with work of Ikodiya, et al, (2016), that opined that drilling fluids with viscosity above desired limit may be exposing the well to property that could cause increased pump pressure due resistance to flow, decrease rate of penetration as well as instability.

Temperature changes affect mud flow property (Dardir, et al., 2013). Increasing the study temperature may change the trend of the PV of the mud slightly. The result may only observe slight decrease in the PV of the mud because of higher temperature resistance capacity and thermal stability of the additives. Additives with higher carbon chain length are known to have higher flash point, good oxidative stability and molecular weight so do not degrade easily(Kania, et al., 2015; Rudnick, 2005).

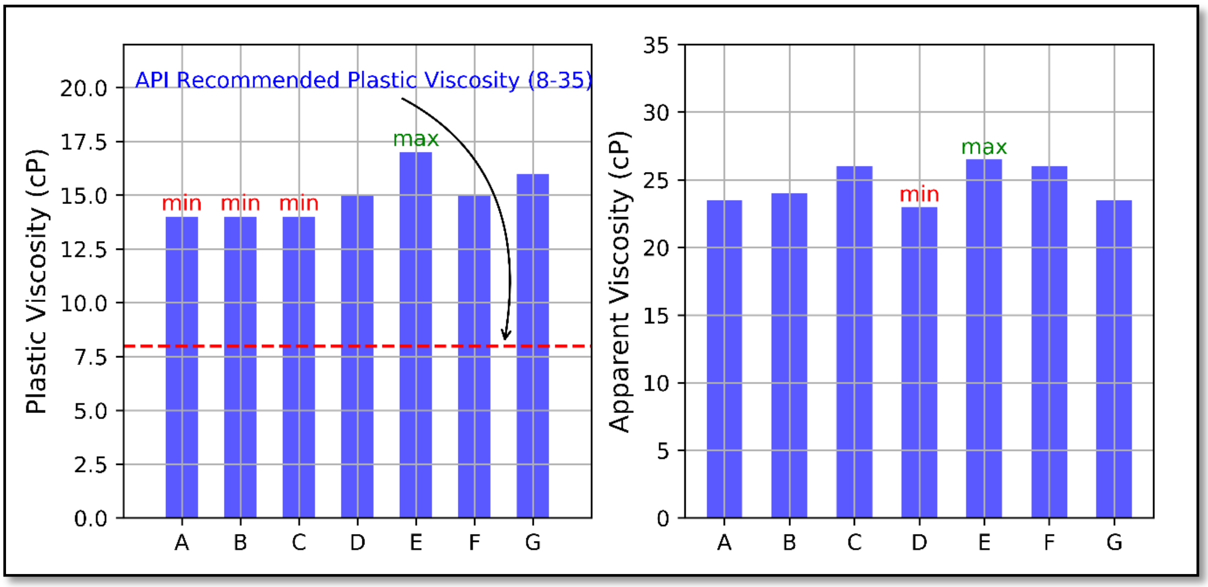

Figure 2: Plastic and Apparent Viscosities of the Samples

The yield points of the mud sample followed the same trend as the PV, see (Fig.3). The reference mud sample gave Yp of 19 Ib/100ft^2. A decrease in YP relative to the blank mud was observed in sample D and sample G. The YP of sample B and C and showed a relative increase from the base mud while no relative change was observed in sample E. The changes are attributed to molecular interactions between solid particles and the chemical constituents of the compounds. Chemical constituents of each the compound was a function of the ratio of the reacting agents during the reaction that produced the compound. YP is function of dispersed particle charges and attractive powers between them under a dynamic condition (Himat et al., 2018). Increasing the concentration of solid material is formulation will increase the YP of the samples. Although, sample D and G showed a negative difference in YP from the reference, YP for all mud samples fell within minimum or maximum acceptablevalues for the temperature condition of 120^{o}F (see table A2) and so could provide a good hole cleaning ability if utilized especially at the annulus where cutting carrying is of great importance(Jorge et al., 2014).

