EVALUATION OF THE RHEOLOGICAL AND PH CONTROL PERFORMANCE OF PLANTAIN PEEL-SNAIL SHELL BIOCOMPOSITE ADDITIVE IN WATER BASED DRILLING FLUID

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ABSTRACT

This study evaluated the applications of Plantain Peel-Snail Shell (PP-SS) bio-composite powder as pH and rheological parameters control additive in Water-Based Drilling Fluid (WBDF). The plant and animal derived wastes were prepared, ground, sieved, and blended together in ratio 1:1 to obtain bio-composite powder. Twelve sets of WBDFs were formulated based on the American Petroleum Institute (API) standard of 25 g bentonite to 350 ml of water. Rheological properties, drilling fluid weight, and pH were conducted on the WBDFs to evaluate the effects of different composite powder concentrations (2, 4, and 6 %w/w) at different temperatures of 30, 50, and 70 ºC. The results showed PP-SS bio-composite powder increased the drilling fluid weight by 5.56-15.74% and pH value by 5.56–27.78% as well as improved the rheological properties (apparent viscosity, plastic viscosity, and yield point) of the WBDF as the bio-composite powder concentration increased. The results also revealed that drilling fluid weight did not change with increasing temperature. Apparent and plastic viscosities decreased with increase in temperature while the pH and yield point increased with increase in temperature. Thus, PP-SS bio-composite powder has the potential to be used as a pH and rheological parameters enhancer.

Key words: Drilling fluid, Plantain peels, Rheological properties, Snail shells.

INTRODUCTION

One of the important materials used in drilling operations in the course of petroleum exploration and production is the drilling fluid which is commonly referred to as drilling mud. Drilling fluid is a complex and heterogeneous mixtures of interacting components with a number of additives (Peretomode, 2018). Drilling fluids possesses rheological properties, filtration loss properties, lubricating quality, pipe sticking tendency, thermal, and bacterial inhibition properties (Nairy et al., 2020). During drilling operations, drilling fluids are added or pumped into the wellbore to enhance the drilling process by removing cuttings from the well, suspending cuttings, providing lubricating, buoyancy, cooling and cleaning as well as stabilizing exposed rock, controlling formation pressure to maintain well-bore stability, and assisting in cementing and completion of well (Nasser et al., 2013). Hence, drilling fluids are often designed as shear-thinning non-Newtonian fluids, which at low shear rates have high viscosity to suspend/transport drill cuttings to the surface but at high shear rates possess low viscosity in order to be rapidly pumped into the wellbore (Li et al., 2018).

Drilling fluid or mud can be categorized according to their base fluid such as oil-based drilling fluid (OBDF), water-based drilling fluid (WBDF), gas-based drilling fluid (GBDF), or synthetic-based drilling fluid (SBDF), and all these types are utilized in variable situations (Gamal et al., 2019). Among these types, the OBDF and WBDF are the most commonly and widely used drilling fluids for petroleum explorations and productions (Ismail et al., 2020). In an unforgiving and complex drilling formations, OBDF has been the drilling fluid of choice for many years, largely due to their efficient carrying capacity of cuttings, high lubricity, high rate of penetration (ROP), high-temperature resistance up to 500 °F, high salt tolerance, and high rate of penetration (ROP) (Amani et al. 2012; Nanthagopal et al. 2019; Ismail et al., 2020). However, some drawbacks on the application of OBDFs has to do with its high cost, negative impacts on the well cementing, and weak adhesion between the casing and the formation (Sayindla et al. 2017). In addition, most of them still have some serious environmental concern that has to do with their high toxicity (i.e. harmful drilling wastes) which limits their use and the issue of degradability. As a result of these, since the 1980s, environmental regulations have thus increased the restrictions on their utilization and thereby from an economic and environmental perspective uplifted the use of WBDFs (Nanthagopal et al. 2019; Oseh et al. 2019). Nevertheless, WBDFs also have few drawbacks, such as increased contact with hydrophilic clay formation, wellbore instability, dispersion and swelling of the clay, low lubricity, and low ROP, (Ismail et al. 2015; Xu et al. 2018).

