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Comparative Study of Impact of Copper (II) Oxide and Silicate Nanoparticles on Viscosity of Water based Drilling Fluid

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Abstract In view of the significance of drilling fluid in the oil and gas industry, the search for ways of improving the rheological properties of drilling fluids is a worthy task to the industry. This research work was aimed at investigating how drilling fluid rheological property can be improved using silicate and copper (II) oxide (CuO) nanoparticles. Water based drilling fluids (WBDF) were prepared using the standard laboratory barrel (350 ml) method from bentonite, xanthan gum and water while the nanoparticles were introduced into the formulation in different concentrations. The rheological properties of the samples were determined using Brookfield rotational viscometer and the structural analysis of the interaction between the nanoparticles and the xanthan gum were determined using Fourier Transformation Infra-red (FTIR) spectroscopy. The results revealed that CuO and Silicate nanoparticle improved the rheological properties of the water based drilling fluid. The CuO at ratio 1:3 with xanthan gum at 30 rpm shear rate increased the viscosity of the drilling fluid from 192.3 to 2543.7mPa.s while the silicate nanoparticles of similar concentration with xanthan gum at 30 rpm shear rate increased from 192.3 to 1771.1 mPa.s at 31.5 ^{o}C. FTIR analysis of the nanoparticles and xanthan gum showed that improvement in the rheological properties of the drilling fluids resulted from the bonds between these nanoparticles and xanthan gum. It is concluded that introduction of Silicate nanoparticles and CuO nanoparticles improved the rheological performance of water based drilling fluids with xanthan gum additive with Silicate nanoparticles exhibiting less improvement than the CuO.

Keywords WBDF, nanoparticles, xanthan, copper (II) oxide, silicate

1. Introduction

Drilling fluid is an integral part of the drilling process in oil and gas industry, hence, many of the problems encountered during drilling of a well can be directly or indirectly attributed to the drilling fluids. The effectiveness of the drilling fluid to perform its primary functions is based on its properties, which are formulated continuously to meet the formation conditions encountered during drilling operations. Failure of the drilling fluid to meet its designed function can prove extremely costly in terms of materials and time, may jeopardize the successful completion of the well and even result in major problems such as stuck pipe, kicks or blowouts [1]. Drilling fluid is an assortment of fluid, basically a mixture of clay, water, minerals and additives which is pumped through the drill string and continuously introduced to the bottom as it squirts out from the drill nozzles. Some of its uses are drilling of deep wells to clean and transport the rock cuttings, maintain the whole integrity, lubricate and cool the drill bit, control the formation pressures. One of the challenges related to drilling deep wells is to maintain the desirable rheological properties of the drilling fluid [2-3]. Environmental and economic considerations have led to the increasing use of the water-based drilling fluids in applications where oil based drilling fluid have previously been preferred, including high-temperature, high-pressure (HTHP) wells. Due to their reputation as easy to maintain, economically competitive drilling fluids, water-based drilling fluids are among the most popular drilling fluids [3]. They can be designed and engineered to be suitable for high temperature and pressure environments. William *et al*. [4] investigated the effect of CuO and ZnO nanofluids combined with Xanthan gum on the thermal, electrical and rheological properties of the water-based drilling fluids. Result showed that the increased concentration of nanoparticles enhances electrical and thermal properties and improves rheological stability when using the nanofluid-enhanced water drilling mud. Moreover, these results are the same as those of additives such as carbon black [5] and multiwall carbon nanotube [2, 6]. Impact of nanoparticles on drilling fluid in various other capacities were investigated by some other researchers [7– 17]. Viscosifying agents like starches, polyacrylates, xanthan gums and a wide variety of synthetic and natural polymers are used to establish and control the rheological properties of water based drilling fluid. However, they are exposed to temperatures that can be in excess of 149^{o}C during the course of drilling a subterranean well and exposure to such temperatures can have a detrimental effect on the viscosifying agents. This will cause loss in velocity of the fluid and a breakdown of the rheology of the fluid. The breakdown of the rheology of water based drilling fluid could make it unable to suspend solid (weighting, bridging agent or drill cuttings) dispersed within it and lead to severe problems such as settlement, loss in fluid density and possibly a blowout of the well. Drilling fluid must have the correct heat transfer and fluid flow characteristics to function in an effective manner, so the use of CuO and silicate nanoparticles to improve the rheological properties such as viscosity etc. of water-based drilling fluids is essential in a drilling process. Thus, in this study, the impacts of combination of xanthan gum and nanoparticles of silicates and CuO in different ratios on viscosities of water-based drilling fluids were investigated. FTIR analysis was used to investigate the interactions of the structures of the nanoparticles with the xanthan gum in different proportions. This study is a follow-up to the previous one done by the members of this research team.

2. Materials and Method

2.1. Materials

Materials used for the study were of high purity and analytical grade. The bentonite clay used was obtained from standard Nigerian chemicals organization. Xanthan gum, CuO and silicate nanoparticles are products of Sigma-Aldrich. The major pieces of equipment used were Brook-field rotational viscometer (Ndj-8S) and Agilent Fourier transform infra-red (FTIR) spectrometer with range of 4000-650 cm^{-1}.

2.2. Sample preparation

2.2.1. Sample one

Sample one which is the basic water based drilling fluid prepared involved the use of water and bentonite clay:
350 ml of water was measured using a measuring cylinder and was put in a 500 ml beaker. 15 grams of Bentonite clay was weighed using weigh balance and was poured into the beaker containing 350 ml of water. A magnetic stirrer was used to mix the 15 g of bentonite clay and 350 ml of water for 10 mins.

