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Effect of Temperature on Oil-Based Drilling Fluid Formulated from Castor Seed Oil and Locally Sourced Nigerian Tongo Bentonite

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Abstract

This research work is aimed at investigating the effect of temperature on oil-based drilling fluid formulated from castor seed oil and locally sourced Nigerian Tongo bentonite. Two different drilling fluids were formulated as formulation A and B, using oil to water ratio of 60:40 of 350ml. Poly anionic cellulose (PAC) was added to formulation B as a viscosifier. Water-based drilling fluid was also formulated to serve as control, which is referred to as formulation C. The rheological properties of the formulated drilling fluids were determined at various temperatures in order to identify the most suitable mud type for high temperature drilling operations. Formulation B has the best rheology with apparent viscosity (AP) of 142.5, 130, 105.5, 75 and 61 cP, while its plastic viscosities (PV) were found to be 82, 80, 63, 60 and 43 cP, and yield point (YP) of 121, 100, 85, 30 and 16 Ib/ft^2 respectively. These values were compared with the water-based formulation (C) having AP of 21, 22, 23.5, 24.5 and 26 cP, PV of 12, 14.8, 14, 14.1 and 16.5 cP, YP of 18, 16.4, 19, 20.8 and 19 lb/ft^2 at temperatures of 30, 60, 90, 120 ^{and} 150 ^{o}C respectively. The mud weight for all the formulations is within the range of 8.80 to 8.88 lb/gal. The results indicate that the formulation B can withstand high temperature condition, therefore, it can be used for drilling application at high temperature reservoir condition. It is also environmentally friendly which can replace diesel oil.

1. Introduction

Drilling fluids are commonly referred to as drilling muds and they are mixtures of natural and synthetic chemical compounds. They are also important part of drilling oil and gas wells that serve the functions of cooling and lubricating the drill bit, cleaning the hole bottom, carrying cuttings to the surface, controlling formation pressures, and improving the function of the drill string and tools in the hole [1].

Drilling fluids are usually formulated to meet certain properties to enable them to carry out the basic intended functions. The most prevalent problem affecting the drilling fluids in high temperature conditions is the potential destruction of the mud properties under such elevated pressures and temperatures. Hence it requires a proper balance of mud properties to avoid oil and gas surge, kicks, formation damage and other drilling hazards associated with high temperatures oil and gas wells [2]. A drilling fluid must have the ability to drill the formation where the bottom whole temperatures are excessively high, especially in the presence of contaminants it can be formulated to withstand high temperatures over long periods of time, however, drilling fluids are designed to ensure that they perform their functions as efficiently as possible throughout the period for which they are used. Periodic fluid testing and treatment are carried out to replace additives that may have been spent or to enhance certain properties (such as mud weight, viscosity or fluid loss control) as may be necessary to drill upcoming hole [3].

The water-based mud (WBM) are mainly composed of aqueous solutions of polymers and clays in water or brines, with different types of additives incorporated to the aqueous solution [4]. WBM is most commonly used drilling fluid due to lower cost and ease of formulation. WBM can break down and lead to loss of viscosity and fluid loss control. For high temperature operations both water-based mud and oil-based mud have been used, however, in reality oil-based mud is more widely used to overcome problems in high pressure high temperature (HPHT) conditions [2]. Some other advantages of the application of oil-based mud are shale stability, faster penetration rates, providing better gauge hole and not to leach out salt. On the other hand, the oil-based muds have thrive in the petroleum industry despite being more costly when compared with their water based counterparts because of their good rheological characteristics at temperatures as high as 500 °F exhibiting better stability and their effectiveness against all types of corrosion, and superior lubricating characteristics [5]. However, in recent times base on various researches, it was established that petroleum oil-based drilling fluid have toxic and high aromatic content which cannot be easily disposed in any geographical locations, especially for environmentally sensitive offshore areas [6].

Petroleum oil-based drilling fluid does not biodegrade easily, so toxins can persist for a long time with serious environmental impact such as death of plant and animals, disrupted reproductive cycles, etc. Therefore, various research works have been done in replacing the high aromatic oil with vegetable oil-based drilling fluid, which has the characteristics of biodegradability, low toxicity and environmentally friendly and can withstand greater heat without breaking down [7]. Castor oil has an advantage over other mineral oils because it is biodegradable, eco-friendly and renewable resource [8]. Castor seeds contain averagely 46 – 55 % oil by weight even though there are various species of the seeds. The fatty acid composition of a typical castor oil contains about 87% of ricinoleic acid [9]. The oil has unique properties such as great affinity for metal surfaces and highl polar [10]. Therefore, there is need to further investigate the thermal stability of castor oil when used as a major consttuent of oil-based drilling fluid for high temperature drilling application.

The aim of this research work is to investigate the effect of temperature on oil-based drilling fluid formulated from castor seed oil, locally sourced Tongo bentonite and poly anionic cellulose as a viscosifier. Bentonite and polymers play an important role in drilling fluid viscosity control. Bentonitic clay plays in addition a central role for wellbore stability [11]. Use of some organic emulsifiers (like Gum Arabic) in clay water/oil drilling fluids can provide a greater degree of stabilization to the emulsions [12].

2. Materials and Methods

The major materials used in this research work are; Castor oil, Tongo bentonite (obtained from Gombe State, Nigeria) and Wyoming grade bentonitic clay, poly anionic cellulose, Gum Arabic and distilled water.

