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Original Research Article

An Experimental Investigation of Temperature and Ageing Effects on Bentonite and Sepiolite Drilling Fluids

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ABSTRACT

The formulation of a suitable drilling fluid is necessary for the successful drilling of an oil and gas well. The rheological properties of drilling fluids vary with changes in conditions such as time and temperature. This makes it necessary to study the rheology of drilling fluids and how it is affected by these changes. As part of this work, experiments were carried out to investigate the density, rheological properties – plastic viscosity, yield point and gel strength and pH of bentonite and sepiolite water-based drilling fluid at different temperature and ageing conditions. In addition, the effect of xanthan gum commonly used as an additive in drilling fluid formulation was also investigated on the rheological properties of these muds. Results obtained indicated that sepiolite water-based drilling fluid offers better plastic viscosity and yield point as compared to bentonite water-based drilling fluids. It was also found that the plastic viscosity and yield point of sepiolite, bentonite and treated bentonite muds decreased with increase in ageing time and temperature while the gel strength increased with ageing time but also decreased with increase in temperature. Results from this work also indicated that plastic viscosity, yield point and gel strength increased as the concentration of xanthan gum increased, all of which decreased with increase in temperature. The beauty of these results is that it will enable mud engineers to appropriately understand the how these mud properties vary downhole where temperatures are relatively higher and how they vary over time.

1. INTRODUCTION

The oil industry as mentioned in many petroleum engineering books started from the famous Drake well which was believed to be the first oil well. Ever since then, engineers continue to come up with new ideas to move the oil and gas from the ground to the market. The use of drilling fluid is one of the advancements achieved from these new ideas with the aim of removing the drilled cuttings from the wellbore, stabilizing the hole and many others (Apaleke et al., 2012).

Failure of a drilling fluid to undertake its required functions may lead to other problems such as stuck pipe and loss circulation which are expensive to solve hence resulting in excessive loss of revenue (Santos, 2000). Bloys et al. (1994) reported that most drilling problems are affected either directly or indirectly by the drilling fluid. Different types of drilling fluids used by drillers today depend on the formation to be drilled. To avoid any problem, the proper mud must be used with the correct properties (Caenn et al., 2011).

To understand the dynamics of drilling fluids during drilling operations, several studies have been carried out (Karstad and Aadnoy, 1998; Santoyo et al., 2001; Osisanya and Harris, 2005; Sukhoboka, 2017). Wyant et al. (1975) determined the effect of mud stabilization system in bentonite-based mud at high temperature. His study showed that mud stabilization system is an effective system to stabilize the mud within short period of time. Thomas (1982) determined the effect of carboxyl methyl cellulose (CMC) as additive for fluid loss control. Although CMC offer good fluid loss control, its usage was found to be limited to temperatures of 100 to 260 ^oC. Clements et al. (1985) studied the rheological factors of lignosulphonate muds. They found out that the mud has stable rheological properties even above 200 ^oC after 16 hours of ageing. They also reported that the lignosulphonate mud has good tolerance of electrolyte concentration. In their study, Al-Marhoun and Rahman (1988) used laboratory test procedures to simulate the bottom hole conditions and investigated the effect of temperature on viscosity, filtration loss and corrosion rate on a 24 hours aged drilling fluid. They found that viscosity increased up to a temperature of 120 oC and then decreased. However, they also reported that viscosity in high pressure high temperature (HPHT) viscometer decreased with temperature. Yield point also decreased with temperature whereas filter loss increased with temperature. Mahto and Sharma (2004) conducted their studies on tamarind gum and polyanionic cellulose on bentonite water suspensions. They also determined the effect of drilling fluid filtrate on formation damage. The developed drilling fluid offered a good rheological properties and good fluid loss control. In addition, the drilling fluid filtrate exhibited minimum formation damage on sandstone cores. In a recent study, Al-Hameedi et al. (2019) investigated the introduction of potato peels powder (PPP) as a drilling fluid additive. The effects of adding various concentrations of PPP on the chemical and the physical properties of the drilling mud (e.g. mud weight (MW), plastic viscosity (PV), yield point (YP), the filtration characteristics, and pH) were evaluated. Result from their work concluded that PPP had a negligible effect on mud weight and solid content. PPP, however, tangibly affected the rheological properties by maximizing plastic viscosity and minimizing yield point and gel strength.