Therefore, the petroleum (oil and gas) industry is in need of drilling fluid that is eco-friendly. To go with the idea of preparing such fluids, two things have to be considered, which are, the efficiency of the drilling fluid and the cost of the drilling fluid. In most of the cases, compromise must be made from either one of these three: eco-friendly, efficiency or economics (i.e. cost), and in a few cases, two of them (Nairy et al., 2020). Hence, the drillings of deeper wells, more complicated wells, and longer-reach wells have been made possible due to the use of more efficient, cost-saving, multipurpose, and environmentally accepted drilling fluids as well as the improvement in field techniques (Nasser et al., 2013; Zhong et al. 2019; Oseh et al. 2019). Thus, the common practice in the petroleum industry is to make use of rheology (e.g. viscosity) modifiers, fluid loss control additives, and lost circulation materials (LCMs) in the formulation of conventional WBDFs as to improve or enhance their overall properties and compositions (Mahto et al., 2013; Choo and Bai 2015; Ismail et al., 2020). Examples of these modifiers, additives, and LCM materials are graphite, bentonite, calcium carbonate, sodium hydroxide, barite, starch, carboxyl methylcellulose (CMC), xanthan gum, polyanionic cellulose (PAC), guar gum, and mica. Bentonite is a montmorillonite clay used for providing the required rheology and filtration control (Song et al., 2016; Gamal et al., 2019). Barite as a weighting material is employed to provide additional weight to the drilling fluid as to increase its density and stability (Afolabi et al., 2017). Starch as an additive is used for controlling fluid loss and has a thermal stability up to 250 °F (Talukdar et al., 2018); xanthan gum is used as a viscosifier which controls the rheology (Nairy et al., 2020); CMC (polymer) tends to increase shear stress of the fluid and decreases the fluid loss as its concentration increases (Patel et al., 2007); and PAC acts as a fluid loss reducing agent (Luz et al. 2017). In addition, calcium carbonate ($CaCO_3$) provides an ionic inhibition and serves as a bridging agent (Abdou et al., 2018; Nairy et al., 2020) while sodium hydroxide or caustic soda is used for pH control-that is, for chemical-reaction control (inhibit or enhance) (Nairy et al., 2020).

Moreover, maintaining wellbore stability is one of the important function of drilling fluids that is strongly been affected by rheology, filtration control, and filter cake thickness (Saboori et al. 2018; Oseh et al. 2020). Water intrusion into the permeable formation weakens the wellbore stability thereby causing serious drilling problems, such as pipe stuck, tight holes, and wellbore collapse, which severely hampers the success of the drilling process (Saboori et al. 2018; Ismail et al., 2020; Oseh et al. 2020). Therefore, drilling fluid's rheology and filtration control properties are the two most critical parameters that needed to be optimized to achieve a successful drilling operation (Ismail et al., 2020). The bentonite-water-based drilling fluids (BT-WBDFs) are more popular in drilling fields because of their low cost and low environmental impact. Globally, approximately 80% of wells are excavated using the BT-WBDFs. In recent years, the low-solid, smart/nano BT-WBDFs have attracted considerable attention from both researchers and drilling engineers due to several advantages, e.g., high drilling rate, low friction in all drilling equipment, thin filter cake, less pipe sticking, good shale stability, and tailor-made rheological and filtration properties. The major drawback for low-solid BT-WDFs has always been their limited carrying capacity for drill cuttings because of the low BT content. Much effort has been devoted to improving the carrying capacity for drill cuttings by adding rheology modifiers such as hybrid nanocomposites (CuO and ZnO in polyethylene glycol and polyvinylpyrrolidone, poly(2-acrylamide-2-methylpropanesulfonic acid)) CuO/polyacrylamide (Mao et al., 2015; Ponmani et al., 2016; Wu et al., 2017; Saboori et al., 2019) and synthetic polymers (Xie and Liu, 2017).

Despite these rheology modifiers (which are synthetic chemicals) allowing effective improvement in the rheological performance of BT-WBDFs, their economic, sustainability, and environmental friendliness have been a big concern. This has therefore driven researchers to keep exploring naturally abundant, inexpensive, sustainable, and environmentally friendly materials as rheology modifiers for the formulation of low-solid, smart BT-WBDFs. Several research workers have investigated the use of natural local products such as cocoa pods and groundnut shell (Aremu et al., 2017), plantain peels (Aremu et al., 2017; Peretomode, 2018), corncobs (Nmegbu and Bekee, 2016), banana peels (Iheagwara, 2015), cashew and mango extracts (Omotioma and Ejikeme 2014), henna leaf and hibiscus leaf extracts (Ismail et al., 2020), bamboo leaf ash (Nairy et al., 2020), egg and snail shells (Onolemhemhen et al., 2019), rice husks (Okon et al., 2014), and mandarin peels (Al-Hameedi et al., 2020) as alternative locally derived green additives to these synthetic chemicals and their effect on the rheological and filtration characterizations of WBDFs.

