Petroleum and Coal

Article **Open Access**

Evaluation of the Impact of pH on the Rheological Property of Drilling Fluid Formulated with *Mucuna flagellipe* and *Brachystegia eurycoma*

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Received August 1 2020; Revised November 21, 2020; Accepted December 11, 2020

Abstract

Hole cleaning remains a key parameter in all drilling program. The design of the drilling mud (DM) is therefore necessary for efficient and effective transportation of drilled cuttings from the bottom hole to the surface. The rheological properties play significant role in DM performance. In this work, experiments were conducted to study the impact of pH on mud rheology. Water-based drilling muds (WBDMs) were formulated with Poly anionic cellulose regular (PAC-R), *Mucuna flagellipe* and *Brachystegea eurycoma* at different pH values. The PAC-R was used as a base mud. Mud rheological properties like low shear yield point (LSYP), yield point, plastic viscosity (PV) and gel strength were determined. Results show that for the *Mucuna flagellipe* drilling mud, LSYP decreased from 17.4 to 2.9 Ib/100ft^2, PV decreased from 70.8 to 35.4cp while yield point decreased from 93.4 to 24.5 Ib/100ft^2 while for the *Brachystegia eurycoma* DM, LSYP decreased from 11.8 to 1.8 Ib/100ft^2, PV decreased from 45.7 to 15.9cp while the yield point decreased from 54.3 to 14.7 Ib/100ft^2. Also the 10-seconds gel strength of Mucuna flagellipes mud decreased from 19 to 6 lb/100 ft^2 when the pH was increased from 6 to 12, that of 10-minutes gel strength for *Mucuna flagellipe* mud decreased from 37 to 6 lb/100 ft^2 when the pH was increased from 6 to 12 and that of 30 minutes gel strength of the same mud decreased from 62 to 6 lb/100 ft^2 when the pH was increased from 6 to 12. For the *Brachystegia eurycoma* mud, the values of the 10-seconds gel strength also decreased from 13 to 3 lb/100 ft^2 when the pH was increased from 6 to 12. The values of the *Brachystegia eurycoma* mud gel strength for 10-minutes decreased from 26 to 3 lb/100 ft^2 when the pH was increased from 6 to 12 while that of 20 minutes gel strength also decreased from 42 to 3 lb/100 ft^2 when the pH was increased from 6 to 12. Similar trend was observed for the PAC-R mud in all the cases tested. At the pH of 12, it was observed that the muds will not be able to lift cuttings due lower yield point. The results obtained in this study show the significant impact of pH on the rheological properties of drilling mud. The changes in the rheological properties at different pH scenarios are attributed to the changes in nanostructure that occur at the particle surfaces and plates of the DM.

Keywords: *Rheological properties; Drilling fluid; wellbore; Mud performance; pH effect; Cutting transport.*

1. Introduction

The energy of any country is dependent on the extent of producible and unproduced oil and gas reserves as well as other natural resources [1]. These reserves are produced via drilling. Drilling is the process of creating a passage for the discovered hydrocarbon reserve to be produced at the surface [2] Drilling is the process of creating a passage (hole) that enables the discovered hydrocarbon to be produced at the surface. It involves the penetration of the earth's crust to thousands feet where the hydrocarbons are deposited in the reservoir by means of rotary drilling process [2-3]. Rotary drilling process utilizes drilling fluid which performs series of functions during drilling operation. Drilling fluids (DFs) are heterogeneous mixture of chemical(s), water or oil and clay materials [2,4] that help to transport drilled cuttings from the wellbore to the surface [2,4-5]. One of the most important functions of DFs is to reduce the amount of DF filtrate that enters the hydrocarbon bearing formation which can cause damage to the formation due to changes in rock wettability, fines migration, plugging of DF solids and eventual incompatibilities in the formation water chemistry [6-7]. Almost all the problems encountered during drilling operations are directly or indirectly associated with DF properties [8-12]. Rheological properties of DFs are important because they are utilized for DF property characterization such as hole cleaning, erosion preservation, removal of drill cuttings, and pump system. They are also used to design and evaluate wellbore hydraulics and assess the performance of drilling fluids [7,13]. The rheological principles can be used to determine the dynamic performance of a DF behaviour in solving problems of cleaning hole, suspension of cuttings, The success of any drilling operation is largely dependent on the performance of the DF used [14-15]. Thus, optimum selection of DF is a important factor in reducing drilling time and cost [12,16-17]. Due to cost, environmental concerns, water-based drilling fluid (WBDF) is generally preferred and attractive option than oil and synthetic fluids for oil and gas well drilling especially in sensitive areas where oil base fluids are undesirable. The development of high performance and very high environmentally friendly water base fluids [12,17] with the lowest possible amount of pollutants [7] are desirable [17]. Care therefore should applied in the selection and preparation of raw materials employed in drilling mud formulation. In recent times, various naturally derived biopolymers (e.g. starch), synthetic, and/or modified (e.g. carboxymethyl cellulose or CMC) polymers, are used in order to control the fluid loss and viscosity of drilling fluids [7]. In oil-drilling, these polymers reduce filtration into permeable formation, stabilize shale and thus promote hole stability, form a thin filter cake of low permeability, reduce drag, and ultimately increase hole cleaning capability [18-19]. They give the proper rheological and filtration control properties. The influx of the liquid phase commonly called filtrate into productive zones can cause a serious reduction of permeability with attendant decrease in well productivity [7,20]. The incorporation of natural biomaterial in DFs compositions is necessary to control this phenomenon [7].