These studies clearly highlight the importance and necessity of selecting the appropriate drilling fluid for a given operation. Once, the appropriate drilling fluid is selected and formulated, it is also vital to understand how that drilling fluid will behave under different operating conditions especially temperature and ageing time mainly because the temperatures downhole are often relatively higher than at the rig floor. Similarly, drilling an oil well could take weeks or even months therefore, it is important to understand how the mud properties will vary as it age.

This work therefore aims is to investigate the effect of temperature and ageing on the density, plastic viscosity, yield point, gel strength, and pH on Bentonite and Sepiolite water-based drilling fluids. The work also aims to determine the effects of xanthan gum used as an additive on the properties of Bentonite water-based drilling fluids.

2. MATERIALS AND METHODS

2.1. Material

This section presents a description of the materials and apparatus used in formulating and testing the mud samples used in the study.

i. Distilled Water: All samples were prepared by mixing 350 ml of distilled water with the clay materials.
ii. Bentonite: 22.5 g of bentonite was mixed as clay mineral to form the viscosity of the fluid
iii. Sepiolite: The same amount as the bentonite was used to formulate the second mud sample.
iv. Sodium chloride (NaCl): 1 g of NaCl was added to improve gel strength and viscosity difference in both samples.
v. Xanthan gum: xanthan gum is a viscosifier used to improve the viscosity of drilling fluids. Different concentrations of xanthan gum were used as additives to improve the Bentonite muds properties

For the experiments, the following apparatus were used.

i. Hotplate with stirrer: This was used to heat up the mud samples to the desired temperature. The stirrer is used to ensure the mud samples are evenly heated.
ii. Weighing balance: This is used to weigh the mud samples to ensure the exact amount is mixed in formulating the drilling fluid samples.
iii. Measuring cylinder: 350 ml of distilled water is used in mixing the mud samples. The exact volume is measured using the measuring cylinder.
iv. Beakers: The mixed mud samples are poured from the glass bottles into beakers before being heated on a hot plate.
v. Thermometer: This was used to measure the temperature of the mud samples while heating and also while carrying out the experiments.
vi. Glass bottles: The mud samples were stored in the glass bottles and allowed to age for the desired days.
vii. Mixer: An electric mixer with an RPM of 500 was used for mixing the mud samples for ten minutes.
viii. Mud balance: The mud balance was used to determine the density / mud weight of the samples.
ix. Fann viscometer: This was used for the rheology measurements.
x. Stopwatch: This was used to keep track of time while mixing the mud samples.
xi. Spatula: This was used to obtain sodium chloride samples from the sodium chloride container.

2.2. Methods

2.2.1. Mud preparation

Mud samples were prepared by mixing 22.5 g of clay sample (i.e. bentonite or sepiolite) with 350 ml of distilled water using an electric mud mixer with an RPM of 500 at 20 ^{o}C for 10 minutes. Static ageing was used in these experiments whereby the prepared samples were stored in a covered container and allowed to age at room temperature (20 °C) for the number of days required. The density, Plastic Viscosity, Yield point, Gel strength and pH of the samples were then determined. Test conducted were divided into three parts. The first part compared the rheological properties of Bentonite and Sepiolite water-based drilling muds and identified how these properties were affected by ageing and temperature. The second part investigated the effect of ageing and temperature on the properties of bentonite treated with 250 mg/L xanthan gum. Finally, the last section determined the effect of xanthan gum concentration on the properties of bentonite water-based drilling mud.

2.2.2. Determination of mud weight

At the start of the experiments, calibrations were checked (calibration mark provided on the scale for fresh water is 8.33 lb/gal or 1.0 S.G.) and the cup was cleaned and dried. The lid was removed from the mud cup and the cup filled with the mud sample. The temperature of the mud sample was then recorded. To ensure all entrapped air bubbles were removed, the cup was taped by the side. The lid on the cup was then replaced and rotated until it was firmly seated with some mud allowed to squeeze through the vent hole in the lid. This excess mud was washed and wiped from the exterior of the mud balance covering the vent hole. The balance was then dried with the vent hole covered and placed in its base with the knife edges on the fulcrum rest. The rider was then moved until the beam is balanced. The spirit level bubble was set on the center line. Finally, the mud weight and hydrostatic pressure or mud gradient at the edge of the rider nearest the fulcrum (toward the knife edge) was recorded.