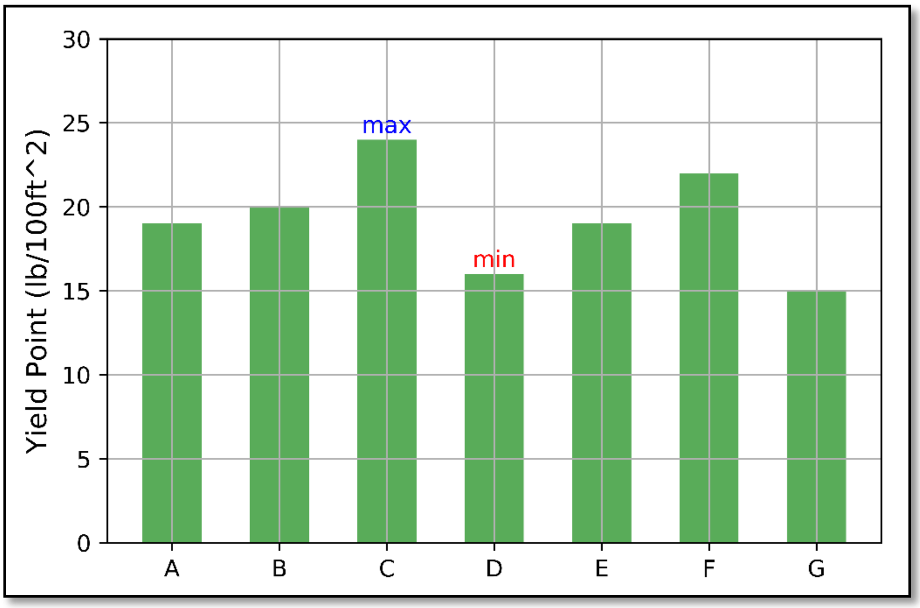

Figure 3: Yield Point of the samples

Gel strength is measure of the lowest shear stress necessary to initiate slip-wise movement of fluid (Dardir, et al., 2013). The strength is developed at static condition and is a function of attractive forces between particles or molecules at this condition. Figure 4 shows the plots of gel strength of the samples at both 10seconds and 10minutes gel time verses temperature of 120^{o}F. The gel strength did not follow any particular trend. For sample A, the 10 sec. and 10mins gel values were recorded as 4Ib/100ft^2 and 4Ib/100ft^{2}respectively.Sample E and F were observed to have 10secs gel time similar to the reference mud but recorded higher values of 5Ib/100ft^{2}respectively for 10min gel than the reference mud. Sample C and D recorded the same value of 2 Ib/100ft^2 10sec gel strength and maintained constant values for 10min. gel. Gel strength for Sample B and G after 10sec was recorded as 3Ib/100ft^{2}which was less compared to reference mud but after 10min, increased to 4Ib/100ft^2 and 4Ib/100ft^2 respectively. The 10 sec and 10min gel time for all samples were within the API recommended range. The values imply that the mud formulation will provide adequate suspension of drill cuttings to reasonable extent when drilling is halted and that a minimal pump pressure will be exerted for flow to be initiated when drilling activity is resumed (Hikmat et al., 2018).Higher values of gel strengths of the mud samples are undesirable since it may cause gelation as a result of flocculation of the particles.