Several researchers have worked on polymers and their use in water-based drilling [15,21-23]. Different natural polymers such as soy protein isolate, starch, Guar gum, cellulose derivative and Xanthan gum, and have been utilized to improve the rheological and filtration performances of water based muds [24-28]. Darley *et al.* [15] investigated the use of polymers such CMC, guar gum and hydroxypropyl starch as filtration control agents and also as viscosifiers in DMs. They reported that filtration parameters such as diffusivity and sorptivity of these polymers are temperature dependent. Sorptivity measures the resistance against the fluid flowing when it passes through the filter cake while diffusivity measures the fluid flow rate [29]. Schizophyllan has been reported to exhibit high viscosity at low concentrations. In comparison with other biopolymers, Scleroglucan is thermally more stable, highly tolerance to divalent and trivalent cations like Ca^{2+}, Fe^{3+} and Mg^{2+} and has excellent carrying capacity characterizes. However, at high temperature, it is very sensitive to chemically reactive additives AWA geological formations [30]. Huang *et al.* [31] carried out a research on Surface chemistry and API bentonite DF rheological properties: yield stress, pH effect, ageing behaviour and zeta potential. In their research, they showed that at low pH, bentonite slurries gave unusual rheology. They reported that viscosity and yield stress of the DF utilized in their study displayed low values at low pH, and at pH of 9, with viscosity and maximum yield stress obtained. Akinade *et al.* [32] in their study showed that bentonite clay required extra improvements to be utilized in DFs to give a mud with optimum filtration and rheological properties as API standards. Li *et al.* [33] in their study concentrated on the effect of pH on bentonite WBDM with chitin nanocrystals as DF modifier. Their research showed that the mud rheology improvement was noticed with pH change from neutral to acidic, and this could result in corrosion of the tubular.

Many indigenous natural polymers are now used to modify rheological properties of clay suspension and, these polymers are environmentally friendly [34]. The common challenges experienced are low gel strength, excessive fluid loss and the necessity to formulate a mud with the desired rheological properties to withstand the increasing temperature and pressure conditions [1,30]. Considering the environmental effect, economics and sustainability of these biopolymers, their use is highly recommended [30,35-36]. In this work natural biopolymers (*Mucuna flagellipe* and *Brachystegia eurycoma*) were examined experimentally to investigate the impact of pH on the Rheological behaviours of DF formulated with these natural biopolymers. Two different DM formulations were proposed from natural biopolymers and the effect of pH on the rheological behaviours of these muds were ascertained.

2. Methodology

2.1 Preparation of samples

The natural biopolymers used for this work were collected from the Niger Delta region of Nigerian. The seeds of the biopolymers are *Mucuna flagellipe* (ukpo) *and Brachystegea eurycoma* (achi) as shown in figures 1 and 2 respectively. The seeds were extracted by removing the thick bark of the fruit and the pulp was scrapped off using a spatula. The various seeds were blended into fine powder with aid of an electric blender. The grinded seeds were dried in a roller oven at 125°F for 6hours and again re-grinded. The coarse powdered materials were sieved using an 80microns sieve until fine powder was obtained. The powder obtained from the seeds were weighed which was used additive for the water based mud formulation. Rheological data utilized for samples calculations were gotten using Fann viscometer Model 35 and the readings were obtained at 600, 300, 200, 100, 6 and 3 rpm using the standard API guidelines.