2.1 Drilling fluid formulation

Two drilling fluids were prepared using 60:40 ratio of castor oil and water respectively, as the base fluid and the third formulation was water-based fluid as depicted in Table 1. The measured materials for each formulation were thoroughly mixed using Hamilton Beach Mixer until homogenous mixtures were achieved. The formulated fluids were then stored into mud sample containers, labeled as A, B and C and allowed to age for 24 hours.

Table 1: Composition of drilling fluids

Drilling Fluid Constituents	Measured Quantity		
	A	B	C
Castor oil (ml)	210	210	-
Water (ml)	140	140	350
Bentonite (g)	24.5	24.5	24.5
Gum Arabic (g)	2.0	2,0	2.0
Polyanionic cellulose (PAC) (g)	-	2.0	-

2.2 Mud Viscosity Measurement

The formulated drilling fluid A was heated to a temperature of 30 ^{o}C using a hot plate, it was then poured into the cup of the fann viscometer and placed on the viscometer stand. The stand was adjusted and held in position as the rotor sleeve was immersed in the cup containing mud at exactly the fill line and then the lock knot on the platform was tightened. The speed selector knob was selected to rotate at 600 rpm and the power was switched on. The 600 rpm dial reading was recorded when a steady dial reading was established. The speed selector knob was then set to proper position of the viscometer switch and gear knob as shown in Table 2, and then the respective dial reading values for 300, 200, 100, 6 and 3 rpm were recorded after establishing steady dial readings. The above procedure was repeated for the temperature of 60, 90, 120 and 150 ^{o}C respectively. The entire procedure was then repeated for formulated drilling fluid B and C respectively. Consequently, the yield point, plastic and apparent viscosity were calculated as explained by [13].

Table 2: Speed combination of Fann viscometer.

Speed RPM	Viscometer Switch	Gear knob
600	High	Down
300	Low	Down
200	High	Up
100	Low	Up
6	High	Center
3	Low	Center

2.3 Mud Weight and Volume

The mud weights of the various heated samples with temperatures 30 , 60 , 90 , 120 and 150 ^{o}C respectively were carried out firstly by determining their densities through measuring the respective mass of the formulated drilling fluid using weighing balance and then measuring their respective volumes using a measuring cylinder. The densities of the fluids were calculated from the mud masses and volumes using equation 1. The values were then converted to lb/gallon by multiplying mud density (g/cm^3) by 8.33 as explained by [14].

$$\text{Density } (g/cm^3) = \frac{Mass}{Volume} \text{ .... } 1$$

3. Results and discussion

3.1 Effect of Temperature on the Viscosity of the Formulated Drilling Fluid

The viscosity readings for all the formulations are presented in Figures 1 to 4. Viscosity is the representation of a fluid's internal resistance to flow, defined as the ratio of shear stress to shear rate. The dial reading values from Figure 1 to 4 depict the viscosity values for the formulated drilling fluid at different temperatures. The plots show that the viscosity of the formulated fluids slightly decreases as temperature increases (inversely proportional) for formulations A and B. While, for the formulation C (water-based fluid) at dial readings 600 rpm and 300 rpm showed inclined increase (42 - 52 and 30.5 - 35.5 cP) from temperature 30 ^{o}C – 150 ^{o}C respectively. This means that with increase in temperature, the viscosity of the water-based fluid becomes thicker. It was observed that generally, the oil-based drilling fluids exhibit higher dial readings (viscosity) than the water- based sample.