2.2.3. Determination of plastic viscosity and yield point

In determining the plastic viscosity and yield point of the mud samples, the test cup was filled to the scribed line with the desired sample. The temperature of the mud sample was measured and recorded. The leg lock nut was loosened, and the rheometer assembly was raised until the mud level reaches just below the rotor sleeve. The rheometer was lowered, and the rotor sleeve was immersed to the scribed line on the rotor sleeve. Thereafter, the leg lock nut was then tightened, and the motor was started by placing the switch to high speed position with the gear shift all the way down. A reading was recorded at 600 RPM after the indicator dial value was steady. The switch was then changed to the 300 RPM and the reading was again recorded after the dial value became steady.

$$\text{Plastic viscosity (cp)} = \text{Reading at } 600 - \text{Reading at } 300 \quad (1)$$

$$\text{Yield point (lb/100sqft)} = \text{Reading at } 300 - \text{Plastic Viscosity} \quad (2)$$

2.2.4. Determination of gel strength

The gel strength of drilling fluid determines its ability to suspend cuttings once circulation is stopped. The measure of minimum shear stress required to create the flow of drilling fluid is referred to as gel strength. For this work, ten seconds gel strength was obtained by recording the maximum dial reading at an RPM of 3 at ten seconds after circulation of the viscometer has been stopped. It should be noted that due to the limitation of the Fann viscometer used for the experiments, readings were taken once at each temperature. A test was conducted where twenty readings were obtained at room temperature to determine the closeness of the measurements. The percentage error based on these results was found to be 1.125% which means that the readings are to a good extent replicable.

3. RESULTS AND DISCUSSION

3.1. Effect of temperature and Ageing on Mud Properties

This section presents the results of the effect of temperature and ageing on density, plastic viscosity, yield point, gel strength and pH on bentonite and sepiolite water-based drilling fluid. Figure 1 present the result of the densities of bentonite (a) and sepiolite (b) water-based drilling fluids at different temperature and ageing time. From Figure 1(a) the density of bentonite mud was found to be between 8.5 and 8.6 ppg while that of sepiolite in Figure 1(b) was found to be between 8.5 and 8.7 ppg. From these results, it can be deduced that the sepiolite mud exerts a slightly higher hydrostatic pressure to the formation in trying to contain the subsurface pressures. Densities of both muds show an inverse relationship with temperature as expected. This change in density is as a result of the expansion of the drilling fluid. The ratio of increase in volume per degree rise in temperature also known as the coefficient of expansion is used to understand this process (Choi and Tan, 1998). However, densities of both muds were unaffected by ageing time.

Figure 2 present the results for the plastic viscosity of bentonite (a) and sepiolite (b) water-based drilling fluids at different temperature and ageing time conditions. The plastic viscosity of bentonite in Figure 2(a) and sepiolite in Figure 2(b) were different even though equal amount of clay materials were added in equal amount of water and mixed for the same period of time. The plastic viscosity of bentonite mud in Figure 2(a) at day 0 at 20 ℃ was found to be 10 cp while that of sepiolite in Figure 2(b) was found to be 15 cp. For the same temperature, as the ageing time was increased, the viscosity of both muds decreased. This clearly shows that at the rig sites where the mud is formulated based on the desired properties, a lesser amount of sepiolite will be required to obtain a particular viscosity as compared to the bentonite.

In Figure 3, the results of yield point for (a) bentonite and (b) sepiolite are presented at different temperature and ageing time. A similar trend to the plastic viscosity is obtained for the muds hole cleaning capability. From Figure 3(a) yield point of bentonite mud was found to be 22 lb/100 sqft at day 0 at 20 ℃ while that of sepiolite presented in Figure 3(b) was 26 lb/100 sqft. This means that sepiolite mud offers a better hole cleaning capacity than the bentonite mud (Echt and Plank, 2019). The yield point of both muds is also affected by ageing time and temperature. This can be seen in Figure 3 where an increase in ageing time resulted in a decrease in yield point at the same temperature. Also, an increase in temperature leads to a decrease in the yield point for both muds at the same ageing time.

