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Performance Evaluation of Rheological Properties of Water-Based Mud Using Unripe Plantain, Eggshell, and Corn-Starch

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Abstract

The study employed locally available materials such as dried plantain, eggshell, and cornstarch as additives for water-based mud. The properties of test and control mud samples were evaluated using API standard procedures. The results indicated a slight increase of 0.5, 1.8, and 0.9% in mud density with the addition of 5 and 15g of dried plantain, eggshell, and cornstarch, respectively. The effect of these additives improved the plastic viscosity with an increase of 38.5, 27.3, and 27.4 %, respectively, while remaining within the recommended range at both 30 and 90°C. The yield point of the formulated mud was also enhanced, increasing by 31.4, 26.5, and 40.5 % with 5 and 15g of each additive, respectively. The gel strength of the mud at 10 minutes was found to increase by 19.1, 32.4, and 32.4 %, respectively, while being in the range of 20–36 lb/100 ft^2 at both 30 and 90°C. The response of the formulated drilling fluid was monitored as the temperature varied from 30 to 90°C. The observed changes in mud properties such as increased plastic viscosity and yield point conforming to API standards make these local additives a viable alternative to traditional additives in drilling operatio.

Keywords: *Drilling; Water based mud; Rheology; Eggshell; Corn starch; Plantain Peel.*

1. Introduction

The oil and gas sector heavily depends on drilling fluids, as they are vital to ensuring successful drilling operations. These fluids have a variety of functions, such as holding and removing drill debris, preserving hydrostatic pressure, cooling and lubricating the drill bits, and minimizing the possibility of formation damage. The performance of a drilling fluid is evaluated by several important characteristics, including its density, viscosity, pH, yield point, gel strength, and other rheological aspects [1]. To optimize efficiency, the composition of the fluid must be precisely aligned with the characteristics of the formation being drilled, to avoid formation damage and facilitate the smooth removal of drill cuttings to the surface.

One can consider drilling fluid to be as crucial to wellbore operations as blood is to the human body. To improve the properties of the fluid, locally sourced, inexpensive, and environmentally friendly materials can be utilized in sub-Saharan countries like Nigeria. In African, Caribbean, and Latin American countries, staple foods such as green unripe plantains have high starchy content and offer a range of nutrients, including complex carbohydrates, fiber, and various vitamins and minerals [2]. Also, eggshells which are primarily composed of calcite ($CaCO_3$) makes up between 75-95% of the shell, is readily available and widely used as an agent for weighting, density, and viscosity [3]. Moreso, corn starch derived from maize, which chemical composition contains amylose and amylopectin, exhibits an increase in viscosity and size when heated and is frequently used as a thickener and adhesive in the food and oil industries [4].

These ecofriendly materials are widely available and affordable in parts of Africa, the Middle East, the Caribbean, the Southern United States, and South America. However, many of these locally available additives are often not utilized and treated as waste.

Wastes are discarded materials that are no longer needed, and they result in daily problems that affect both the environment and the health of the general population. The objective for mud engineers is to create a mixture of fluids, clay, and other minerals used in drilling, well casing, and workover operations that is environmentally sound and cost-effective. It is estimated that 25% of total oil field expenses are focused on well drilling exploration and development, and approximately 15-18% of this amount is spent on the use of drilling fluids [5]. Conventional drilling fluids contain additives such as chromium, potassium chloride, potassium sulphate, and polyamines, which are toxic and expensive to use [6]. Thus, it is essential for drilling fluid to be optimized with techniques that minimize the negative impact of chemicals and non-biodegradable materials to promote economic objectives in sustainable development. A sustainable and healthy environment also requires the use of non-toxic materials as substitutes for toxic materials, leading to an increase in the use of water-based mud over oil-based mud.