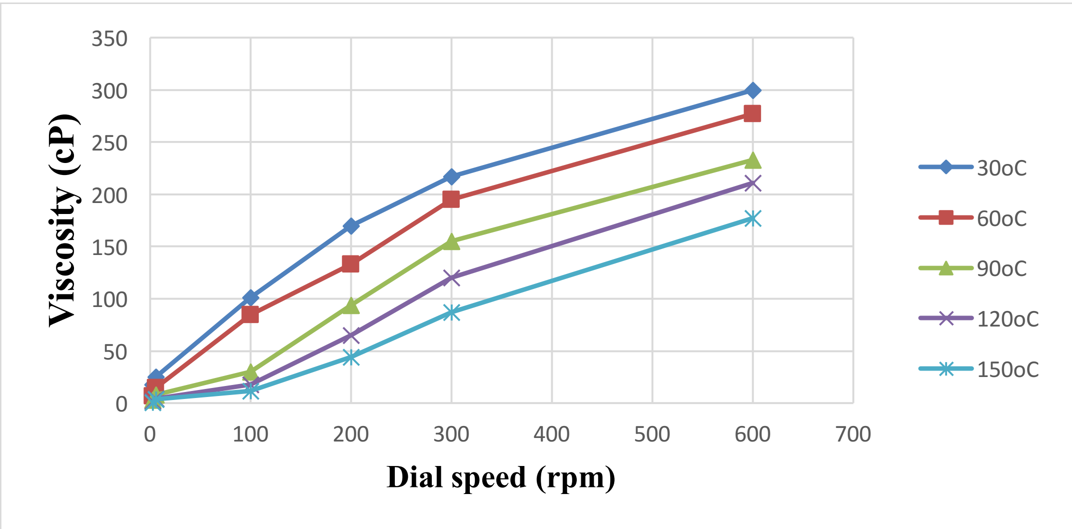

Figure 1: Viscosity of castor oil at different temperatures

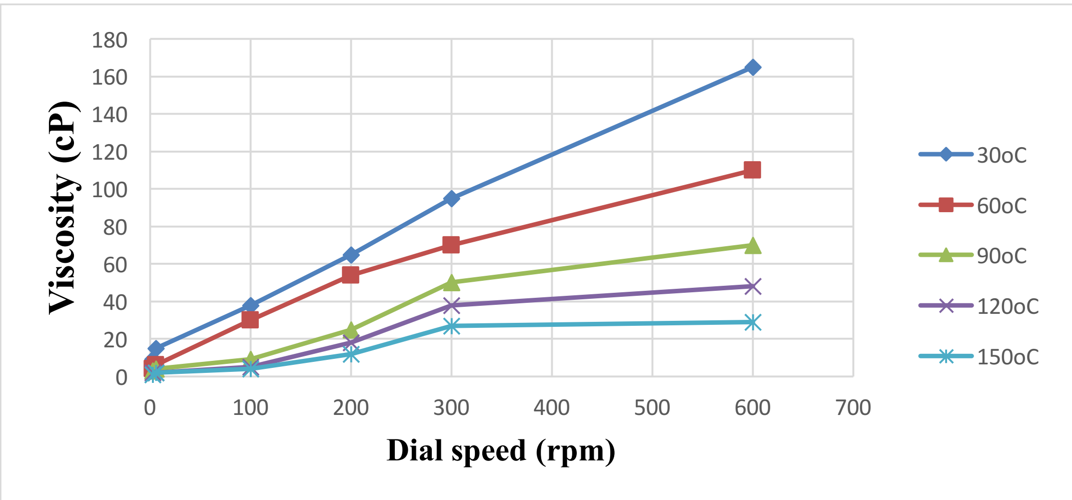

Figure 2: Viscosity of sample A at different temperatures

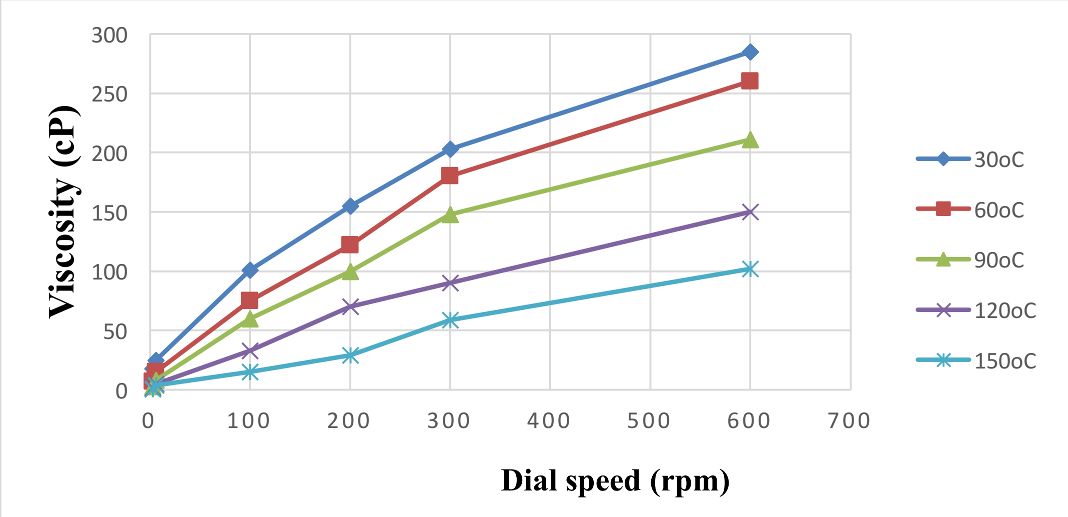

Figure 3: Viscosity of sample B at different temperatures

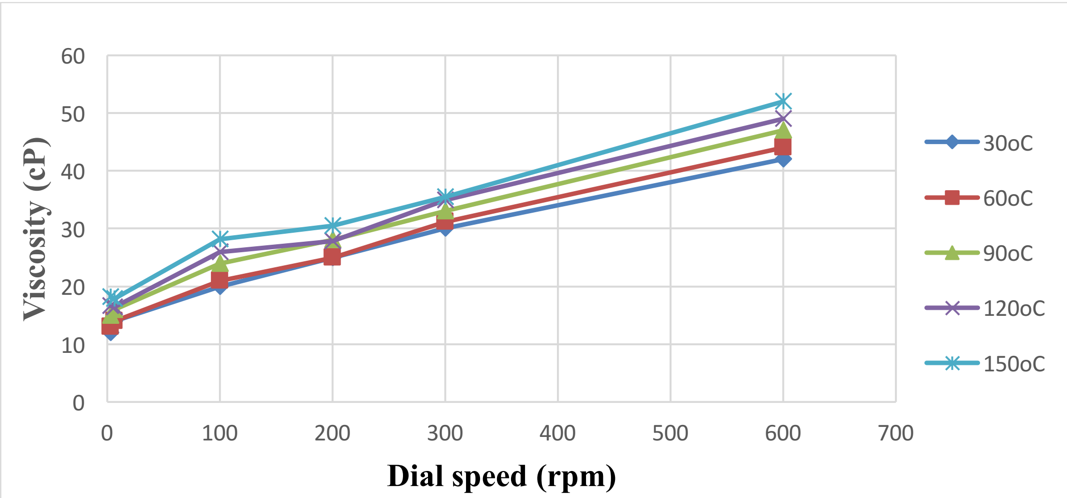

Figure 4: Viscosity of sample C at different temperatures

3.2 Effect of Temperature Variation on the Viscosities of Different Formulations

The comparative analyses of the effect of temperature variation at 30, 60, 90, 120 and 150 ^{o}C on the viscosities of different formulations A, B and C are shown in Figures 5 to 9, and all the samples depict change in viscosity with increase in temperature. The viscosity of the formulated drilling fluid was highest at 30 ^{o}C than at other temperatures of 60, 90, 120 and 150 ^{o}C. Then the viscosity steadily decreased as the temperature was increased. Highest viscosity values were obtained from formulation B compared to formulations A and C. At the same viscometer dial speed of 600 rpm and temperature of 30 ^{o}C, the viscosities were 165, 285 and 42 cP for sample A, B, and C respectively. The viscosities of the sample B were higher than those of samples A and C. This is expected because of addition of poly anionic cellulose (PAC) to the formulation. Even at higher temperatures, the viscosities of the oil-based formulations (A and B) were still higher and more stable than the water-based formulation C. This is a clear indication that in the high temperature reservoir condition, oil-based drilling fluids would perform better than water-based drilling fluids in terms of mud stability, cooling effect and enhancement of its ability to suspend and carry cuttings from formation to the surface. Formulation A shows consistent good premise at all temperatures except at 120 ^{o}C where the viscosities of the sample C were higher. Generally, though, drilling fluids with lower viscosities at higher temperatures give better overall performance than the more viscous type.