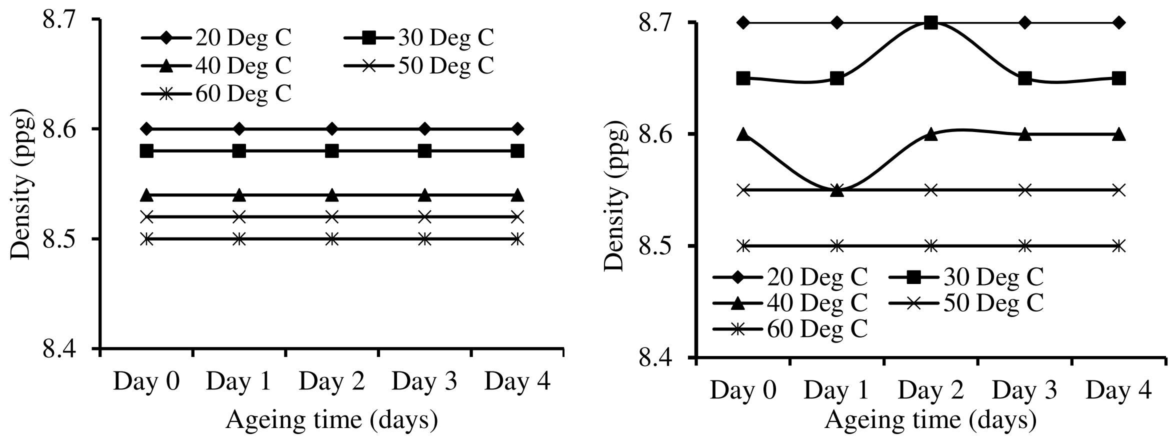

Figure 1: Density of bentonite mud (left) and sepiolite mud (right)

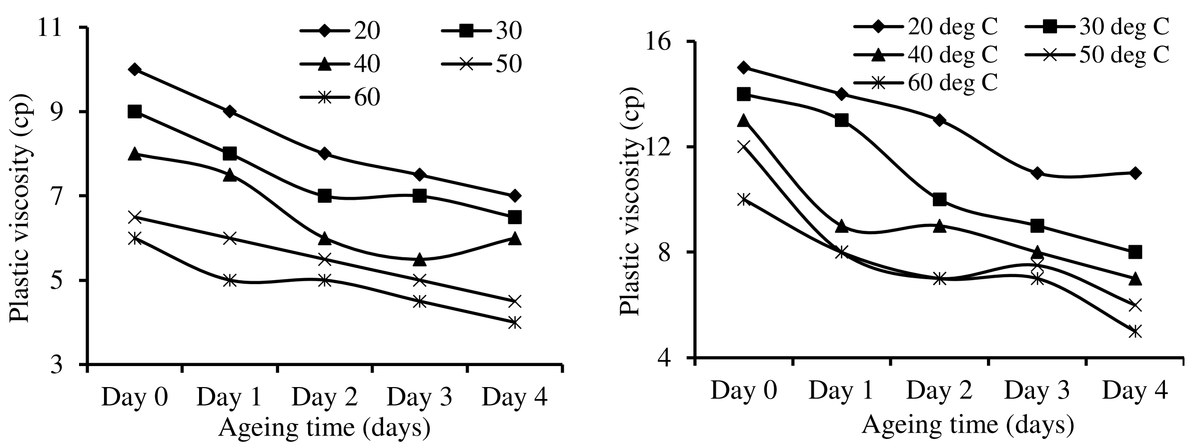

Figure 2: Plastic viscosity of bentonite mud (left) and sepiolite mud (right)