These plant and animal based-extracts are low-costs, biodegradable, non-toxic, and environmentally benign and were found to be effective in enhancing or improving the physicochemical properties of the BT-WBDF system. The above research workers made use of the plant and animal derived additives in their mono or single form. However, in nature it is both plant and animal derived wastes which could be referred to as food wastes or kitchen wastes that are usually found together in the environment. There is the need to get rid of this kind of waste from the environment by investigating their potential as bio-composite additives in DF formulation. Therefore, to the best of my knowledge there is no information or literature data on the effect of the use of these plant and animal derived additives as bio-composites on the rheological characterizations of BT-WBDFs. Hence, the objective of this study is to evaluate the effect of locally derived plantain peels powder and snail shell powder as bio-composites as well as the effect of temperature on the pH, weight (density), and rheological characterizations of BT-WBDFs. To determine their suitability as pH and rheological properties control agents and their possible applications in the field.

MATERIALS AND METHOD

Materials

Nigerian bentonite clay was obtained from Kwale, Delta State of Nigeria. Plantain peels used as source of both local sodium hydroxide and potassium hydroxide were obtained from several restaurants located in Yenogoa, Bayelsa State, Nigeria. Snail shells were gotten from de-shelled snails bought from a local market in Yenogoa, Bayelsa State. All other chemicals and reagents used in this study are of analytical grade.

Sample preparation

Unripe plantain peels were washed with tap water to remove dirt and debris. The washed peels were cleaned and sliced into smaller sizes. The sliced plantain peels were dried in the open sun for two weeks and thereafter dried in an oven-dryer at 70 ^{o}C for 1 h. The peels were then pulverized into powder, sieved, and packaged in a sealed plastic bag and stored at room temperature prior to their application in the WBDF system. The snail shells were dried under the open sun for two weeks. The shells were then ground using a manual grinder and thereafter sieved to less than 2 µm particle size using a BS mesh. The pulverized shell powder was then packaged in a sealed plastic bag and stored at room temperature prior to use.

Preparation of bentonite water-based fluid and beneficiation

Twelve (12) BT-WBDFs were prepared or formulated according to the American Petroleum Institute (API, 2000) standard of 25 g of bentonite and 350 ml of water for non-treated bentonite. The different components (additives) added to the distilled water to formulate the drilling fluid are presented in Table 1. Various powder concentrations of blended plantain peels powder and snail shell powder bio-composite at 2, 4, and 6% weight by weight were slowly added to the base fluid inside the mixer cup of a spindle multi-mixer equipment (REG no 402260 VICCO), thoroughly and homogeneously mixed together for 1 h duration (Fig. 1)

Fig. 1: Fluid or mud mixer

The formulation of the WBDFs shown in Table 1 was performed to study the effects of the PP-SS powder bio-composite additives and temperature in the complex WBDF system. The WBDF weight or density was measured using a Baroid mud balance. All the experiments were carried out in triplicate and the average value of each parameters determined was used.

Table 1. Components of the water based drilling fluids mixed with additives

S/N	Temperature (°C)	Base	Additive (%w/w)
1	30	25 g Bentonite + 100 g Barite + 350 ml Water	-
2	50	25 g Bentonite + 100 g Barite + 350 ml Water	-
3	70	25 g Bentonite + 100 g Barite + 350 ml Water	-
4	30	25 g Bentonite + 100 g Barite + 350 ml Water	2
5	30	25 g Bentonite + 100 g Barite + 350 ml Water	4
6	30	25 g Bentonite + 100 g Barite + 350 ml Water	6
7	50	25 g Bentonite + 100 g Barite + 350 ml Water	2
8	50	25 g Bentonite + 100 g Barite + 350 ml Water	4
9	50	25 g Bentonite + 100 g Barite + 350 ml Water	6
10	70	25 g Bentonite + 100 g Barite + 350 ml Water	2
11	70	25 g Bentonite + 100 g Barite + 350 ml Water	4
12	70	25 g Bentonite + 100 g Barite + 350 ml Water	6

pH determination of water-based drilling fluid

The pH of the WBDF with and without the addition of commercial and natural additive was determined using the 1-inch universal pH paper strip or indicator. The 1-inch pH paper indicator was inserted into the WBDF samples and left for about few seconds to 1 min. The color change of the pH paper strip after it has absorbed sufficient fluid was matched with reference chart colors provided. The pH values of the color indicated by the WBDF sample in turn was read and recorded as the pH of the fluid samples being tested.