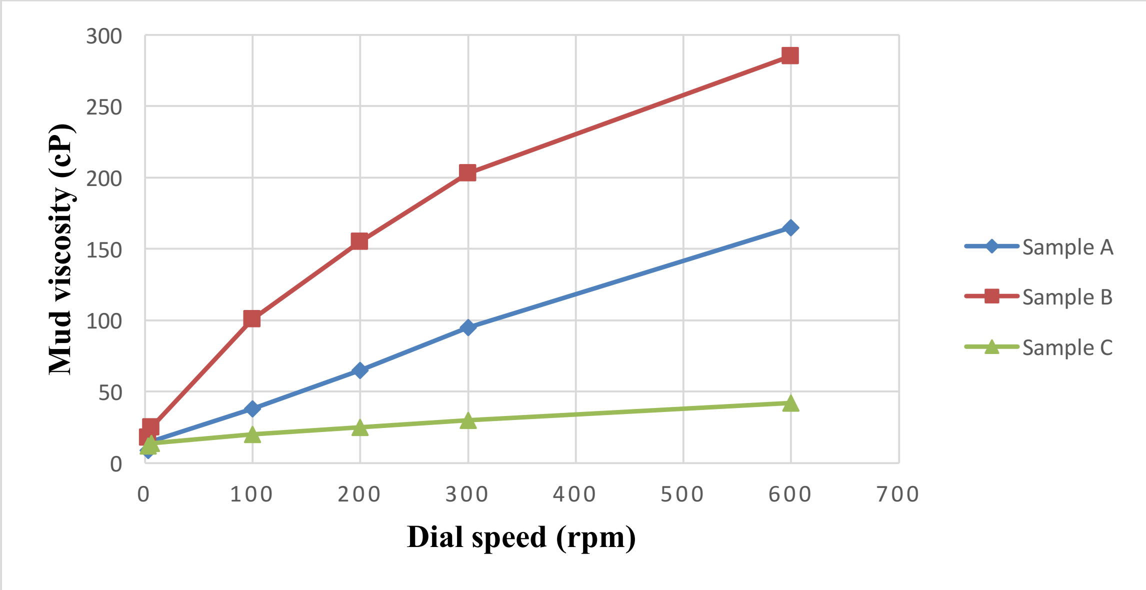

Figure 5: Effect of temperature on viscosity of various formulations at 30 °C

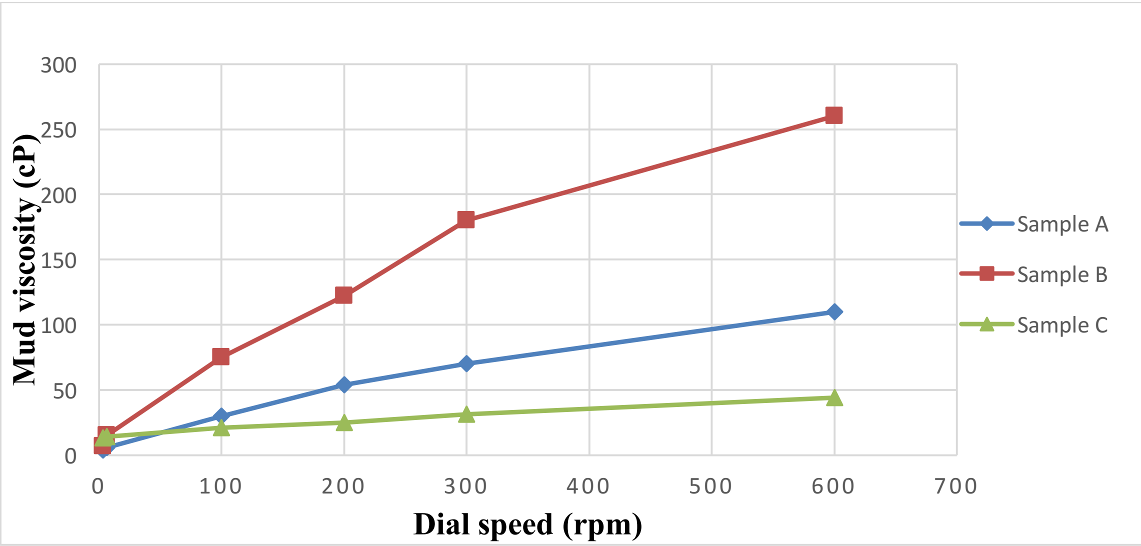

Figure 6: Effect of temperature on viscosity of various formulations at 60 °C

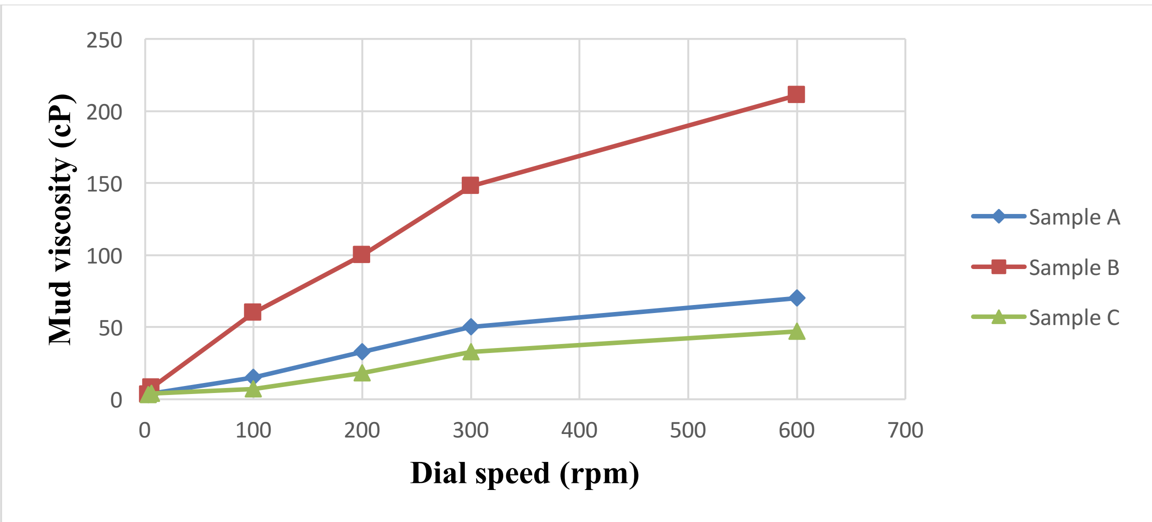

Figure 7: Effect of temperature on viscosity of various formulations at 90 °C

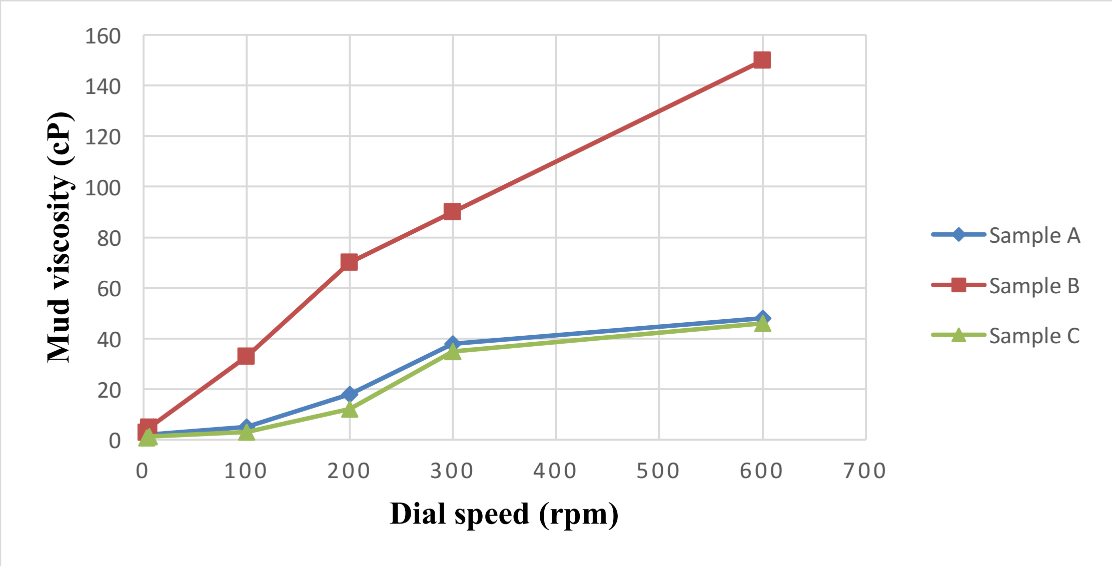

Figure 8: Effect of temperature on viscosity of various formulations at 120 ^{o}C