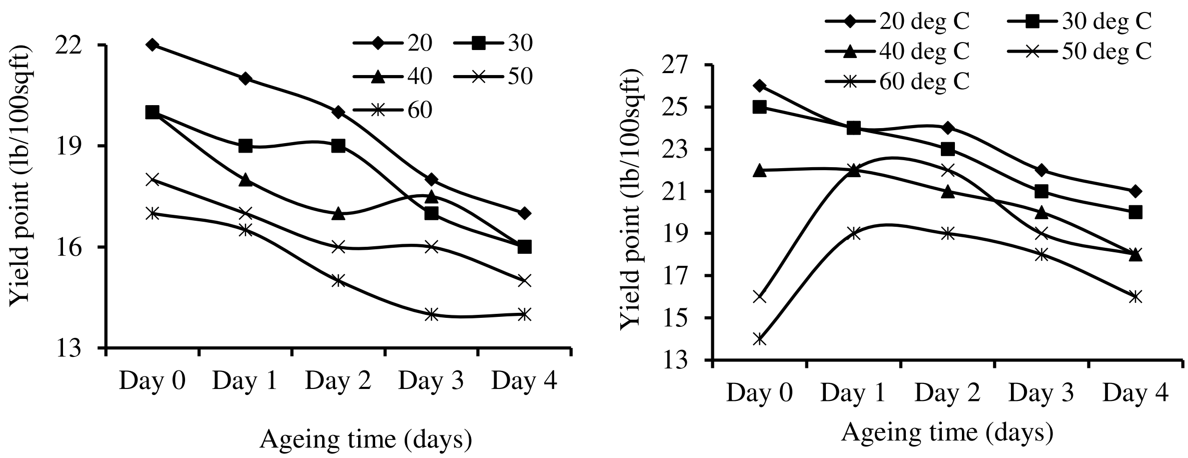

Figure 3: Yield point of bentonite mud (left) and sepiolite mud (right)

The results for gel strength of bentonite (a) and sepiolite (b) as a function of temperature and ageing time are presented in Figure 4. These results showed that the gel strength of both muds increased as ageing time increased. Similarly, for the same ageing time, gel strength decreased as temperature increased. Gel strength of bentonite is slightly higher than that of sepiolite. This means that bentonite muds have the ability to contain more solids once circulation is stopped but at the same time the higher gel strength has a negative effect since the higher pressure is needed to break the gel to resume circulation of the mud (Bjørkevoll et al., 2003). Care must be taken in breaking this gel. Application of too much pressure can cause formation fractures which can result to loss circulation or kicks. From this, it can be deduced that though the bentonite mud offers higher gel strength it is preferable to use sepiolite mud since it also offers a good gelling property.

In this work, pH of both muds was found to be almost the same at day 0 at 20℃ as shown in Figure 5. Results obtained from the pH test of bentonite mud shows that the pH turns slightly alkaline from its neutral initial reading of 7.8 to 9.95 at 20℃ after been aged for 4 days. With sepiolite mud, the initial pH was 8.1 and there was not much difference even after been aged. Both muds show a decrease in pH at the same ageing time as temperature increased.

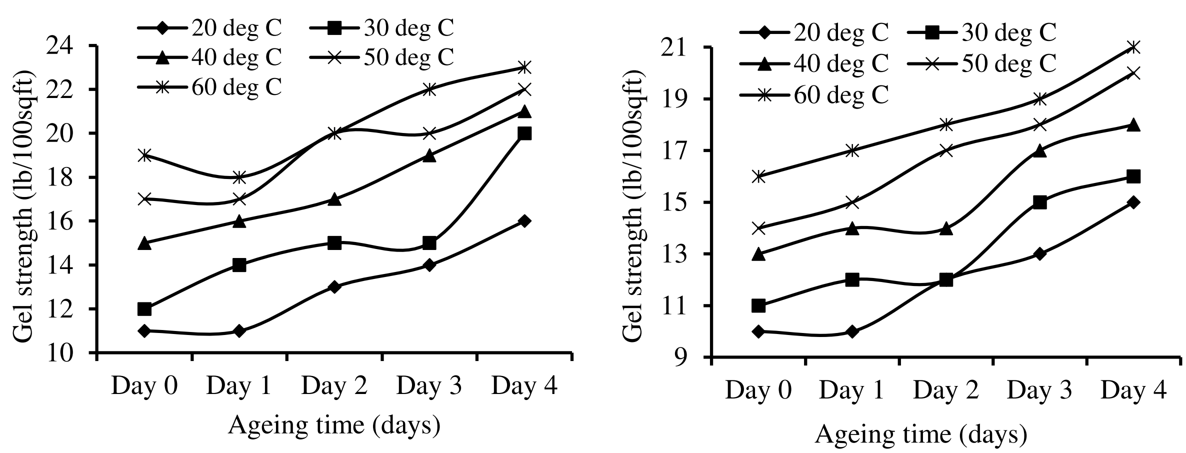

Figure 4: Gel strength of bentonite mud (left) and sepiolite mud (right)