2.2.2. Sample two

The second sample water based drilling fluid prepared involved water, bentonite clay and Xanthan gum:
A measuring cylinder was used to measure 350 ml of water. 15 g of bentonite clay was weighed using weigh balance. Different proportions of Xanthan gum were used for this experiment.

a) 350 ml of water and 15 g of bentonite clay was stirred for 10 minutes in a beaker using a magnetic stirrer. 1 g of Xanthan gum was added and mixed thoroughly for 15 minutes using a magnetic stirrer.
b) A solution containing a thoroughly mixed 350 ml of water and 15 g of bentonite clay using a magnetic stirrer was prepared. 1.5 g of Xanthan gum was mixed thoroughly with the solution for 15 mins using a magnetic stirrer.
c) 2 g of Xanthan gum was weighed using a weigh balance. A solution of 350 ml water and 15 g bentonite clay mixed thoroughly for 10 mins was prepared in a beaker. 2 g of Xanthan gum was mixed with the solution for 15 mins using a magnetic stirrer.

2.2.3. Sample three

Sample three water based drilling fluid involved water, bentonite clay, xanthan gum and Silicate nanoparticle:
350 ml of water was measured using a measuring cylinder and was put into a beaker. 15 g of bentonite clay was measured using weigh balance. Different proportions of Xanthan gum and Silicate were used for this experiment.

a) 350ml of tap water was mixed with 15 g of bentonite clay in water in a beaker. This solution was mixed for 20 minutes. 1 g of Xanthan was weighed and added to the solution, it was mixed for 20 minutes. 1 g of Silicate was weighed, added to the solution and mixed thoroughly for 20 minutes.
b) 350ml of tap water was mixed with 15 g of bentonite clay in water in a beaker. This solution was mixed for 20 minutes. 1.5 g of Xanthan was weighed and added to the solution, it was mixed for 20 minutes. 0.5 g of Silicate was weighed, added to the solution and mixed thoroughly for 20 minutes.
c) 350ml of tap water was mixed with 15 g of bentonite clay in water in a beaker. This solution was mixed for 20 minutes. 0.5 g of Xanthan was weighed and added to the solution, it was mixed for 20 minutes. 1.5 g of Silicate was weighed, added to the solution and mixed thoroughly for 20 minutes.

2.2.4. Sample four

Sample four water based drilling fluid prepared involved water, bentonite clay, Xanthan gum and CuO nanoparticle:
A measuring cylinder was used to measure 350 ml of water. 15 g of bentonite clay was weighed using weigh balance. Different proportions of Xanthan gum and CuO were used for this experiment.

a) 350 ml of tap water was mixed with 15 g of bentonite clay in water in a beaker. This solution was mixed for 20 minutes. 1 g of Xanthan was weighed and added to the solution, it was mixed for 20 minutes. 1 g of CuO was weighed, added to the solution and mixed thoroughly for 20 minutes.
b) 350 ml of tap water was mixed with 15 g of bentonite clay in water in a beaker. This solution was mixed for 20 minutes. 1.5g of Xanthan was weighed and added to the solution, it was mixed for 20 minutes. 0.5 g of CuO was weighed, added to the solution and mixed thoroughly for 20 minutes.
c) 350 ml of tap water was mixed with 15 g of bentonite clay in water in a beaker. This solution was mixed for 20 minutes. 0.5 g of Xanthan was weighed and added to the solution, it was mixed for 20 minutes. 1.5g of CuO was weighed, added to the solution and mixed thoroughly for 20 minutes.

2.3. Sample analysis

2.3.1. Test for viscosity

Viscosity of the prepared water based drilling fluid samples were determined using Brookfield rotational viscometer. For a material of a given viscosity, the resistance will be greater as the spindle size and/or rotational speed increase.

Viscosity= $\frac{shear\ stress}{shear\ rate}$

The model of the Brookfield viscometer used is Ndj-8S digital viscometer. Its measuring range is 20 -2,000,000 mPa.s, and rotational speeds (rpm) of 0.3, 0.6, 1.5, 3, 6, 12, 30, 60 (i.e. eight adjustable speeds). It also consist of various spindles (code L1, L2, L3, L4) and a LCD screen display to display the viscosity, speed, torque, spindle and maximum viscosity can be measured in the current spindle speed value. The prepared solution of drilling fluid was poured into a beaker and placed under the viscometer. A spindle that suits the sample was used and knotted tight at the joint under the viscometer. The viscometer was then adjusted at the knob to the bottom to make the spindle enter the sample placed, the knob was stopped when the "stop-point mark" on the spindle was no longer visible as this indicates that the spindle was well inserted into the solution. The viscometer was powered on, the speed was picked by pressing a button that reads "speed" on it, it was pressed number of times till the speed used was picked, the thermometer from the viscometer was then inserted into the solution/sample to be examined, the spindle used was selected (i.e. spindle 1, 2, 3 or 4). After all these selections, the run viscometer showed the viscosity value button was pressed and the temperature of the sample, the speed and spindle used were recorded. Before another reading was taken, the spindle was removed, washed using distilled water and cleaned using a clean cloth.