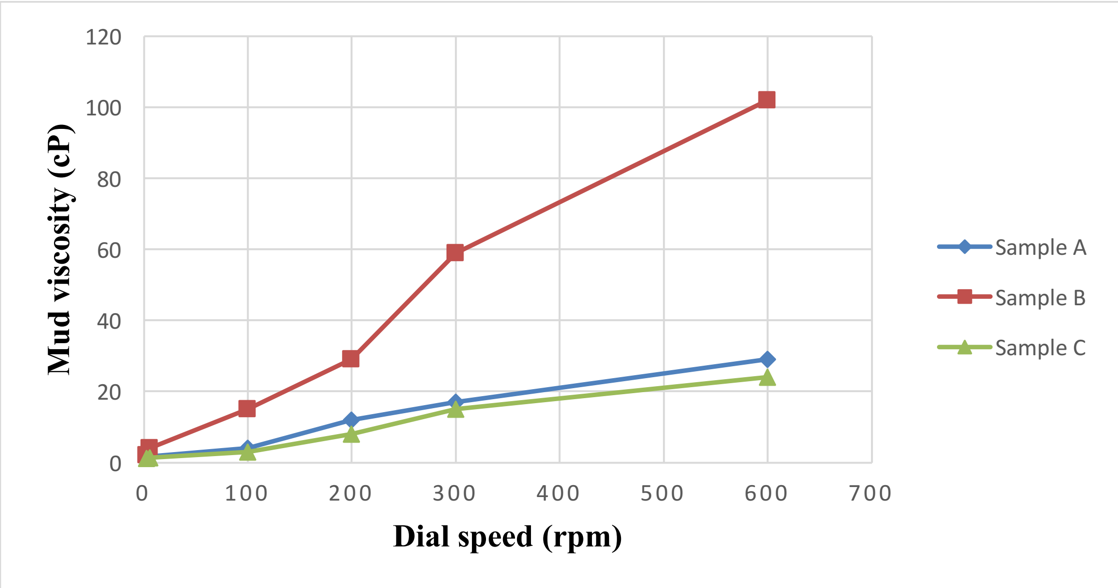

Figure 9: Effect of temperature on viscosity of various formulations at 150 ^{o}C

3.3 Effect of Poly Anionic Cellulose (PAC) on The Viscosity of Oil-Based Drilling Fluid

The viscosity of the oil-based drilling fluid was tested by adding 2 g of PAC to the oil-based mud (formulation B). Figure 10 shows that the viscosity of the drilling fluid increases with the addition of PAC. The viscosity almost doubled with the addition of PAC. At dial speed of 600 rpm the viscosity of formulation A (without PAC) was 165 cP while that of formulation B (with PAC) was 285 cP. PAC is a thickening agent and stabilizing agent used in oil drilling fluid for fast penetration.

3.4 Effect of Temperature on the Rheological Properties

3.4.1 Apparent viscosity

The Apparent viscosity values for the various formulated drilling fluids with change in temperature are shown in Figure 11. Similar to viscosity, apparent viscosity for formulations A and B revealed that it is generally higher at low temperatures. The apparent viscosity of the drilling fluid formulations A, B and C at 30^{o}C were 82.5, 142.5 and 21 cP respectively. Generally, the apparent viscosity of the oil-based formulations A and B were higher than that of the water-base formulation (C). This is means that in the geological Formations of very high temperatures, oil-based drilling fluid would perform better than water-based in terms of mud stability, cooling effect and enhancement of its ability to suspend and carry cuttings from formation to the surface.