The duty of a research scientist or engineer is to relate, compare, and improve on experiments previously carried out by other researchers. Many research studies have been conducted on water-based drilling mud. Sarah and Oluwaseyi [7] in a study, compared micronized carboxymethyl starch (CMS) derived from yam, potato tubers, and rice with carboxymethyl cellulose (CMC). The results showed that CMS is a recommended alternative viscosifier to CMC for drilling operations. Rita *et al.* [8] assessed the effects of local natural additives like eggshell and snail shell on the pH and mud weight of water-based mud. It was determined that the combination of an eggshell and a snail shell had a low potential for increasing mud weight and a high potential for enhancing pH. Also, an investigation on the effectiveness of a bio-enhancer with the addition of 3% banana peel as an additive led to an increase in gel strength and the formation of a good filter cake thickness [9]. However, the study also noted an increase in salinity and a decrease in calcium content of 6.5%. Furthermore, in the study conducted by Akintola *et al.* [10], the author compares the impact of various chemically modified local starches on the properties of water-based drilling fluid, including rheology and fluid loss. The results showed that as the temperature increased, the effective viscosity, plastic viscosity, and yield point decreased. Despite this trend, the use of chemically modified local starches led to improved filtration and rheology properties of the drilling mud.

The purpose of this study is to determine if locally sourced and cheap materials like unripe plantain, eggshells, and corn starch can be used to make water-based drilling fluid when combined with Bentonite and barite, which are readily available in Nigeria. To meet this objective, the plan is to create drilling fluid using various local additives, examine the physical and chemical properties of the fluid, evaluate its effectiveness, and compare it to regular additives used for pH enhancement, viscosification, and weighting.

2. Experimental section

2.1. Materials

The study used the following materials to test for the mud weight and rheological properties of the drilling fluid, namely: bentonite, barite, water, unripe plantain peel, eggshell powder, and corn starch.

2.1.1. Unripe plantain peel powder

Unripe plantain peels were procured from a local market in Lagos, Nigeria. The plantain peels were sun dried for about 5 days in other to remove its moisture content.

The calculated moisture content of plantain peel: M_1= wet plantain peel =3.5 kg; M_2= dried plantain peel= 0.56 kg; moisture content removed = M_1 - M_2 = 3.5-0.56= 2.94 kg. The removal of moisture content was followed by a breaking down of the plantain peel to increase its surface area using an electric grinder and pulverized using a 250mm sieve. The powered plantain peel was stored in a clean, dried, airtight container.

2.1.2. Eggshell powder

The eggshells were procured from a local market in Nigeria. The eggshells we sun dried for about 3 days in other to remove its moisture content, and for effective grinding. It was then pulverized using 250mm sieve and transferred into an airtight container for storage.

2.1.3. Corn starch powder

Corn seed was first peeled and soaked in water overnight, then blended. This was followed by sun drying for 5days and sieved into a 250-micron size particle. The corn starch powder was stored in a clean, dry, airtight container.

2.1.4. Drilling mud sample

The controlled drilling mud sample was formulated using the constituents from Table 1 without the additives. Table 1 also shows the high and low values of the base formulation and additives used for this experiment.

Table 1. High and low values of the weight of the additives.

Constituents	Low values	High values
Bentonite (g)	15	15
Barite (g)	70	70
De-ionized water (mL)	350	350
Egg shell (g)	5	15
Corn starch (g)	5	15
Dried okro (g)	5	15
Temperature (°C)	30	90

2.2. Methods of analysis

2.2.1. Design of experiment

Based on this study we employ formulation, selection, analysis and visualization of data gotten from the experimental procedure using a software called MINITAB. A Fractional factorial (partial combination) was carried out using this tool. The factors varied includes dried plantain, eggshell, corn starch, and temperature for enhancing the mud weight rheological properties.

2.2.2. Mud density determination

The recommended API standard was followed in the preparation and determination of mud weight (API RP 13B–1, 2019) [11]. The test procedure was followed while testing for mud density using Fann mud balance. Fresh water was used for calibration which must give 8.2lb/gal- 8.3lb/gal. The cup was filled with mud sample to the brim and tapped to remove any dissolved air bubble in the mud. The lid was replaced and rotated until it is seated firmly, making sure some mud vented out of the hole on the lid. The mud was cleaned from the exterior of the balance and the mud balance was placed on base with its knife edge resting on the fulcrum. The rider was moved until a balanced instrument is gotten, as plumed by the spirit level. Mud weight and hydrostatic pressure/gradient at the rider edge fulcrum was measured and recorded.