In this study, samples 2A, 2B, 2C, 3A, 3B, 4A, 4B used spindle 3 as a result of the obvious thickness in the fluid. They were done individually and each of them was poured into a beaker. The thermometer was inserted into the solution which displayed the room temperature 31.5^o C and a speed of 30 rpm was inputted into the viscometer. The run button was pressed and the value displayed by the viscometer was recorded.
Another analysis was done with a speed of 60 rpm for these samples and the readings were recorded. Samples 2A, 2B, 2C, 3A, 3B, 4A, 4B were heated with the use of heating mantles to a temperature of 40 ^{o}C, these heated samples were taken to the viscometer, using spindle 3 and at a speed of 30 rpm, and the viscosity was recorded. Another reading using spindle 3 and at a speed of 60 rpm was recorded from the viscometer.
These samples were heated again using a heating mantle to a temperature of 45 ^{o}C. These heated samples were taken to the viscometer, using spindle 3 and at different speeds of 30 and 60 rpm, each viscosity value was recorded for each sample.
Sample 1, 3C and 4C used spindle 2 because of their less-thick nature. They were done differently and each of them was poured into a beaker. The thermometer was inserted into the solution and a speed of 12, 30 and 60 rpm were used and two values of viscosity were recorded for each of these samples at 31.5 ^{o}C (room temperature). These samples were heated using a heating mantle and were heated to 40 ^{o}C. The same procedure was used to record the two values for viscosity of each sample. These samples were heated to 45 ^{o}C and the same procedure was used to record the two values of viscosity of each sample at this temperature.

2.3.2. Structure analysis

Fourier transform infra-red (FTIR) equipment was used to carry out the structure analysis of all the three additives and their blends in different ratios in order to evaluate how the structures of the additives affected the properties of the drilling fluids samples. The additives were categorized into samples A to G as follows:
Sample A: 1g Xanthan gum
Sample B: 1g CuO
Sample C: 1.5g Xanthan gum + 0.5g CuO
Sample D: 1g Silicate
Sample E: 1.5g Xanthan gum + 0.5g Silicate
Fourier transform infra-red analysis was done at the central laboratory of Yaba College of Technology, Lagos, Nigeria. FTIR uses an infrared (IR) light source to pass through the sample and onto a detector, which precisely measures the amount of light absorbed by the sample. This absorbance creates a unique spectral fingerprint that is used to identify the molecular structure of the sample and determine the exact quantity of a particular compound in a mixture. An Agilent Fourier transform infra-red spectroscope (range: 4000-650) was used to obtain the infrared radiation for the sample and the result is plotted on a graph of transmittance against wavelength.

3. Results

The results obtained showed that there is decrease in viscosity of the drilling fluid as the shear rates increases at any given temperature (Figures 1, 2 and 3). Thus, the drilling fluids produced are non- Newtonian and shear thinning. Furthermore, the viscosity of the drilling fluid sample increases with increase composition of xanthan gum, at every given temperature, (Figures 1, 2, and 3). This is in agreement with findings of previous researcher that the xanthan gum could act as a viscosifier [18-19]. However, it was observed that as addition of xanthan gum to the water based drilling fluid increases the rate of increase in viscosity tend to reduce for all temperatures considered (Figures 1, 2, and 3). For instance at 31.5^{o}C, the apparent viscosity of the drilling fluid sample at 12 rpm increased from 3236.4 mPa.s at 1 g xanthan gum concentration to 4532.1 mPa.s on addition of 1.5g xanthan gum (Figure 1) while further addition of 0.5g xanthan gum to make it 2 g just increased the apparent viscosity to 4783.5 mPa.s under the same condition (Figure 1). It was also observed that as the temperature increases the viscosity of the drilling fluid reduces (Figures 1, 2, 3). This is in agreement with the findings of previous researchers [18-19].
It was observed from Figure 4 that the little quantity of xanthan gum (0.5 g) and 15 g of CuO had very little impact on the viscosity of the water based drilling fluid sample, which implied that CuO nanooparticles may not

be able to increase the viscosity of the water based drilling fluid. However, the results showed that 1g of xanthan gum and 1g of CuO had appreciable impact on the viscosity of the drilling fluid but not as much as when 1.5 g xanthan gum to 0.5 g CuO concentration was used. Furthermore, the impact of the 1.5 g xanthan gum to 0.5 g CuO in the viscosity was found to be greater than that of sample containing only 2 g xanthan (Figure 4). Thus, a little dosage of CuO with appropriate quantity of xanthan gum mixed in ratio 1 g : 3 g can improved the rheological performance of the water based drilling fluid appreciably for a 350 ml volume and this can be scale-up for larger volume production of water based drilling fluid.