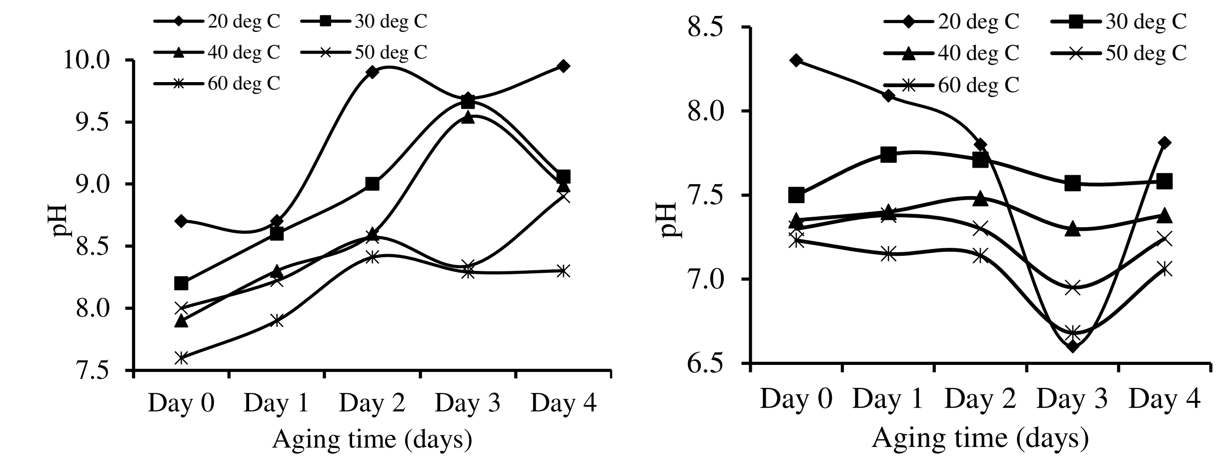

Figure 5: pH of bentonite mud (left) and sepiolite mud (right)

3.2. Effect of Temperature and Ageing on Bentonite Treated with Xanthan Gum

In the second part of the work, the mud rheological properties of a sample treated with 250 mg/L of Xanthan gum were studied with respect to ageing time at different temperatures. According to Zhu et al. (2021) nearly 40% xanthan gum is used in drilling and oil production in the United States and Western Europe due to its strong viscosity, salt-resistance, pollution resistance, and shear stability. In this part of the work, a 1% concentration of Xanthan gum reported to be commonly used for drilling fluid formulation was used (Wang, 2015). The result obtained for the effect of temperature and ageing time on drilling fluid treated with 250 mg/L Xanthan gum are presented in Figures 6 to 9. Figure 6 shows that the plastic viscosity of the treated mud decreased with ageing time similar to the untreated discussed earlier, but in this case, since treated, the mud offers a higher viscosity at all ageing time. From **Error! Reference source not found.**6, it can be seen that the mud treated with 250 mg/L of xanthan gum gives a viscosity similar to that of the sepiolite mud. A rise in temperature causes the plastic viscosity to reduce.

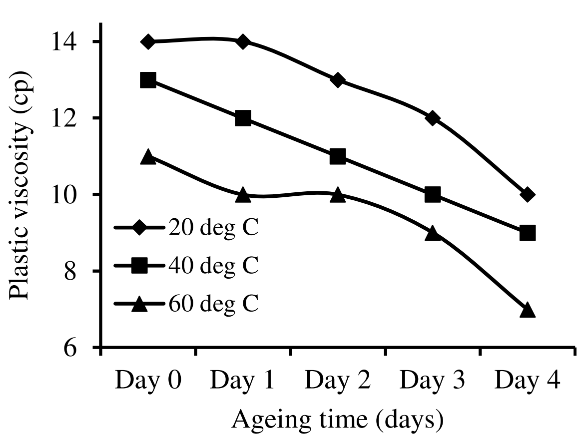

Figure 6: Plastic viscosity as a function of ageing time at different temperature of bentonite mud + 250 mg/L xanthan gum

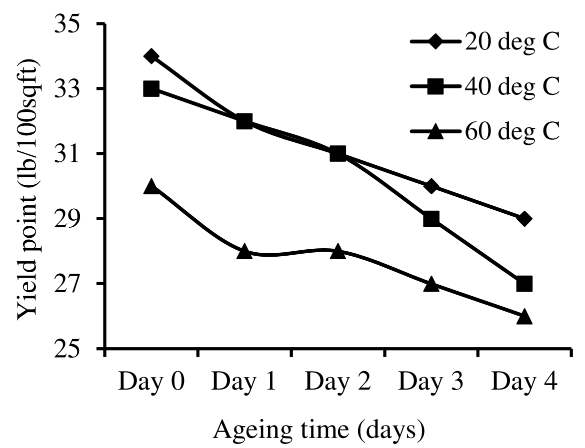

Figure 7: Yield Point as a function of ageing time at different temperature of bentonite mud + 250 mg/L xanthan gum