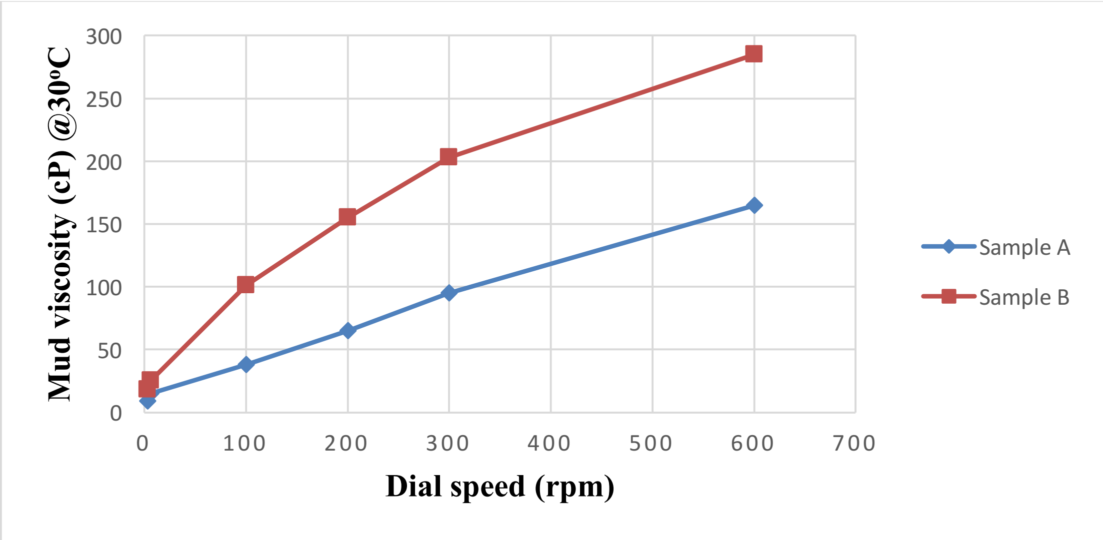

Figure 10: Effect of PAC on oil-based drilling fluid formulations

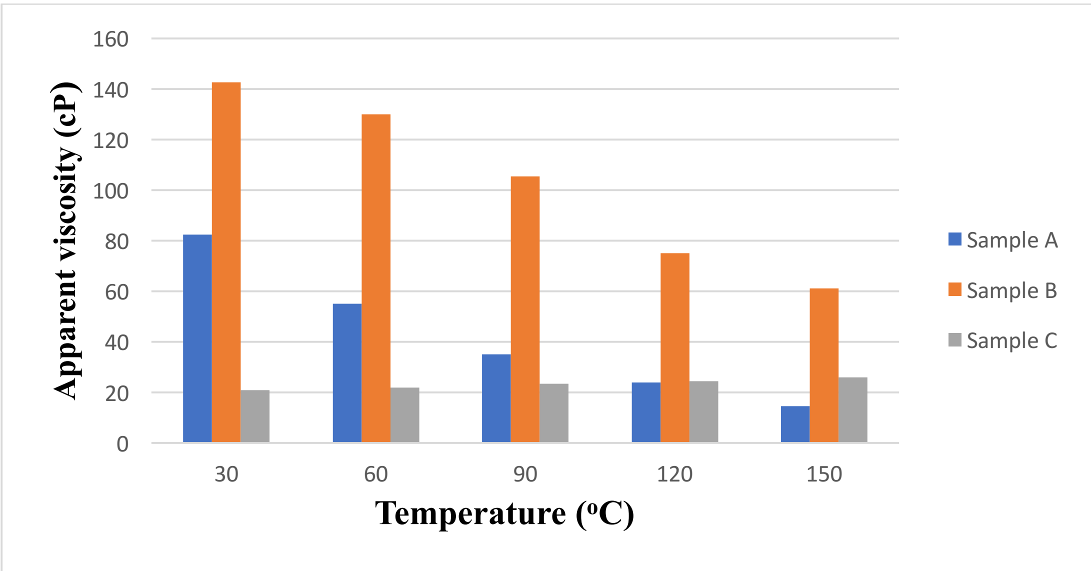

Figure 11: Apparent viscosity of the various drilling fluid samples at different temperatures

3.4.2 Plastic viscosity

Plastic viscosity values for the various drilling fluid formulations at different temperatures are depicted in Figure 12. Similar to viscosity, plastic viscosities for the three formulations indicate that it is generally higher at low temperatures for samples A and B, while it is slightly higher at high temperatures for sample C. The plastic viscosities of the drilling fluids (A, B and C) at 30 °C were 60, 82, and 12 cP respectively.

Generally, the plastic viscosities of the oil-based samples (A and B) were higher than that of the water base mud (sample C). Plastic viscosity of sample A has little bit fluctuation with increasing temperature until temperature 120 °C. It is lower than that of sample C. Addition of 2 g of PAC make the plastic viscosity of the oil-based mud more resistant to temperature even above 150 °C.

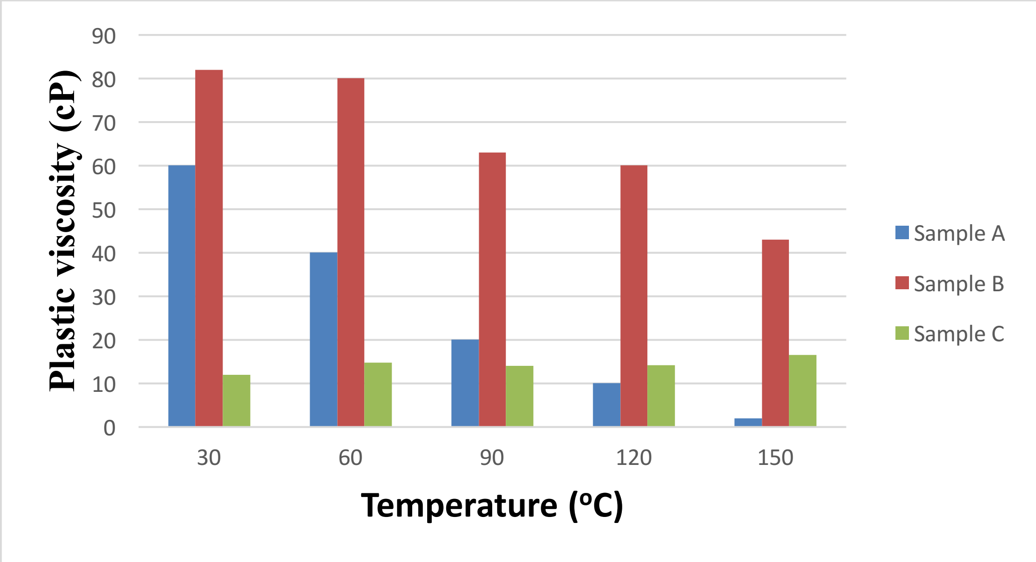

Figure 12: Plastic viscosity of the various drilling fluids at different temperatures

3.4.3 Yield Point

Figure 13 shows the yield point values for the various drilling fluid samples with increase in temperature. The yield point plot for both oil-based drilling fluids show that it is generally higher at low temperatures. The yield points of the formulated drilling fluids A, B and C at 30 ^{o}C were 45, 121 and 18 lb/100ft^2 respectively. The yield point of sample B is much higher. Generally, the yield points of the oil-based samples (A and B) were higher than that of the water-base mud (sample C). The yield point for the oil-based drilling fluid was much higher than the water-based drilling fluid, which enhances the drilling operation.