Determination of the water-based drilling fluid rheological parameters

The WBDF viscosity was determined using Fann V G Rheometer equipment (Rheomat RM 200) presented in Fig. 2.

Fig.2: Baroid rheometer

The prepared or formulated WBDF was poured into a container and then subjected to shear in a rheometer at a rotation speed of 600 and 300 rpm, respectively. At each rotation speed, the dial reading (θ) was recorded at the time when the speed of rotation was steady. Where $\theta_{600\,rpm}$ and $\theta_{300\,rpm}$ are the dial readings at 600 rpm and 300 rpm, respectively.
Plastic viscosity (P μ) is the shearing stress that is in excess of the yield point which will induce a unit rate of shear (Nguanthaisong, 2016). The P μ expressed in centipoises (cP) can be calculated using Eq. (1) (Afolabi et al., 2017):

$$P\mu = \theta_{600\,rpm} - \theta_{300\,rpm} \tag{1}$$

The apparent viscosity (APV) measures the drilling fluid shear rate specified by API. The apparent viscosity expressed in centipoises (cP) indicates the amount of force needed to move one layer of fluid in relation to another. It can be estimated using Eq. (2) (Afolabi et al., 2017):

$$AP\mu = \frac{\theta_{600rpm}}{2} \tag{2}$$

The yield point (YP) of the formulated WBDF expressed in lb per 100 sq ft was estimated using Eq. (3) (Afolabi et al., 2017):

$$YP = \theta_{300\,rpm} - P\mu \tag{3}$$

The power law model's parameters in the term of behavior index (n) and consistency (k) are calculated from viscometer reading using the following equations.

$$n = 3.322 \log(\theta 600 / \theta 300) \tag{4}$$

$$k = 5.10\, \theta 300 / 511 n \tag{5}$$

The parameters, k and n are constants characteristic of a particular fluid. Where n is a measure of the degree of non-Newtonian behaviour of the fluid (i.e. flow behaviour index) and k is a measure of the consistency of the fluid (i.e. fluid consistency index). The higher the value of k the more viscous the fluid. When n = 1, the fluid behaves as a Newtonian fluid and the Power-Law equation is identical to the Newtonian fluid equation. For n >1, the fluid is classified as dilatant while for n <1, then the fluid is referred as pseudoplastic.

RESULTS AND DISCUSSION

Influence of concentration and temperature on properties of WBDF

Additives of drilling fluid are often developed to be mixed with water with a pH level that range from 8.5 to 10 for the occurrence of the required chemical reaction and to provide a proper yield (Gamal et al. 2019; Ismail et al., 2020). After the additive mixing with the prepared WBDF system, the pH of the WBDF was measured at different temperatures of 30, 50, and 70 °C and the results are presented in Fig. 3. Fig. 3 shows the results for the WBDF pH using different concentrations of the plantain peel-snail shell bio-composite powder as additive at different temperature of 30, 50, and 70 °C, respectively.