2.2.3. Rheological measurements

The rheology measured includes plastic viscosity, yield point, and gel strength at 10 minutes. A multi-speed rheometer or viscometer was used to measure the mud viscosity. The prepared water-based mud is poured into a stainless cup and place on a base like plate under the rotor sleeve, which is immersed in the mud at the scribed line and held firmly by tightening the lock screw on the right leg of the rheometer. The mud was subjected to a rotation speed of 600 and 300RPM respectively. At each rotation speed, the dial reading was taken at the time the rotation speed was stabilized. This process was repeated for all other prepared mud samples.

2.2.4. Procedure

A preliminary experiment which encompasses the control mud samples and the final experiment which varies the mass of dried unripe plantain, eggshell, and corn starch at 5 and

15g as seen in table 1 was investigated. A factorial experiment of sixteen mud samples, varying the combination of dried plantain, eggshell, and corn starch at 5 and 15g was investigated at temperatures of 30°C and 90°C. The corresponding mud weight, and rheological properties were measured and recorded. Figure 1 shows the experimental procedures to formulate the drilling fluid samples. The results of the local additives on the mud rheology were compared to the standard API values as seen in Table 2.

Table 2. API standard numerical value requirement for drilling fluids.

Parameter	Numerical value specification
Mud Weight (lb/gal)	8.65 -9.00
Viscometer dial reading @600rpm	30cP
Plastic viscosity (cP)	8 – 10
Yield point (Ib/100ft2)	3 x plastic viscosity
Fluid loss (water)	15.0ml maximum
pH level	9.5min – 12.5max
Sand	(1 - 2)% maximum
Screen analysis	4 (maximum)
Moisture content	10% (maximum)
Ca 2+ (ppm)	2.50 (maximum)
Marsh funnel viscosity	52 – 56 sec/q+
Mud yield (bbi/ton)	91 (maximum)
API filtrate (ml)	30 (minimum)
Montmorillonite	70 – 130
Vermiculite	100 – 200
Illite	10 – 40
Kadinite	3 – 15

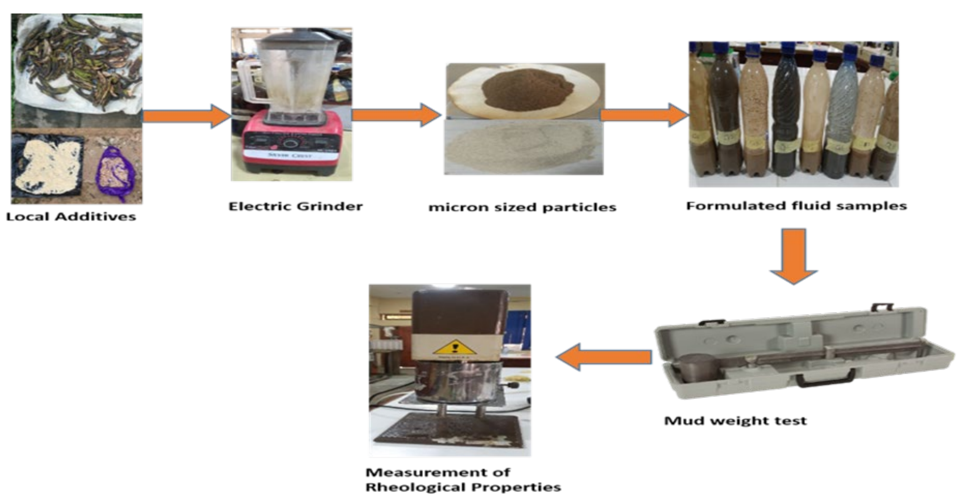

Figure 1. Experimental steps of drilling fluid preparation.

3. Result and discussion

The examination of the mud density and other rheological characteristics of the mud samples made from unripe plantain peel, eggshell, and corn starch at different temperatures was performed. The results were presented and analysed. A statistical design known as a factorial design was used with the help of MINITAB software to visualize the impact through Pareto plots, main effect plots, and interaction plots.

Table 3 presents the findings for the controlled mud sample prior to introducing local additives. The research was conducted at 30 and 90°C at which mud weight ranged 8.85 to 9.3 lb/gal. The plastic viscosity measured 5 and 7 cP, yield point gave 34 and 14 lb/100ft^2 while gel strength measured 30 and 11 lb/100ft^2 respectively.

Table 3. Results for controlled mud samples.