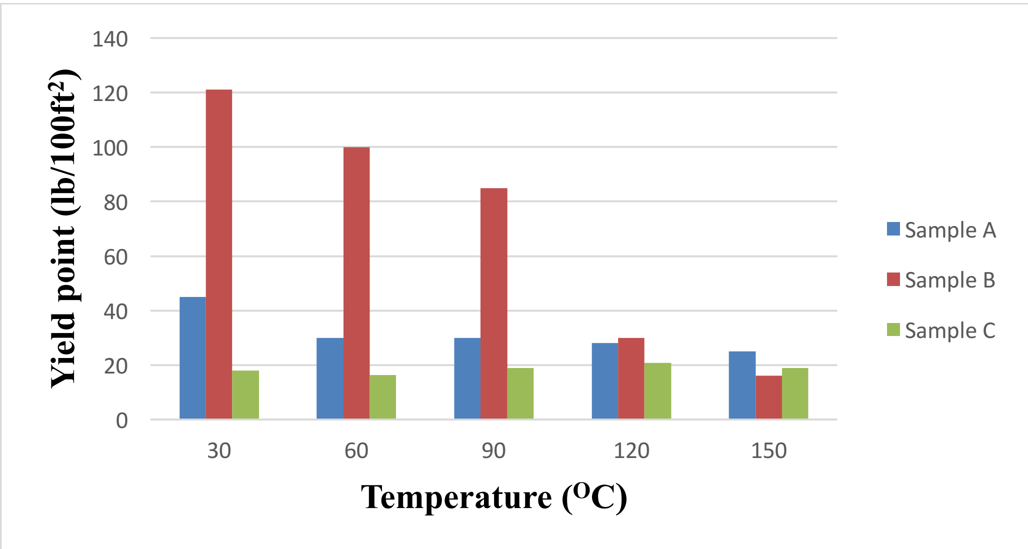

Figure 13: Yield point of the various drilling fluid samples at different temperatures

Yield Point (YP) is the initial resistance to flow caused by electrochemical forces between the particles. Yield Point is dependent upon the surface properties of the mud solids and also the volume concentration of the solids. Yield Point could be used to evaluate the ability of a mud to lift cuttings out of the annulus [2].

3.5 Effect of Temperature on Mud Weight

Densities were measured for the various samples at various temperatures ranging between 30 to 150 ^{o}C. Figure 14 shows an increase in the density of the mud samples. This is because they were heated at constant atmospheric pressure, and in an open system. This could be due to the differences in temperature and heat energy required to dissipate bonds, which vary with fluid properties [15].

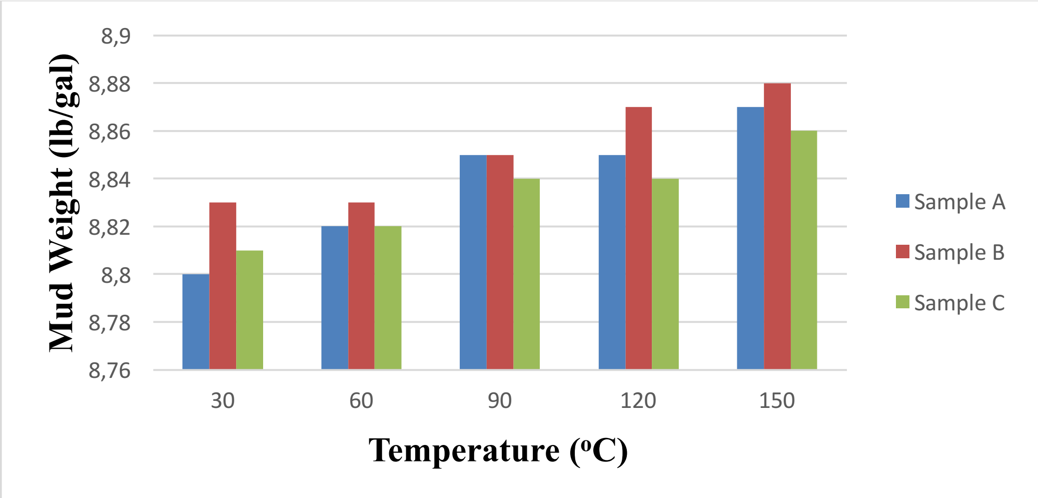

Figure 14: Mud weight of the various drilling fluid samples at different temperatures

At temperatures of 30 and 60 ^{o}C, the densities of sample B are constant (8.83 lb/gal), while at temperature of 90 and 120 ^{o}C densities of samples A and C were constant (8.85 and 8.84 lb/gal). The higher the density of the mud sample, the better it helps to maintain column or hydrostatic pressure and suspend cuttings in the mud leading to better clearing of the bore hole. Although, the density of the mud to be used depends on the reservoir conditions. Some reservoirs require a denser drilling fluid especially when faced with problems like influx of other fluids into the bore. Whereas, some other conditions like lost circulation would require a less dense fluid to regulate it. The performance of the oil-based mud is quite encouraging and thus may serve as potential replacements for water-based mud formulations.

Conclusion

The effect of temperature on oil-based drilling fluid formulated from castor seed oil and locally sourced Tongo bentonite was investigated. Two different drilling fluids were formulated as formulations A and B, using oil to water ratio of 60:40 of 350ml. Poly anionic cellulose (PAC) was added to formulation B as a viscosifier. Formulation B has the best rheology with apparent viscosity of 142.5, 130, 105.5, 75 and 61 cP; plastic viscosity (PV) of 82, 80, 63, 60 and 43 cP, and yield point (YP) of 121, 100, 85, 30 and 16 Ib/ft^2, compared to the water-based formulation (C) with AP of 21, 22, 23.5, 24.5 and 26 cP; PV of 12, 14.8, 14 , 14.1 and 16.5 cP, YP of 18, 16.4, 19, 20.8 and 19 lb/ft^{2}at temperatures of 30, 60, 90, 120 and 150 ^{o}C respectively. The mud weights for all the formulations are within the range of 8.80 to 8.88 lb/gal. The results indicate that at high temperature reservoir condition, the oil-based drilling fluid would perform better than water-based in terms of mud stability, cooling effect and enhancement of its ability to suspend and carry cuttings from formation to the surface. Therefore, the locally sourced Tongo bentonite can be successfully used for drilling fluid formulation and castor oil can serve as a good alternative to diesel as the base fluid to take advantage of its biodegradability and environmental friendliness.

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