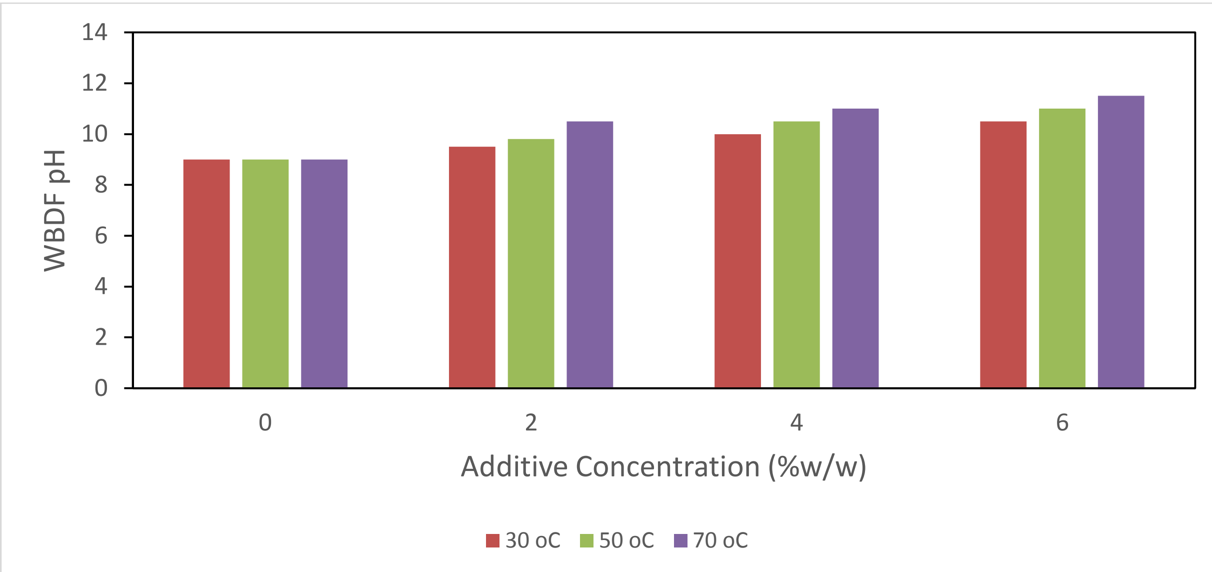

Fig. 3: pH of WBDF at different temperature and concentration

It was observed from Fig. 3 that there were changes in the WBDF pH with the addition of PP-SS bio-composite powder at different concentrations. It could be seen that the pH of the formulated WBDF without additive was found to be 9 and this relatively increased from a pH of 9 to a pH range of 9.5 to 11.5 when a concentration of 2 to 6 %w/w of PP-SS bio-composite powder as additive was added to the formulated WBDF system. It is also seen that at each of the different additive concentration, the pH of the WBDF slightly increased with increasing temperature. Onolemhemhen et al. (2019) have similarly reported an increase in the pH of WBDF due to the increase in the concentration of snail shell powder, egg shell powder, and their combination in their study of the suitability of egg shell and snail shell waste for pH and mud weight enhancement of water based drilling mud. On the other hand, Al‐Hameedi et al. (2020) reported a decrease in the pH of WBDF due to increasing mandarin peel powder concentration in their experimental investigation of environmentally friendly drilling fluid additives (mandarin peels powder) to substitute the conventional chemicals used in water‐based drilling fluid.

Effect of additive concentration and temperature on the weight of WBDF

In drilling operations, one of the key parameters is the drilling fluid or mud weight. Most of the problems that are usually faced during rotary drillings are related to the drilling fluids weight (Fattah and Lashin, 2016; Ismail et al., 2020). To effectively determine the influence of PP-SS biocomposite powder on the fluid loss, fluid cake thickness, and formation damage, the weight of the drilling fluid is the first property to be investigated. The stability of a drilling fluid is governed by its uniformity after aging for a long period of time (Ismail et al., 2020). The results obtained for the weight of the drilling fluid after mixing with additives are provided in Fig. 4.