S/N	T	M	Viscosity @ 600rpm	Viscosity @ 300rpm	P	Y	G
	oC	lb/gal	cP	cP	cP	lb/100ft^2	lb/100ft^2
1	30	8.85	44	39	5	34	30
2	90	9.3	28	21	7	14	11

3.1. Effect and significance of unripe plantain peel, eggshell and corn starch on mud density

Figure 2 depicts the main effect plots showing how each factor affects the density of mud individually. When the quantity of dried plantain (DP) was raised from 5 to 15 g, the average mud density increased from 9.15 to 9.2 lb/gal, resulting in approximately 0.5% increase. The results showed both eggshell and corn starch followed a similar pattern, where the average strength of the mud density increased by 1.8% for eggshell from 9.13 to 9.3 lb/gal and by 0.9% for corn starch from 9.14 to 9.22 lb/gal. The rise in temperature from 30 to 90 ^oC resulted in increase in mud weight from 8.8 to 9.5 lb/gal, representing a 7.4% increase. Therefore, temperature was a contributing factor to the change in mud weight in the presence of the additives added. The findings indicate that the mud weight was affected by a minimal impact at the incremental change in temperature and other local additives added. However, the mud density remained within the range of 8.65 to 9.6 lb/gal, as specified by the API standard for mud density. One can infer that by increasing the weight of additives or carefully combining them in specific ratios, it is possible to achieve the necessary hydrostatic pressure in the wellbore that is essential for maintaining stability during drilling activities thus avoiding the collapse of the formation.

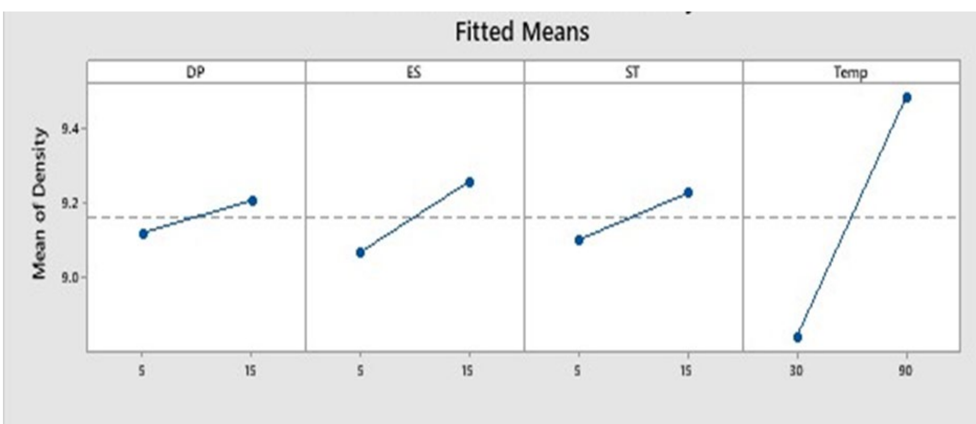

Figure 2. Main effect plot for mud density.

3.1.1. Interaction effect on mud density

Figure 3 shows the effects on mud density based on the interaction between each factor. The plots between eggshell and temperature (ES*T), corn starch and temperature (ST*T), and dried plantain and eggshell (DP*ES) were parallel, signifying no interaction between them. However, the combination of eggshell, temperature, corn starch, and dried plantain reveals an observable interaction effect between dried plantain and corn starch (DP*ST), eggshell and corn starch (ES*ST) and dried plantain and temperature (DP*T) as the line plots were not all parallel. As DP increased from 5 to 15 g along with 5g of corn starch, there was a 3.1% increase in mud density while further increase to 15g, yielded 0.3% slight decrease in mud density. In the same way, when the mass of the eggshell was increased from 5 to 15 g, there was a minimal impact on the density of the mud at both 5 and 15g of ST of about 2.0 and 1.6 % respectively. The relationship between DP and temperature is interactive, with a negative effect observed at 30°C as DP increases from 5 to 15 g, and a positive impact seen at 90°C as mud density increases from 9.3 lb/gal to 9.6 lb/gal. Based on the main effect and interaction plot, it can be inferred that ST has a stronger interaction effect with other local additives in changing mud density compared to other additives. Specifically, the combination of DP*ST and ES*ST gave an interactive effect with mud density within the API standard range of 8.65-9.0 lb/gal.