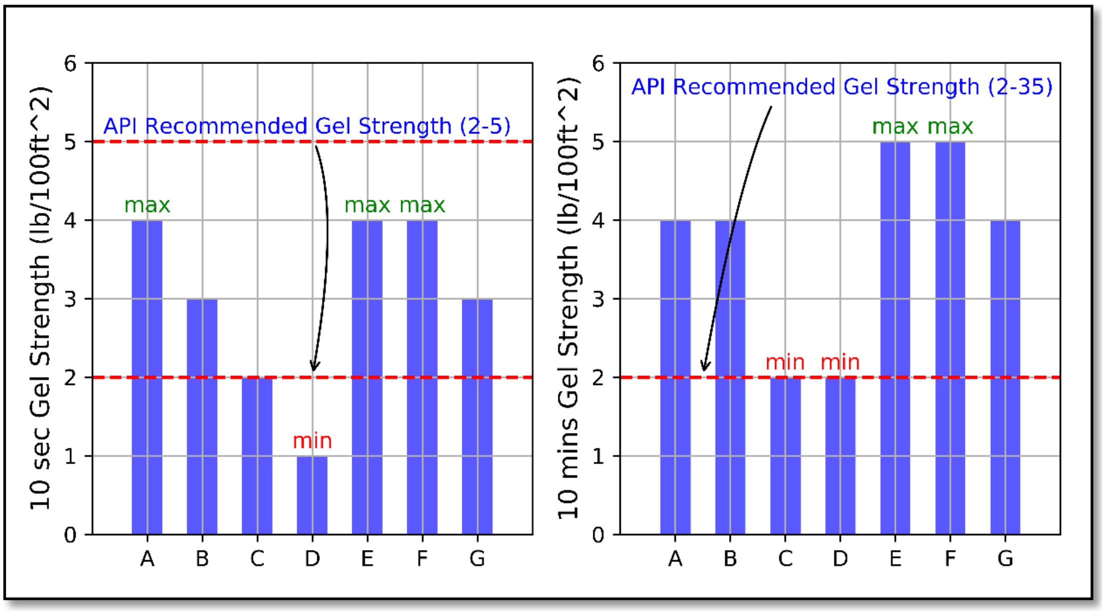

Figure 4: 10 sec and 10 min Gel strength for all samples at 120°F

The performance of these polyesters on the rheological profile of the mud samples compared to the reference or blank sample within the study temperature investigated is attributed to chemical structure and the phenolic materials present in the compound. CNSL has chemical compound made up of phenolic material with longer carbon chain structure having branched alkyl group which allows them to be modified to any desired property for diverse application (Eke, et al., 2019;Damodhar and Ramesh2014).The products were characterized and have the same physical characteristic of biodegradable ester derived from vegetable oil (Kania, et al., 2015; Rudnick, 2005; Amorin, 2011).They have higher flash and fire points, moderate viscosity and molecular weights hence tend to resist early degradation at increased temperatures.

IV. CONCLUSIONS

With numerous laws and restriction on the use of environmental damaging additives for mud formulations, re-evaluation and search for applicable substitutes for currently used synthetic once led to this research. In this study, potential impacts of novel compounds synthesized from agro-waste were tested on the flow properties of standard drilling fluid. Evaluation was done on Plastic Viscosity, gel strength and yield point of different fluid samples investigated at 120°F using 2grams only. The result obtained shows PV, YP for all mud formulations with different values were within API recommended range. These proved that the compounds were compatible with other drilling fluid additives. The PV and YP values connote that mud formed with these natural ester can provide good hole-cleaning and minimal pressure losses. Both the 10 sec and 10 min gel strength values were within acceptable range except for sample D when compared to API standard for water- based mud. It therefore implies that a minimal pump pressure will be required to initiate flow after circulation is re-initiated. The extent to which these compounds impact on the fluids rheology depends on the molecular weight, flash point, structure and concentration of other additives utilized in the formulation hence the different values of PV, YP and GEL. Physical properties and long carbon chain attached to an alkyl structure of the CNSL component used during synthesisled to interaction between the fluid components and product molecules. However, increasing the quantity of basic additives utilized in the formulation will further improve the rheological profiles.

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APPENDIX

A1:Effects of 2grams of the synthesized esters on flow property of the mud samples at temperature 120^0 F

Viscometer (rpm)	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
600	47	48	52	46	53	52	47
300	33	34	38	31	36	37	31
200	29	27	31	24	28	29	26
100	18	17	21	15	18	19	18
6	4	3	2	2	4	4	3
3	3	2	1	1	3	3	2
Gel 10sec	4	3	2	1	4	4	3
Gel 10mins	4	4	2	2	5	5	4

A2: Recommended Values for PV, YP and Gel Strength (Amosa et.al. 2010)

Mud Property	Recommended value
Plastic Viscosity(cp)	8-35
Yield Point (Ib/100ft^2	Min=5 Max=Yp≤ 3(PV)
Gel strength (Ib/ft^2) 10sec.	2-5
Gel strength (Ib/ft^2) 10mins.	2-35

A23: Summary of experimental values for PV, YP and Gel Strength for all mud formulations @120^{o}F

Parameter	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
PV	14	14	14	15	17	15	16
AV	23.5	24	26	23	26.5	26	23.5
YP	19	20	24	16	19	22	15
GEL 10sec.	4	3	2	1	4	4	3
GEL 10m 10 mins	4	4	2	2	5	5	4