Figure 1. *Mucuna flagellipe* (ukpo)

Figure 2. *Brachystegea eurycoma* (achi)

2.2. Drilling mud samples formulation

Three (3) mud samples (A, B and C) were formulated with the additives concentration constant (8g) while the pH varied (6, 8, 10 and 12). The compositions of the different samples of mud are depicted in tables 1, with the next pH variation being 8, 10 and 12 respectively. The mud comprised of water which represents the base fluid, bentonite used as viscosifier, caustic soda used to control the activity of water, barite used as weighting agent, PAC-R, *Mucuna flagellipe* and *Brachystegia eurycoma* were used as viscosifiers. The pH was controlled by increasing the quantity of caustic soda [NaOH] of the mud with nitric acid (HNO_3) also added not to cause excessive dilution in order to reach the pH value desired.

Table 1. Composition of formulated Water Based Mud samples with 8g of Natural Biopolymer as additive

Additives	Sample A	Sample B	Sample C
Water, (mL)	340	340	340
Caustic soda, (mol/L)	9.32	9.32	9.32
Nitric Acid, HNO_3, (mol/L)	5	5	5
Soda ash, (g)	0.25	0.25	0.25
Bentonite, (g)	10.2	10.2	10.2
PAC R, (g)	8.0	-	-
Mucuna flagellipe, (g)	-	8.0	-
Brachystegia eurycoma, (g)	-	-	8.0
Barite(g)	65	65	65

2.3. Laboratory procedure

2.3.1. Mixing procedure for drilling mud samples formulation

350mLs of drilled water was measured with soda ash of 0.25g added to pre-treat the water to get rid of any hardness. 10.2g of bentonite was then added to the pre-treated water and the bentonite slurry sheared for 20 minutes, thereafter allowed to static yield for 12hours. After allowing for Pre-hydration for 12hours, the slurry of bentonite was then subjected to agitation with 9.32mol/L of caustic soda added to the bentonite slurry and the whole formulation mixed for 2minutes with nitric acid (HNO_3) also added not to cause excessive dilution of the mud in order to achieve the desired pH of 6. Thereafter, 8g of Pac- R was also added and mixed for 2minutes. Finally, Barite of 65g was added and allowed for agitation for 20minutes. The above stated procedure was repeated to obtain mud sample of pH 8, 10 and that of 12 for Pac-R. The mixing was carried out at medium speed using Hamilton Beach mixer and the total mixing time for the mud formulation was 30minutes. The same procedure for mixing Pac R mud (Sample A) was also employed for samples B and C respectively at pH of 6, 8, 10 and 12 respectively as the case be for each mud preparation.

2.3.2. Mud density determination

Measurement of the mud density was carried out with the mud balance. The mud density of each formulated mud was read at the edge of the left hand of the sliding weight and the readings were recorded. The measurement of the mud density was carried out at ambient conditions.

2.3.3. Determination of mud sample pH

The pH test is a test carried out to measure the concentration of hydrogen ions in the aqueous solution. This is carried out using the pH meter and the measurement must be carried out after calibration. The probe of the pH meter was placed in the DM sample and the reading was taken after the stabilization of the needle. The probe was then washed clean before it was used again.

2.3.4. Gel strength determination

The gel strength is a property that describes the attractive forces of the mud while it is static. It is the capability of that mud to ensure that the drilled cuttings are held in suspension peradventure the circulation stopped. It is described as the stress needed to keep the mud moving. Gel strength measurement is carried out using the viscometer. The initial gel strength was taken at 10seconds and subsequently at 10 minutes and then 30minutes by placing the nub at 3rpm. These measurements were taken in a static condition. The procedure was carried out for all the formulated mud samples.

2.3.5. Rheology test

The rheological properties of the formulated mud were determined using Fann 35 viscometer. The viscometer was first calibrated, thereafter the rheological properties of the formulated mud was taken. The mud was then heated to 180°F with a thermo-cup and at the attainment of 180°F, viscometer nub was placed on 600, 300, 200, 100, 6 and 3rpm and the rheological parameters were taken at these readings respectively while the dial readings were taken and recorded at intervals. The test procedure stated above was repeated for mud samples B and C respectively at different pH. At the end of the rheology test, the rheological properties of the mud were computed from the test data as stated below:

$$Plastic\ Viscosity\ (PV) = 600rpm\ reading - 300rpm\ reading$$

$$Yield\ Point (Ib/100ft^2) = 300rpm\ reading - PV$$

Applying the Herschel-Bulkley model, the low-shear yield point (LSYP) was calculated as [42]:

$$LSYP = 3R_e - R_6$$

where: R_e is the viscometer reading at 3rpm; while R_6 is the viscometer reading at 6rpm.