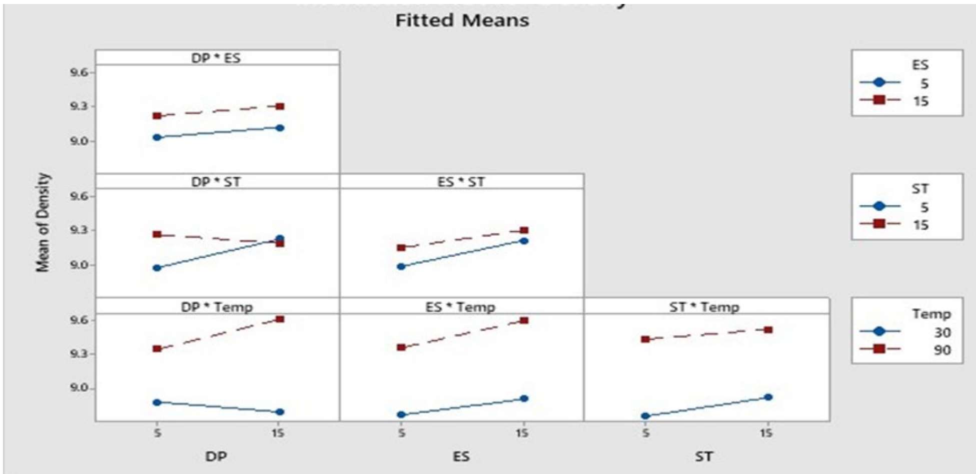

Figure 3. Interaction plot for mud density.

3.2. Effect and significance of unripe plantain peel, eggshell and corn-starch on plastic viscosity

Figure 4 shows the effect on plastic viscosity as DP, ES and ST changes were positively affected by increasing the amount from 5 to 15 g and temperature from 30 to 90 ºC. This resulted in an increase of approximately 61.8, 40.0, and 40.0 % respectively. These results indicate that the local additives have a significant impact on plastic viscosity, and using a combination of these additives in water-based mud can thus enhance drilling efficiency by improving drill bit penetration and hole cleaning.

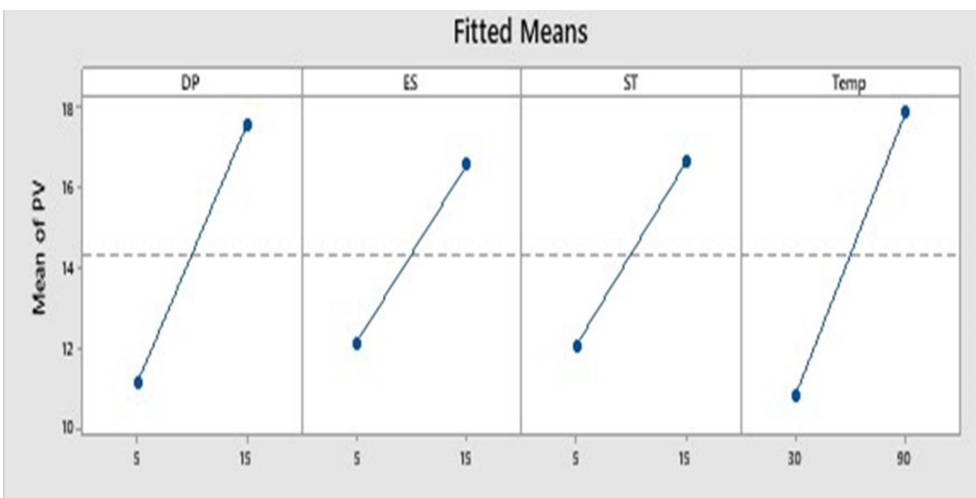

Figure 4. Main effect plot for plastic viscosity.

3.2.1. Interaction effect on plastic viscosity

According to Figure 5, there is an interaction between local additives DP*ES, DP*ST, and ES*ST, which affects the plastic viscosity. Increasing DP from 5g to 15g resulted in a 40% and 83.3% increase in PV when interacting with 5g and 15g of eggshell, respectively. When DP interacted with ST, the PV increased by the same percentage as ES. The combination of ES and 5g of ST had almost no significant effect on PV but increasing ST to 15g resulted in a 53.8% change in PV. This means that the presence of ST in combination with ST*ES caused a positive effect on PV. Moreover, increasing the temperature from 30^{o}C to 90^{o}C with DP interaction caused a significant change of about 100% in PV. Based on the interaction plot and main effect plot, dried plantain, eggshell, and corn starch are suitable combinations that meets the API standard of plastic viscosity.