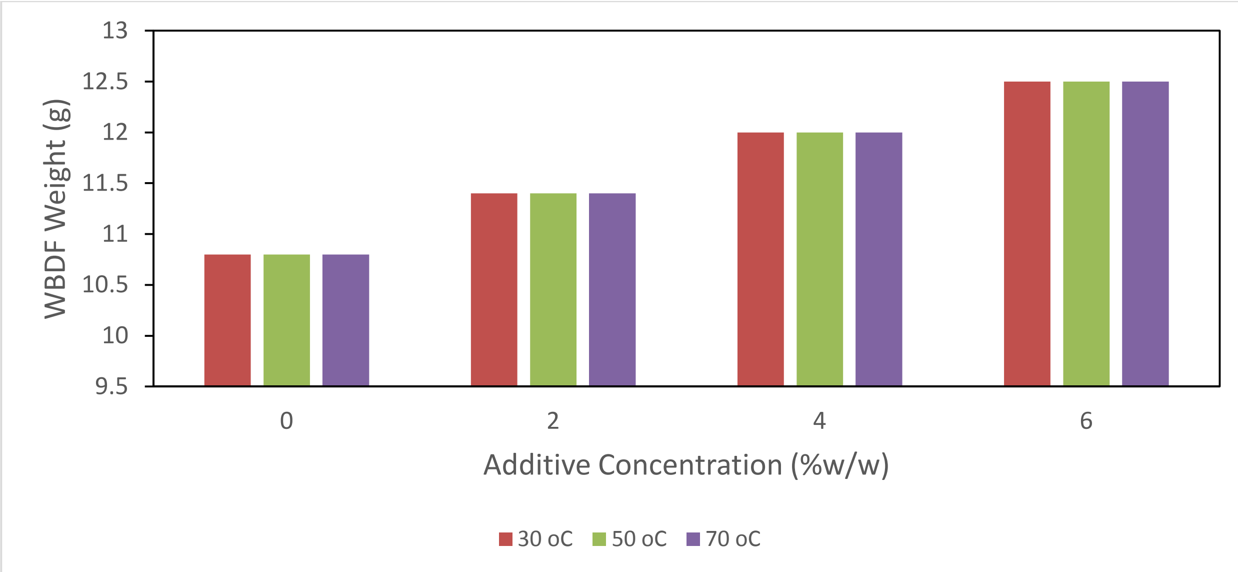

Fig. 4: WBDF weight at different temperature and additive concentration

The results demonstrated the ability of additives to provide weight to drilling fluid. The WBDF weight relatively increased with increasing concentration of the additive (PP-SS biocomposite powder) while at each of the different temperature, the drilling fluid weight invariably did not change. Onolemhemhen et al. (2019) have similarly reported an increase in mud weight due to the increase in the concentration of snail shell powder, egg shell powder and their combination in their investigation of the suitability of egg shell and snail shell waste for pH and mud weight enhancement of water based drilling mud; while Ismail et al. (2020) observed no change in mud weight with increasing concentration of henna leaf and hibiscus leaf extracts in their study of the improvement of rheological and filtration characteristics of water□based drilling fluids using naturally derived henna leaf and hibiscus leaf extracts. Al□Hameedi et al. (2020) reported a slight decrease in mud weight due to increasing mandarin peel powder concentration in their study of the experimental investigation of environmentally friendly drilling fluid additives (mandarin peels powder) to substitute the conventional chemicals used in water□based drilling fluid.

Effect of additive concentration and temperature on the WBDF rheological parameters

Rheological parameters (apparent viscosity, plastic viscosity, and yield point) of WBDF and drilling fluid mixed with additive samples are illustrated in Fig. 5.