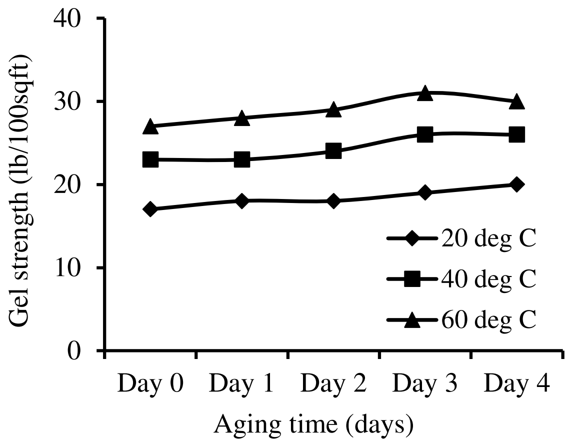

Figure 8: Gel Strength as a function of ageing time at different temperature of bentonite mud + 250 mg/L xanthan gum

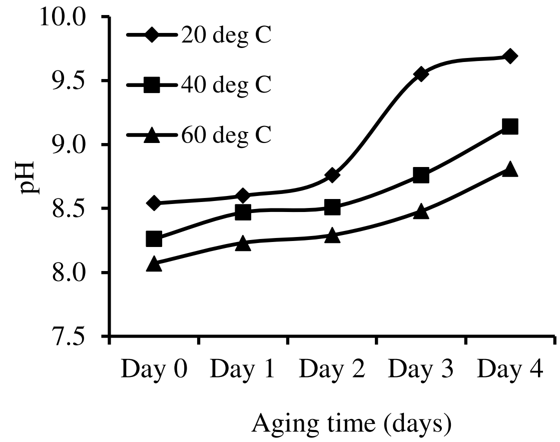

Figure 9: pH as a function of ageing time at different temperature of bentonite mud + 250 mg/L xanthan gum

The yield point of bentonite mud treated with 250 mg/L xanthan gum as shown in Figure 7 decreased slightly with ageing. For the same ageing time, an increase in temperature caused a decrease in the yield point. An increase in gel strength was obtained from Figure 8 as the ageing time increases. Therefore, as ageing increases, the internal structure of the mud becomes stronger and will require more pressure to initiate flow. Secondly, gel strength is greatly affected by the temperature of the treated mud. pH was found to be slightly alkaline between 8 – 10 as shown in Figure 9 where a gradual increase is obtained as the ageing time increases. In addition, an increase in temperature leads to a decrease in the pH for the same ageing time.

3.3. Effect of Xanthan Gum on Rheological Properties

The third part of this work investigated the effect of temperature and concentration of Xanthan gum on the rheological properties of bentonite water-based drilling fluid. Xanthan gum concentrations of 250 mg/L, 500 mg/L, 750 mg/L and 1000 mg/L representing 1%, 2%, 3% and 4% were prepared and analyzed. Figure 10 present the results of plastic viscosity against the concentration of xanthan gum.

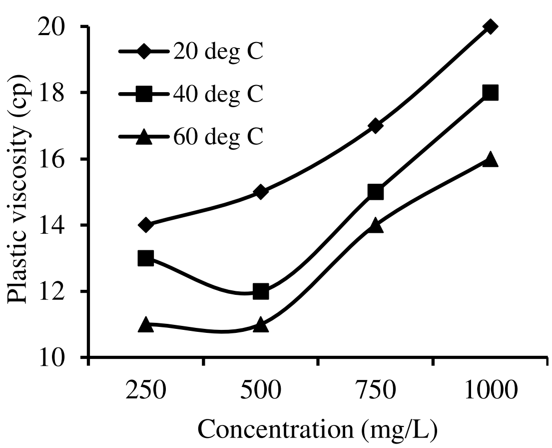

Figure 10: Plastic viscosity as a function of concentration of xanthan gum at different temperatures of bentonite mud