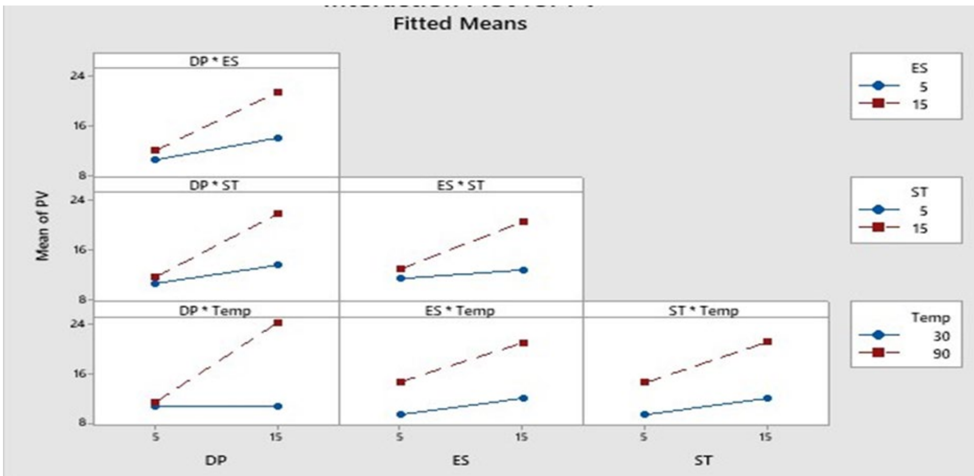

Figure 5. Interaction plot for plastic viscosity.

3.3. Effect and significance of unripe plantain peel, eggshell and corn-starch on yield point

Figure 6 displays the specific influence of each factor on yield point. Increasing the amount of dried plantain, eggshell, and corn starch from 5 to 15 g resulted in a 45.8, 36, and 68.2 % increase in mean strength, respectively, from 24 to 35 lb/100ft^2, 25 to 34 lb/100ft^2, and 22 to 37 lb/100ft^2. Temperature also had a significant impact on yield point, with a mean strength of 39 lb/100ft^2 at 90°C, and approximately 20 lb/100ft^2 at 30°C, which represents a 95% increase. This reflects the mud's ability to transport cuttings to the surface. Higher yield point values than that of plastic viscosity are directly linked to greater frictional pressure loss.

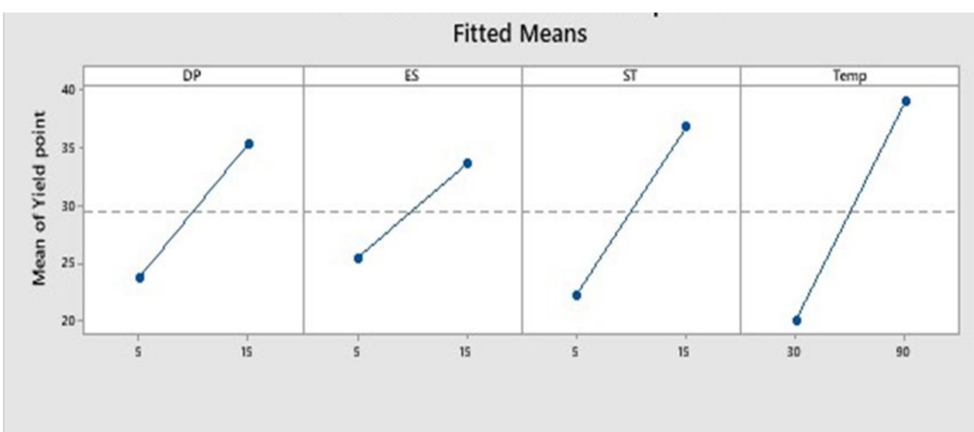

Figure 6. Main effects plot for yield point.