Also, the results obtained showed that addition of silicate nanoparticles to the xanthan gum bentonte mixture formulated drilling fluid had impact on the viscosity of the fluid (Figure 5). A concentration of 1 g silicate and 1 g xanthan gum in the drilling fluid samples gave higher apparent viscosity than presence of only 1 g xanthan gram in the samples tested just as it was the case with CuO nanoparticles. However, samples with 0.5 g silicate and 1.5 g xanthan gave a better increase in viscosity than that of 1 g: 1 g concentration but as much as 2 g xanthan gum alone can do in the water based drilling fluid. Hence, the performance of the viscofier (xanthan gum) can be improved by appreciable addition of the silicate nanoparticles. These observations are in agreement with the findings of other previous researchers [17-18]. Just as the case was with CuO, the results further showed that the 1.5 g silica and 0.5 g xanthan gum mixture in the drilling fluid caused reduction in apparent viscosity when compared with water based drilling fluid containing either 1 g or 2 g xanthan gum alone. Thus, the silicate nanoparticle alone may not be able to improve the viscosity of the water based drilling fluid without the xanthan gum or any other vioscosifier just as it applied to the CuO nanoparticles (Figures 4 and 5). From Figure 6 it was observed that as the concentration of the xanthan gum increased in the water based drilling fluid without nanoparticles, the viscosity of the fluid increases but the rate of increment reduces as the concentration increases. Comparison of the impacts of the xanthan gum, CuO and silicate on the viscosity of the water based drilling fluid revealed that the mixture of 1 g xanthan gum and 1 g nanoparticles also increased the viscosity of the water based drilling fluid, but the CuO nanoparticles performed better than the silicate nanoparticles at lower temperatures for this concentrations (Figure 6). The ratio of 1: 3 concentrations of nanoparticles to xanthan gum (i.e. 0.5 g nanoparticles and 1.5 g xanthan gum) in the water based drilling fluid performed better than the 1: 1 ratio in increasing the viscosity of the drilling fluid. The CuO nanoparticles also performed better than the silicate nanoparticles in this ratio of concentration and even better than when 2 g of xanthan gum was used alone (Figure 6). The CuO at ratio 1:3 with xanthan gum at 30 rpm shear rate increased the viscosity of the drilling fluid from 192.3 to 2543.7mPa.s while the silicate nanoparticles of similar concentration with xanthan gum at 30 rpm shear rate increased from 192.3 to 1771.1 mPa.s at 31.5 ^{o}C (Figures 4, 5 and 6).

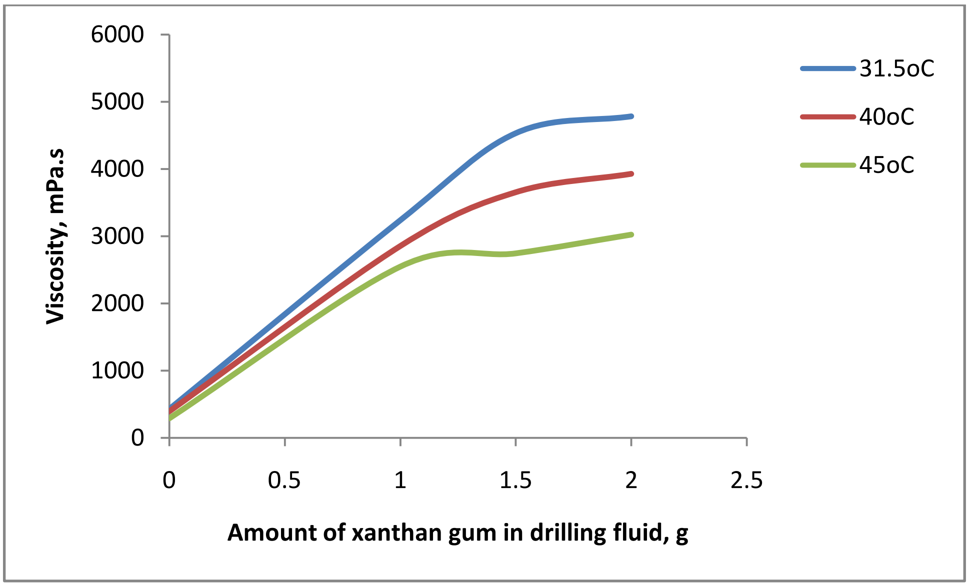

Figure 1: Viscosity against concentration of xanthan gum in the water based drilling fluid at 12 rpm

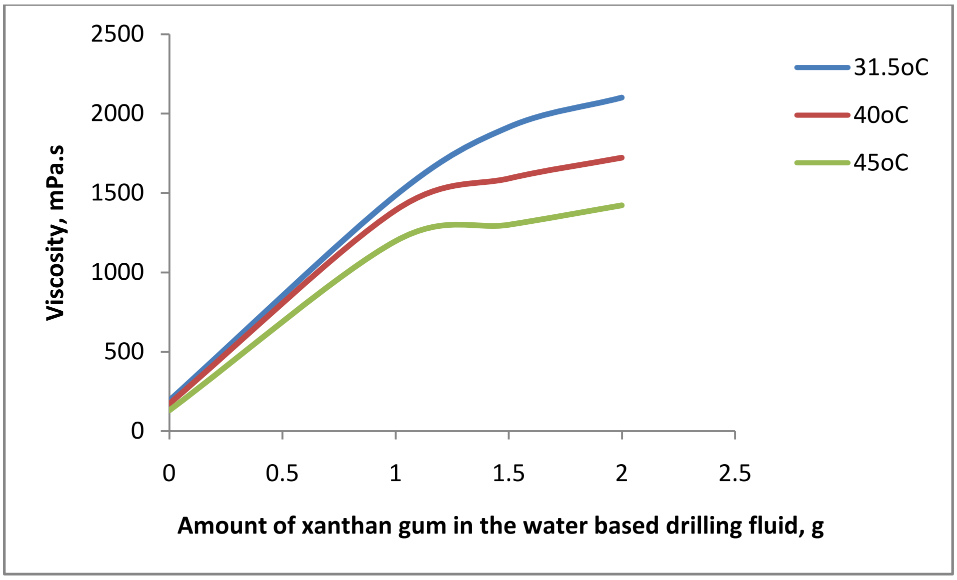

Figure 2: Viscosity against concentration of xanthan gum in the water based drilling fluid at 30 rpm