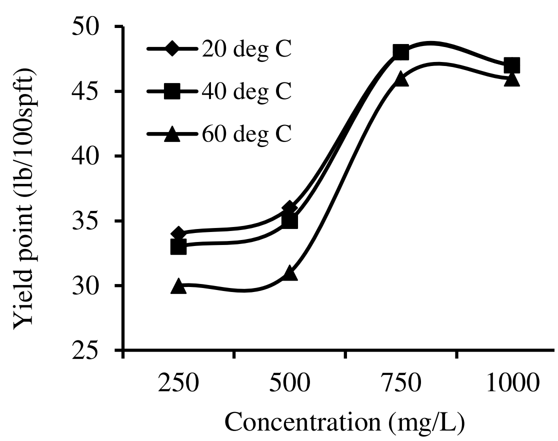

Figure 11: Yield point as a function of concentration of xanthan gum at different temperatures of bentonite mud

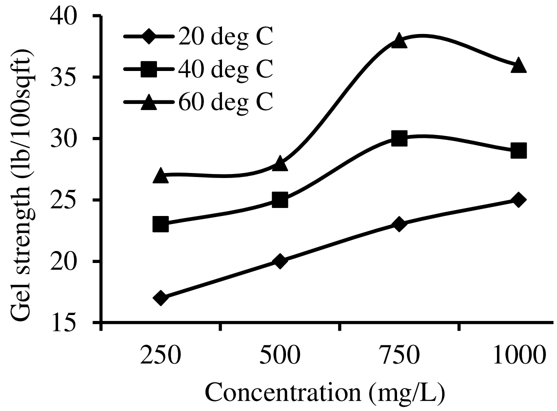

Figure 12: Gel strength as a function of concentration of xanthan gum at different temperatures of bentonite mud

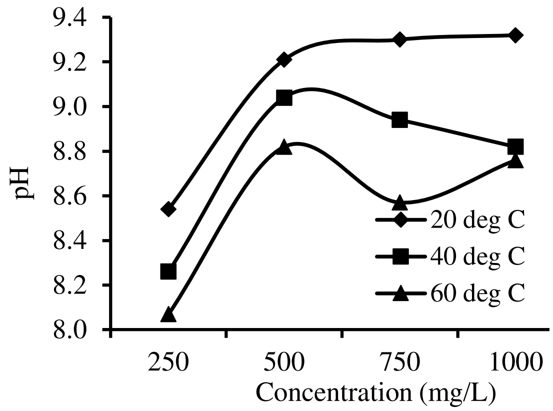

Figure 13: pH as a function of concentration of xanthan gum at different temperatures of bentonite mud

From this result, it can be observed that the plastic viscosity of bentonite mud increased with increase in the concentration of xanthan gum in the sample. It was found that for the same concentration of additive, plastic viscosity of the mud decreased as the temperature was increased. Result of the yield point as a function of concentration of Xanthan gum at different temperatures of bentonite mud are presented in Figure 11. Similar to the plastic viscosity, the yield point of bentonite mud increased as the concentration of additive increased. A step increase in yield point of the mud is observed as the concentration of xanthan gum increased from 500 to 700 mg/L. Figure 12 present the result of gel strength against the concentration of xanthan gum. From this result, it is clear that the muds ability to form gel once circulation is stopped increased as the concentration of xanthan gum increased. Also, an increase in temperature improved the gel strength property of the mud. Figure 13 present the result for pH against xanthan gum concentration at different temperature conditions. From the result a slightly basic pH that ranges from between 8 to 10 was obtained for all ageing time and temperatures studied. It is clear from Figure 13 that for all concentrations of xanthan gum considered, an increase in temperature slightly decrease the pH of the bentonite water-based drilling fluid.

4. CONCLUSION

The performance of drilling fluid affects the overall drilling efficiency. Hence, drilling fluids must be formulated and controlled properly. Test conducted in this work shows that most of the properties of water-based drilling mud are affected by ageing and temperature. From the results obtained, it can be concluded that:

i. The plastic viscosity and yield point of bentonite and sepiolite water-based drilling fluids decrease as ageing and temperature increase.
ii. Sepiolite water-based drilling fluid produces higher viscosity and yield point values as compared to bentonite muds showing that it offers a greater hole cleaning capacity than bentonite water-based drilling mud.
iii. Density of both bentonite and sepiolite mud slightly decrease with increase in temperature but is not affected by ageing time.
iv. The plastic viscosity, yield point and gel strength of bentonite mud increases as concentration of xanthan gum added as an additive to the mud increases.
v. Higher values of plastic viscosity and yield point were obtained after treating the mud with xanthan gum. Both of which decreases with ageing and temperature.

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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