3.3.1. Interaction effect on yield point

Figure 7 displays the strong interactive effect between dried plantain, eggshell, corn starch and temperature on yield point. For interaction between dried plantain and eggshell, as mass of dried plantain increases from 5g to 15g, the effective change in yield point for eggshell at 5 and 15g are 14.6% and 93.7%, respectively while corn starch is approximately 15.8% at 5g, and 68.2% at 15g. For the interaction between eggshell and corn starch, no significant change was observed when eggshell was increased to 15g, but a significant change of approximately 58% was observed when corn starch was increased to 15g. This suggests that corn starch possesses interactive effects when combined with eggshell on yield point. Moreover, temperature had a significant interactive effect on each additive. At 30°C, the yield point was constant at 20lb/100ft^2 for each additive, while at 90°C, there was an increasing effect of 81.8, 48, and 143.2 % for dried plantain, eggshell, and corn starch, respectively. This indicates that corn starch has the highest effect on yield point when the temperature is increased.

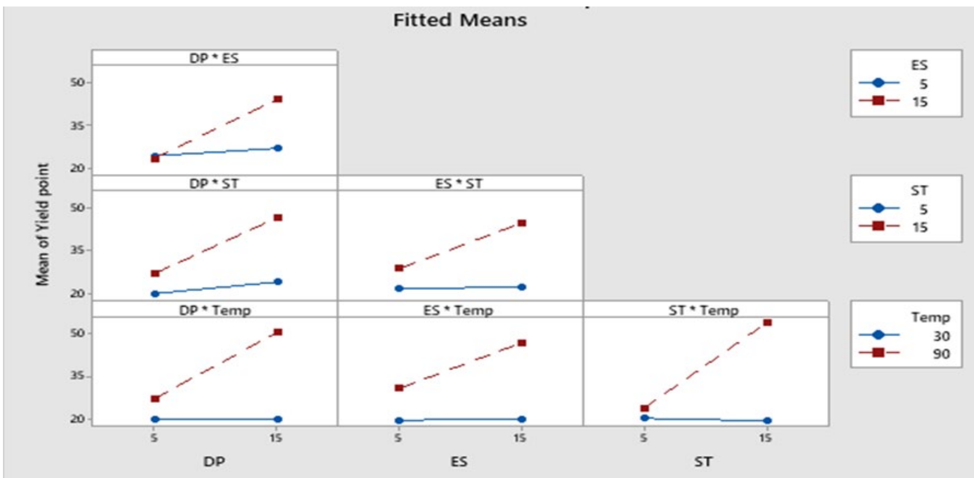

Figure 7. Interaction plot for yield point.

3.4. Effect and significance of unripe plantain peel, eggshell and corn-starch on gel strength

Figure 8 shows that increasing the amount of DP, ES, and ST from 5 to 15g had a positive and significant impact on gel strength, resulting in changes of 22.7, 33.3, and 33.3 % respectively. The gel strength was highest at 90°C, with a value of 38 lb/100ft^2, compared to 21 lb/100ft^2 at 30°C, representing an increase of 81.0%. When combined appropriately in WBM under standard and reservoir conditions, the study found that the formulations could effectively suspend cuttings for up to 10 mins when drilling stopped, preventing them from settling at the wellbore bottom or causing pipe sticking during static drilling operations.

3.4.1. Interaction effect on gel strength

The impact of additives on gel strength at 10 mins, as presented in Figure 9, was affected by the interaction of DP and ST. An increase in DP from 5 to 15 g resulted in a negative slope on GS for 5g of ST, but when the mass of ST increased to 15g, an increasing slope of gel strength was observed, with approximately 66.6% increase. However, DP*ES and ES*ST did not show any interactive effect on GS at 10 mins. The temperature had an interactive effect on gel strength for ES and ST additives. With an increase in temperature from 30 to 90 °C, the effective change in gel strength for 5 to 15 g for ES, and ST was 26 and 27 lb/100ft^2 respectively. The interaction plot combined with the main effect plot indicates that the combination of dried plantain, eggshell, and corn starch satisfies the API standard of gel strength when used in the appropriate formulation in WBM at standard and reservoir conditions to prevent cuttings from settling during drilling.