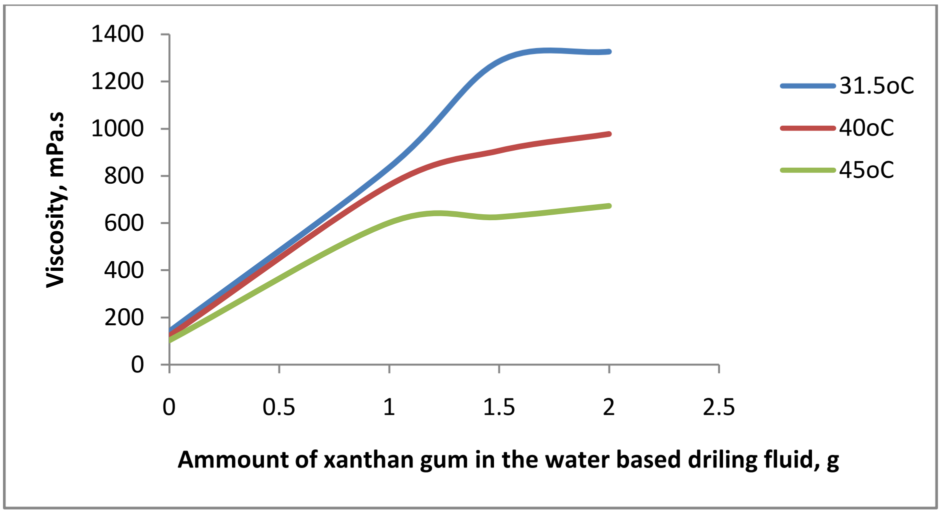

Figure 3: Viscosity against concentration of xanthan gum in the water based drilling fluid at 60 rpm

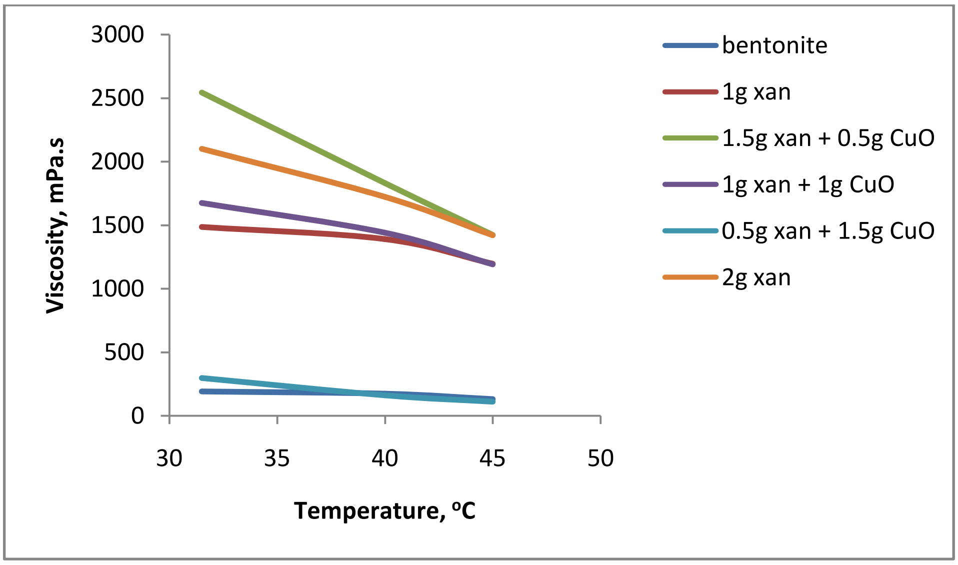

Figure 4: Viscosity against temperature at 30 rpm for drilling fluid containing bentonite, xanthan and CuO in different concentration

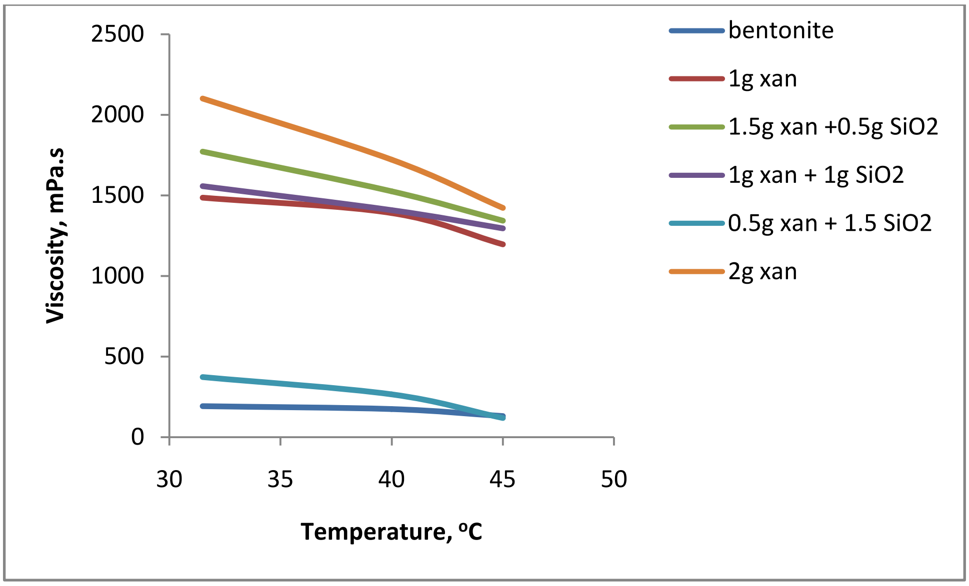

Figure 5: Viscosity against temperature at 30 rpm for drilling fluid containing bentonite, xanthan and silicate in different concentration