3. Results and discussions

In this study, three water-based drilling mud samples at different pH with viscosifiers as Pac R, *Mucuna flagellipe* (Ukpo) and *Brachystegea eurycoma* (Achi), were tested to ascertain the impact of pH on the rheological behaviour of these muds.

3.1. Mud density

From Figures 3, 4 and 5, the mud density remained constant at 9.8 ppg for Pac-R mud, 8.9 ppg for *Mucuna flagellipe* mud and 6.4 ppg for *Brachystegea eurycoma* mud respectively as pH increased from 6 to 12. Pac-R mud had the highest mud density of 9.8 ppg, followed by that of *Mucuna flagellipe* of 8.9 ppg and finally *Brachystegea eurycoma* mud of 6.4 ppg. It is evident from Figures 3 and 4 that DM formulated with 8g of *Mucuna flagellipe* had as good mud density as that of Pac-R mud. DF density is usually the first barrier against well kick and significantly contributes to the stability of the wellbore as well as ensure the stability of the DM for cuttings transport to the surface. Therefore the higher the mud density, the better stability the DM has for cuttings transport to the surface, and also better control against well kick.

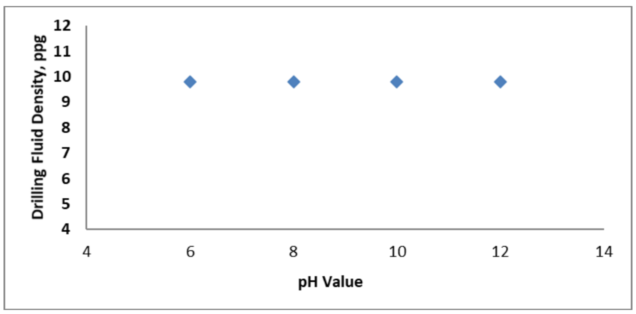

Figure 3. Density of DM formulated with PAC-R at different pH

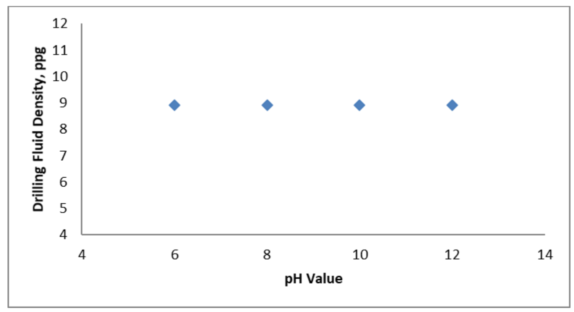

Figure 4. Density of DM formulated with *Mucuna flagellipe* at different pH

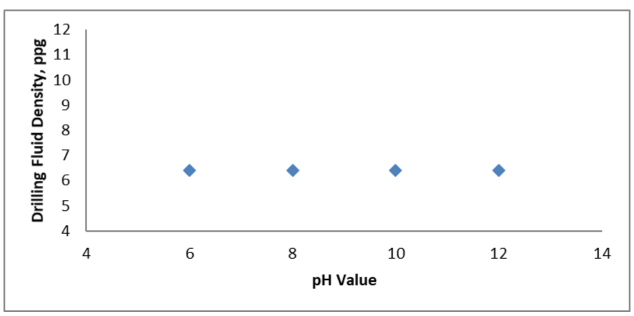

Figure 5. Density of DM formulated with *Brachystegia eurycoma* at different pH

3.2. Gel strength

From Figures 6, 7 and 8, it can be observed that when the values of the pH were increased, the values of the gel strength significantly decreased. This indicates that pH plays a major role in the gel strength of a mud. PAC-R mud had the highest gel strength at all the pH scenarios tested, followed by *Mucuna flagellipe* mud and lastly *Brachystegia eurycoma* mud, but the gel strength of PAC-R mud was only slightly higher than that of *Mucuna flagellipe* mud at different pH values tested. For the PAC-R mud, the values of the 10-seconds gel strength tremendously decreased from 22 to 7 lb/100 ft^2 when the pH was increased from 6 to 12. The values of the PAC-R mud gel strength for 10-minutes decreased from 40 to 7 lb/100 ft^2 when the pH was increased from 6 to 12 while that of 30 minutes gel strength also decreased from 66 to 7 lb/100 ft^2 when the pH was increased from 6 to 12. The same trend was also observed for *Mucuna flagellipe* mud and *Brachystegia eurycoma* mud with the 10-seconds gel strength of *Mucuna flagellipe* mud decreasing from 19 to 6 lb/100 ft^2 when the pH was increased from 6 to 12, that of 10-minutes gel strength for *Mucuna flagellipe* mud decreased from 37 to 6 lb/100 ft^2 when the pH was increased from 6 to 12 while the 30 minutes