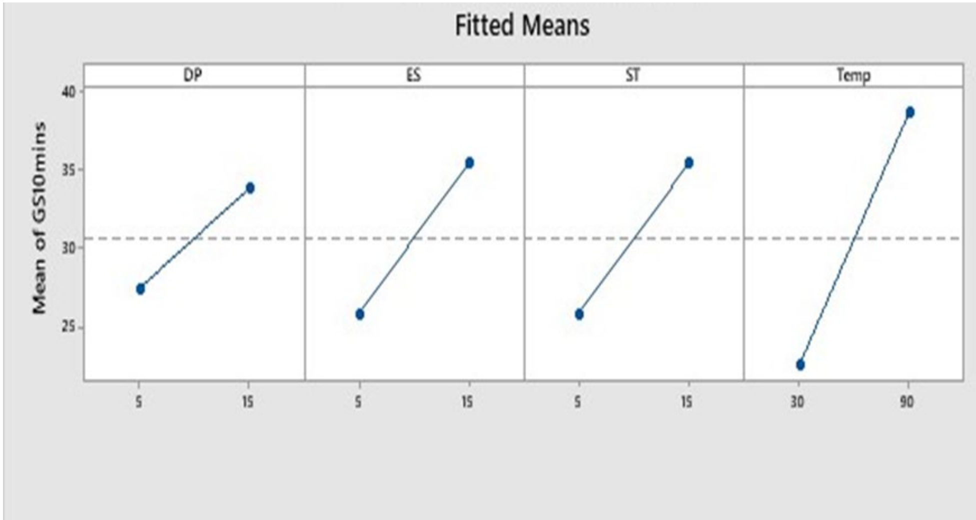

Figure 8. Main effect plot for gel strength@10mins.

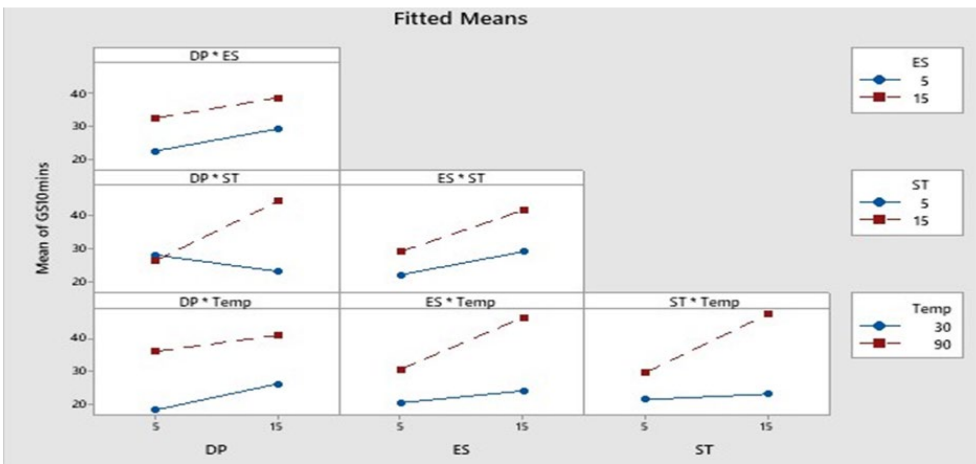

Figure 9. Interaction plot for gel strength @10mins.

4. Conclusion

The effect of the mud density and rheological properties on the water-based drilling fluid was experimentally investigated. Based on the experimental data and analysis, the following conclusion were drawn.

The effect of dried plantain, eggshell, and corn starch gave a minimal change in mud density stable at elevated temperatures. The interactive effect of dried plantain with eggshell and corn starch shows it is a good viscosifier. This increased with plastic viscosity.

The combination of dried plantain and corn starch gave a positive interactive effect on gel strength. The formulated drilling fluid can thus effectively transport cuttings while preserving its structural stability under downhole pressures. Dried plantain, eggshell, and corn starch gave a positive significant effect on yield point. However, corn starch gave the highest effect with temperature increase. Implementation of these additives on drill sites will help provide a sustainable economy in Nigeria; eradicating biomass deposition and improving a non-adverse and healthy environment for humans, animals and nature.

5. Recommendation

We recommend further analysis of additives used in this work using an ageing cell to examine the stability of the rheological and filter loss properties at bottom hole conditions. Thus, a comparative study at high temperature high pressure (HPHT) analysis of the mud samples is considered. Further tests should also be conducted based on salt and sand content analysis.

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