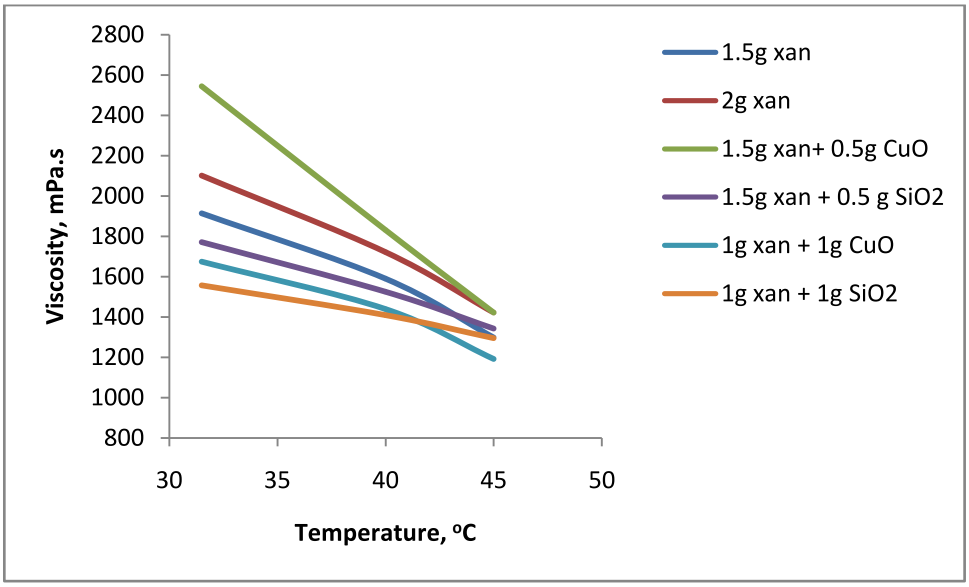

Figure 6: Viscosity against temperature at 30 rpm for drilling fluid containing bentonite, xanthan, CuO and silicate in different concentration

It was observed from the results of structural analysis of the xanthan gum and its mixture with the nanoparticles using FTIR that there were some interactions between the xanthan gum and the nanoparticles. Various peaks/bands are shown by the FTIR spectrum of the xanthan gum in Figure 7: the band at 786.5cm^{-1} is assigned to aromatic group C-H, the band at 1017.6 cm^{-1} represents C-OR stretching and the band at 1155.5 cm^{-1} indicates C-O stretch. Also, the band at 1244.9 cm^{-1} corresponds to C-O stretching and the band at 1367.9 cm^{-1} corresponds to –C-H bending. The 1401.5 cm^{-1} indicates C-C (ring) stretch, the band at 1599.0 cm^{-1} indicates C-C (ring) stretch, the band at 1714.6 cm^{-1} indicated carbonyl group C=O stretching. Furthermore, O-H functional group was indicated by 2877.5 cm^{-1}, 3291.2 cm^{-1} and bands, 3354.6 cm^{-1} the presence of a stretching of strong hydroxyl groups was indicated by the band at 3418.0 cm^{-1}. These observations are in agreement with the findings of other researchers [17-18].

From Figure 8 showed the FTIR spectrum of copper (II) oxide: Peaks/bands observed from the spectrum are 2496.1 cm^{-1}, 2452.6 cm^{-1}, 2352.0 cm^{-1}, 2322.1 cm^{-1}, 2117.1 cm^{-1}and 2083.6 cm^{-1}. The band at 2083.6cm^{-1} and

2117.1cm^{-1} indicate stretching of Cu-H. The bands 2322.1 cm^{-1} indicate linear molecule of Cu=O while 2452.6 and 2496.1 indicates OH.

Figure 9 showed the spectrum of CuO blend with xanthan gum in ratio 1:3. It was observed from the spectrum that out of the 15 peaks/bands displayed only six initially existed in the xanthan gum spectrum when xanthan was analysed alone (Figures 7 and 9). The presence of the six peaks/bands (786.5, 1017.6, 1244.9, 1367.9, 1599.0 and 1714.6) only showed that the xanthan gum had interacted with the CuO nanoparticles to form nanocomposite. Furthermore, none of the peaks/bands shown in the spectrum of the CuO nanoparticles appeared in the spectrum of the nanocomposite (Figures 8 and 9) but nine new peaks/bands were obtained. This is an indication that the interaction between the CuO and the xanthan gum was very strong. Consequently, this contributed to great performance of the CuO nanoparticles and xanthan gum of ratio 1 to 3 blend in improving the viscosity of the water based drilling fluid as indicated in Figure 6.