gel strength of the same mud also decreased from 62 to 6 lb/100 ft^2 when the pH was increased from 6 to 12. For the *Brachystegia eurycoma* mud, the values of the 10-seconds gel strength also decreased from 13 to 3 lb/100 ft^2 when the pH was increased from 6 to 12. The values of the *Brachystegia eurycoma* mud gel strength for 10-minutes decreased from 26 to 3 lb/100 ft^2 when the pH was increased from 6 to 12 while that of 30 minutes gel strength also decreased from 42 to 3 lb/100 ft^2 when the pH was increased from 6 to 12. Authors [37-38] pointed out that a flat rheology is required for the mud where the gel strength values of the mud will be constant with time without any increase. From Figures 6, 7 and 8, the gel strength measurements for 10 seconds, 10 minutes and 30 minutes with no increase were achieved at a pH of 12 with 7 lb/100 ft^2 for PAC-R mud, 6 lb/100 ft^2 for *Mucuna flagellipe* mud and 3 lb/100 ft^2 for *Brachystegia eurycoma* mud. These are the flat rheology.

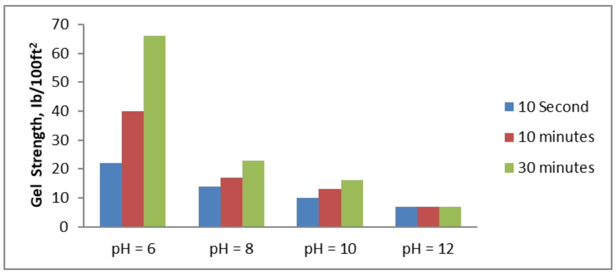

Figure 6. Gel strength measurements of DM formulated with PAC-R at different pH

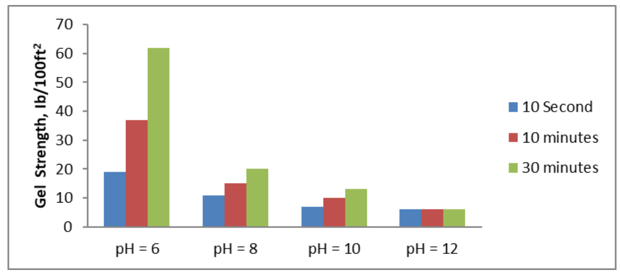

Figure 7. Gel strength measurements of DM formulated with *Mucuna flagellipe* at different pH

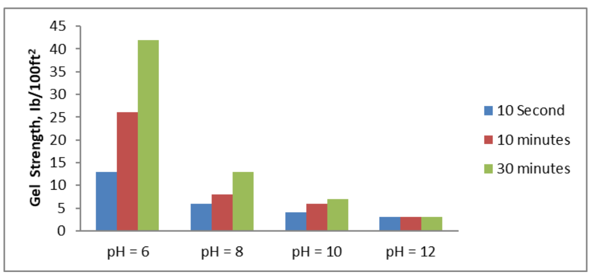

Figure 8. Gel strength measurements of DM formulated with *Brachystegia eurycoma* at different pH

3.3. Rheological properties

Yield Point values are used to evaluate the capability of a DM to carry drill cuttings out of the annulus. Thus, it plays a major role in hole cleaning efficiency. Figures 9, 10 and 11 show changes in low shear yield point (LSYP), yield point and PV for the formulated mud sample at different pH scenarios. From Figures 9, 10 and 11, it can be observed that when the pH was increased from 6 to 12, the LSYP, PV and yield point decreased significantly. From Figure 9 for the PAC-R mud, LSYP decreased from 20.6 to 3.5 Ib/100ft^2, PV decreased from 75.9 to 39.7cp while the yield point decreased from 96.4 to 27.4 Ib/100ft^2. From figure 10 for the *Mucuna flagellipe* DM, LSYP decreased from 17.4 to 2.9 Ib/100ft^2, plastic viscosity decreased from 70.8 to 35.4cp while yield point decreased from 93.4 to 24.5 Ib/100ft^2. From figure 11 for the *Brachystegia eurycoma* DM, LSYP decreased from 11.8 to 1.8 Ib/100ft^2, PV decreased from 45.7 to 15.9cp while the yield point decreased from 54.3 to 14.7 Ib/100ft^2. From figures 9,10 and 11, since the muds have high yield point at pH of 6 to 10, it implies the formulated muds have the ability to lift cuttings from the annulus to the surface which is typical of non-Newtonian fluids. At the pH of 12, the muds will not be able to lift cutting due lower yield point as is observed in Figures 9, 10 and 11.