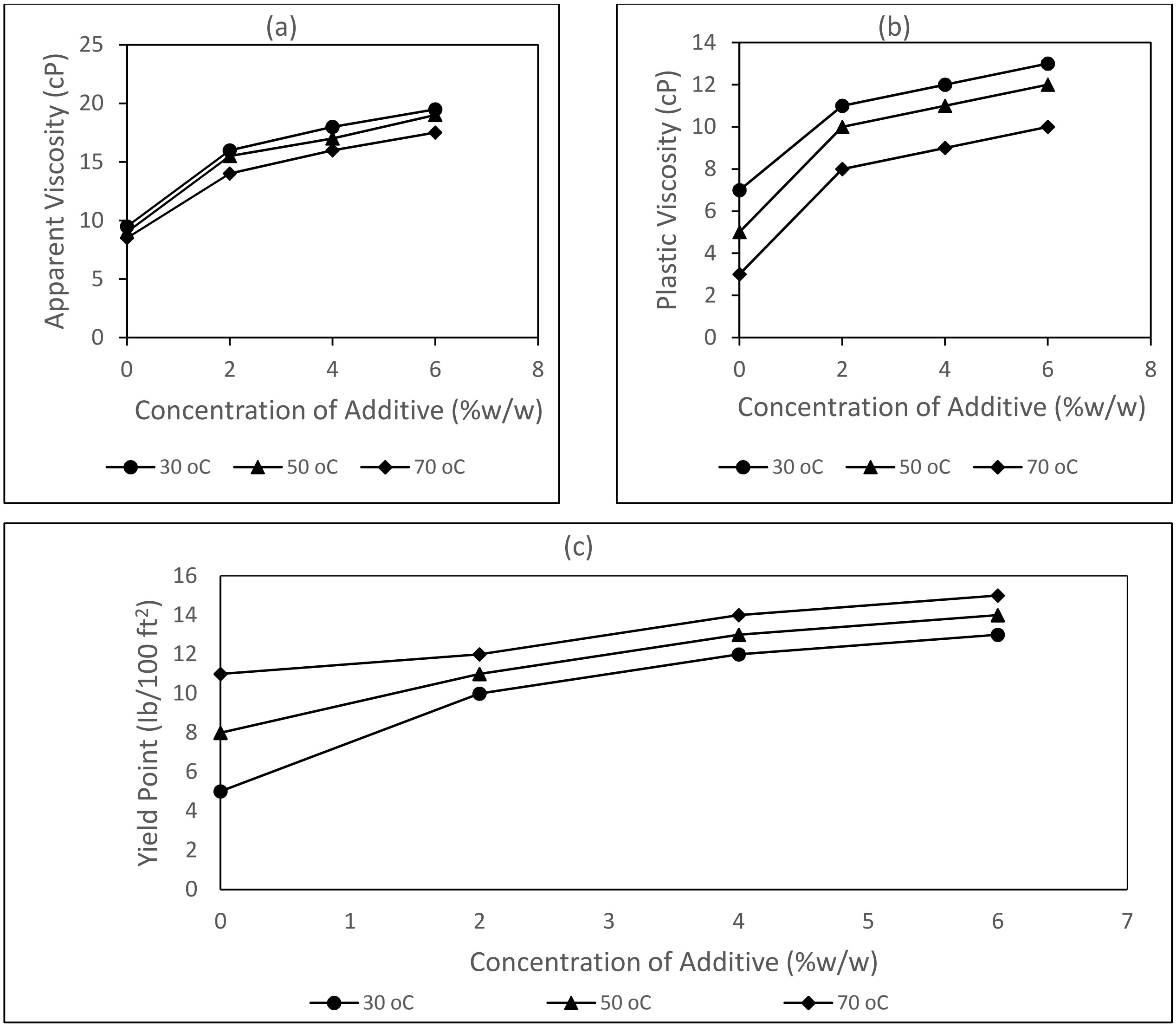

Fig. 5: Effects of additive concentration and temperature on (a) apparent viscosity, (b) plastic viscosity, (c) yield point of WBDF

Apparent viscosity

Fig. 5 (a) illustrate the effects of additive concentration and temperature on the apparent viscosity of the formulated WBDF. It is seen that the apparent viscosity of the WBDF systems containing the plantain peel-snail shell biocomposite powder at each of the different temperature (30, 50, and 70 ºC) increased significantly with an increase in additive concentration over that of the WBDF system that is without additive. However, this apparent viscosity increase can be detrimental to drilling operations with regards to equivalent circulating density, lost circulation, and excess pump power requirement (Ismail et al., 2020), This implies that a lower range of concentration are required to achieve an effective removal of drilled cuttings and successful drillings without causing harm to the formation (Ismail et al., 2020). Also, it could be observed that at each of the different additive concentration, the apparent viscosity relatively decreased with increasing temperature. Furthermore, Ismail et al. (2020), Aremu et al. (2017), and Anawe et al. (2014) have similarly reported a decrease in the apparent viscosity of WBDF as a result of an increasing temperature in the presence or absence of additives.

Plastic viscosity

The plastic viscosity is an indicator of the viscosity of the high shear rate and is dependent on the liquid phase viscosity and the amount of solids in a liquid. The rheometric plastic viscosity data provided in Fig. 5 (b) showed that at the different temperature of operation, as the PP-SS bio-composite powder increase in concentration, the plastic viscosity also increases over that of the WBDF system without the bio-composite additive. Furthermore, at each of the different additive concentration, the plastic viscosity decreases as the operating temperature rises from 30 to 70 ^oC. A similar observation of an increased plastic viscosity of a WBDF as a result of an increasing concentration has been reported for the use of green additives such as mandarin peel powder (Al□Hameedi et al., 2020), henna leaf and hibiscus leaf extracts (Ismail et al., 2020), Furthermore, Ismail et al. (2020), Aremu et al. (2017), and Anawe et al. (2014) have similarly reported a decrease in the plastic viscosity of WBDF due to rise in the operating temperature in the presence or absence of additives.