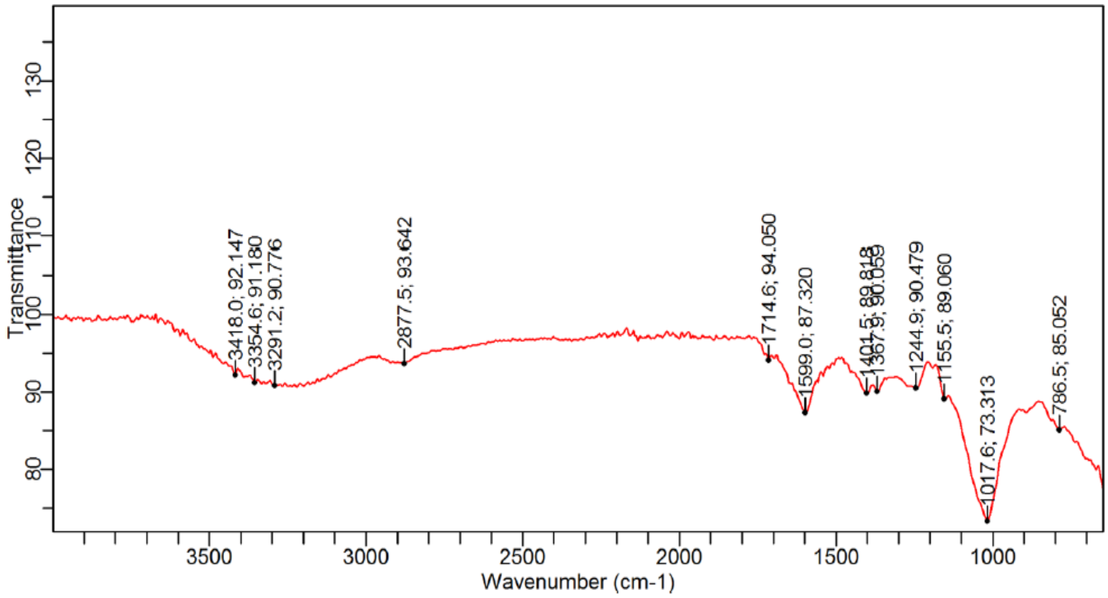

Figure 7: FTIR spectrum for xanthan gum (sample A)

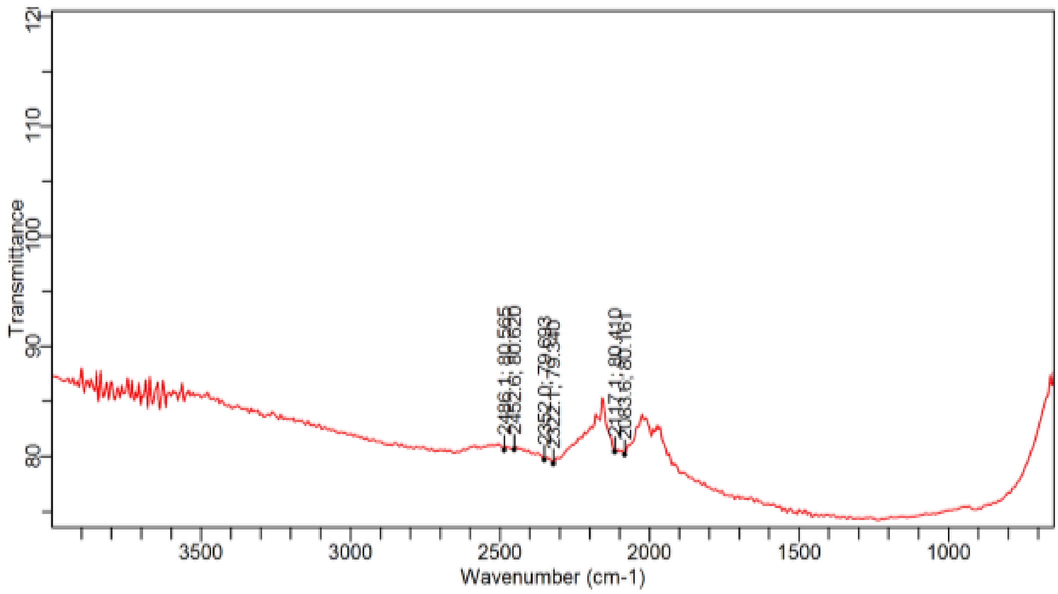

Figure 8: Spectrum of copper (II) oxide (CuO) nanoparticles (sample B)

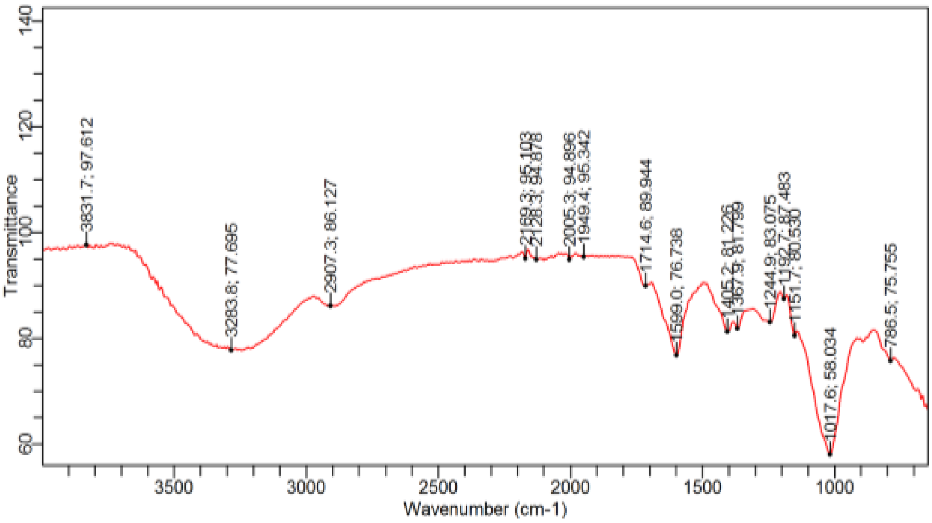

Figure 9: Spectrum of blend of CuO nanoparticles and xanthan gum in ratio 1:3 (sample C)