The results obtained in this study show the significant impact of pH on the rheological properties of DM. The changes in the rheological properties at different pH scenarios are attributed to the changes in nanostructure that occur at the particle surfaces and plates of the DM.

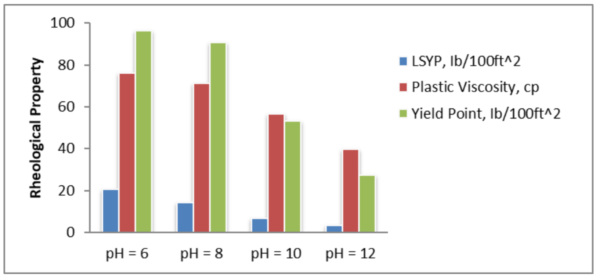

Figure 9. Rheological properties behaviour of PAC-R drilling mud at different pH

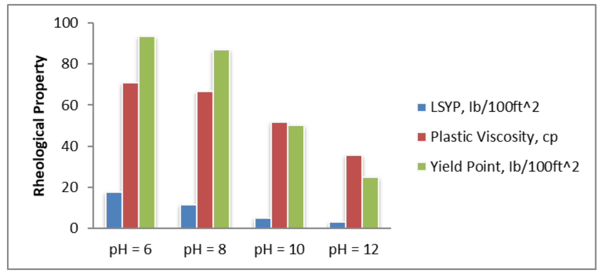

Figure 10. Rheological properties behaviour of *Mucuna flagellipe* drilling mud at different pH

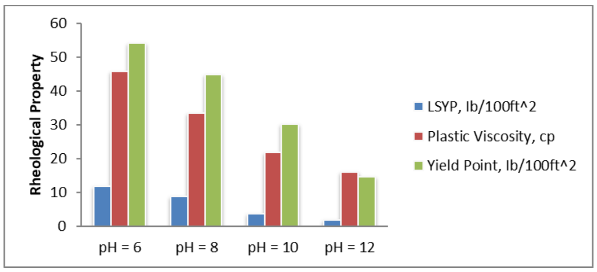

Figure 11. Rheological properties behaviour of *Brachystegia eurycoma* drilling mud at different pH

4. Conclusion

The pH greatly affected the rheology of the formulated *Mucuna flagellipe* mud and that of *Brachystegea eurycoma* mud with the mud densities remaining constant at 8.9 ppg for *Mucuna flagellipe* mud and 6.4 ppg for *Brachystegea eurycoma* mud respectively as pH increased from 6 to 12.

The pH also has great impact on the gel strength of the mud. When the values of the pH were increased from 6 to 12, the values of the gel strength significantly decreased for all the gel strengths tested, that is, 10seconds gel strength, 10minutes gel strength and 30minutes gel strength. This indicates that pH plays a major role in the gel strength of a mud.

The pH again has great effect on the rheological properties of the mud, namely, the LSYP, PV and yield point. When the pH was increased from 6 to 12, the LSYP, PV and yield point decreased significantly. The *Mucuna flagellipe* mud and the *Brachystegea eurycoma* mud had high yield point at pH of 6 to 10, it implies the formulated muds have the ability to lift cuttings from the annulus to the surface. At the pH of 12, the muds will not be able to lift cutting due lower yield point of 24.5 Ib/100ft^2 for the *Mucuna flagellipe* mud and 14.7 Ib/100ft^2 for *Brachystegea eurycoma* mud respectively.

Nomenclature

PACR	*Poly anionic cellulose regular*
LSYP	*low shear yield point*
AWA	*As well as*
DF	*Drilling fluid*
DM	*Drilling mud*
WBDM	*Water-based drilling mud*
WBDMs	*Water-based drilling muds*
PV	*Plastic viscosity*
WBDF	*Water-based drilling fluid*
CMC	*Carboxymethyl cellulose*

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