Yield point

Fig. 5 (c) provides the yield point (YP) results as calculated using Eq. (3). The plot reveals that the addition of plantain peel-snail shell biocomposite powder changes the YP of the WBDF. It is observed that there are significant enhancement in the YP with increasing concentration of the plantain peel-snail shell biocomposite powder at each of the different operating temperature conditions. In addition, according to the results shown in Fig. 5 (C), an increase in temperature from 30 to 70 ^oC significantly affects the YP of the WBDF in an increasing manner. Similar observation of an increase in the YP of WBDF due to increasing concentration of green additives has been reported by Al-Hameedi et al. (2020) for the use of mandarin peels powder, Ismail et al. (2020) for the use of henna leaf and hibiscus leaf extracts. Also, Aremu et al. (2017) have reported similar observation of an increased WBDF YP due to increasing temperature in the use of cocoa pods, groundnut shell, plantain peels, and rice husk. On the other hand, Ismail et al. (2020) and Anawe et al. (2014) have respectively reported a decrease in the YP of WBDF as a result of a rise in temperature for the use of henna leaf and hibiscus leaf extracts and rice husk as green additives in WBDF formulation.

Rheological behaviour of WBDF

The power law's model parameters for WBDFs with or without plantain peels-snail shell bio-composite powder samples are provided in Table 2.

Table 2. The power law's model parameters of the formulated WBDF

Temperature (^oC)	Fluid Base	Additive (%w/w)	n	k
30	25 g Bentonite + 100 g Barite + 350 ml Water	-	0.66	0.18
50	25 g Bentonite + 100 g Barite + 350 ml Water	-	0.47	0.28
70	25 g Bentonite + 100 g Barite + 350 ml Water	-	0.28	0.50
30	25 g Bentonite + 100 g Barite + 350 ml Water	2	0.61	0.34
30	25 g Bentonite + 100 g Barite + 350 ml Water	4	0.58	0.41
30	25 g Bentonite + 100 g Barite + 350 ml Water	6	0.58	0.45
50	25 g Bentonite + 100 g Barite + 350 ml Water	2	0.56	0.37
50	25 g Bentonite + 100 g Barite + 350 ml Water	4	0.50	0.48
50	25 g Bentonite + 100 g Barite + 350 ml Water	6	0.55	0.47
70	25 g Bentonite + 100 g Barite + 350 ml Water	2	0.49	0.41
70	25 g Bentonite + 100 g Barite + 350 ml Water	4	0.48	0.48
70	25 g Bentonite + 100 g Barite + 350 ml Water	6	0.49	0.51

The index parameter 'n' indicated that all drilling fluid samples exhibited pseudoplastic flow when n is less than 1. Therefore, as seen in Table 2, the parameter n is less than 1 for all concentrations and temperatures. Hence, the flow behaviour of WBDF follows the parameters of Bingham plastic and power law models as a pseudoplastic fluid. For the WBDF formulated at 50 and 70 ^oC, the value of n generally increases with increase in the bio-composite concentration while it decreased with increasing concentration for WBDF formulated at 30 ^oC. Also, it is seen that the consistency factor k of the WBDFs relatively increased with increasing quantities of the added bio-composite powder as well as with increasing temperature. A similar observation was reported by Nguanthaisong (2016) for the use of sugarcane bagasse, corncobs, and rice husk as additives in the formulation of WBDF.

CONCLUSION

This study has investigated the effects of adding varying concentrations of PP-SS bio-composite powder on WBDF rheological properties, pH, and fluid or mud weight at different operating temperatures and the following conclusions can be deduced as follows:

(1) The drilling fluid or mud weight was slightly affected by the addition of the plantain peel-snail shell bio-composite powder. The drilling fluid weight increased by 5.56-15.74% as the bio-composite powder concentration increased from 2-6 %w/w and remained unchanged with increasing operating temperature.

(2) The PP-SS bio-composite powder significantly increased the apparent viscosity, plastic viscosity, and yield point of the WBDF as the bio-composite powder concentrations increased. Hence, PP-SS bio-composite powder showed the potential to be used as rheological properties modifier.
(3) The PP-SS bio-composite powder has the capability to be used as pH enhancer as it increased the alkalinity by 5.56–27.78% when the bio-composite powder concentration increased from 2-6 %w/w. Thus, it can serve as a good alternative to commercial pH additives like sodium hydroxide which will be of benefit to the petroleum industries as this will reduce the production cost of WBDFs.
(4) The flow behaviour of WBDF follows the parameters of Bingham plastic and power law models as a pseudoplastic fluid.

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