From Figure 10, the FTIR spectrum of the silicate revealed some peaks/bands: the band in the region at 1632.6 cm^{-1} corresponds to hydrogen bond O-H groups while the band at 1077.2 cm^{-1} represents Si-O-Si bond stretching, and. Also, the 965.4 cm^{-1} infrared band indicates Si-O stretching while the band at 797.7 cm^{-1} indicates the Si-OH-Si bending.

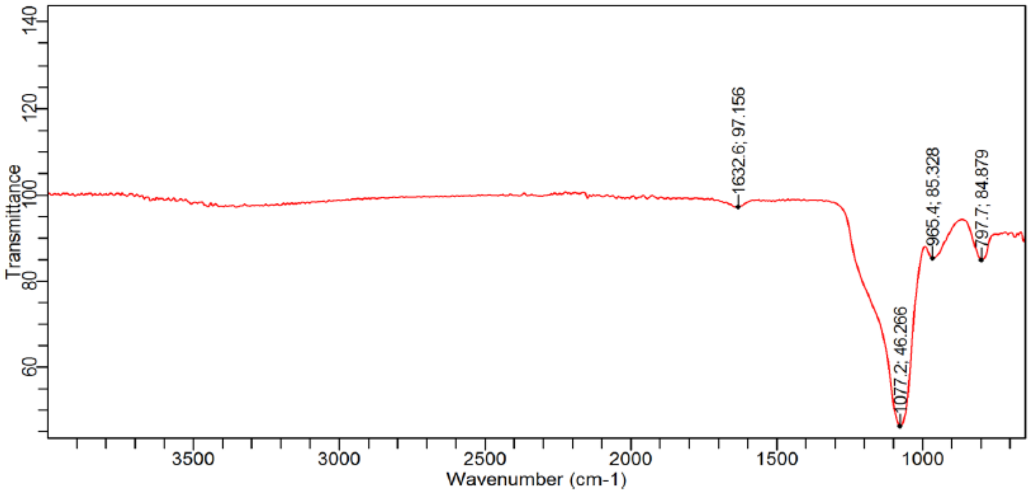

Figure 10: FTIR Spectrum of silicate nanoparticles (sample D)

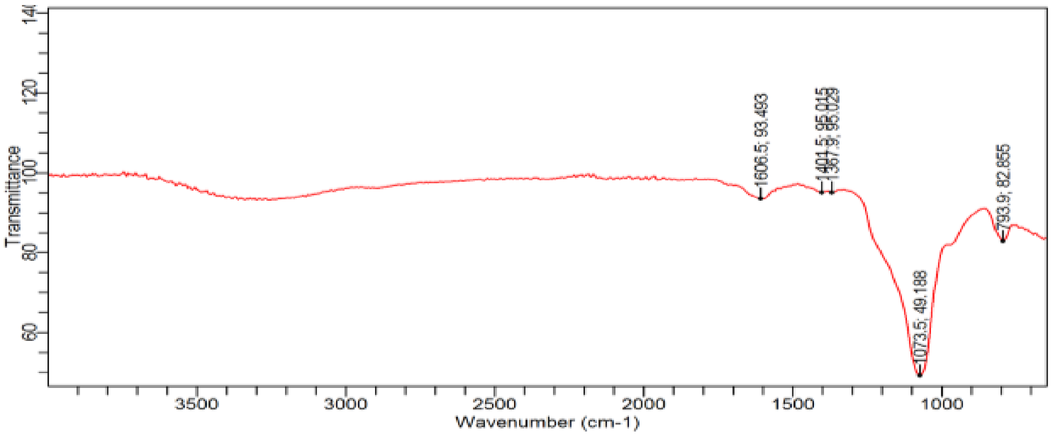

Figure 11: Spectrum of blend of silicate nanoparticles and xanthan gum in ratio 1:3 (sample E)

The FTIR spectrum for the blend of 1.5 g xanthan with 0.5 g silicate showed about five bands (Figure 11): Comparing Figures 7, 10 & 11, it is observed that the peaks present in the xanthan gum individual structure are not present in silicate and xanthan molecules structure. The presence of less peak/bands in the infrared spectra of this molecule shows that there is less bonds between the intermolecular structures of xanthan and silicate in the sample. The width of infrared bands which relates the strength of the intermolecular interaction i.e. the bonding of this sample is little; it ranges from 1605.3 cm^{-1} to 793.9 cm^{-1}. The few interactions, however, attributed to the improvement in the viscosity of the water based drilling fluid when the silicate nanoparticle was introduced into the bentonite/xanthan gum mixture (Figure 6).

4. Conclusion

How drilling fluid rheological property can be improved using silicate and copper (II) oxide (CuO) nanoparticles was investigated using viscosity and FTIR analysis. The CuO at ratio 1:3 with xanthan gum at 30 rpm shear rate increased the viscosity of the drilling fluid from 192.3 to 2543.7mPa.s while the silicate nanoparticles of similar concentration with xanthan gum at 30 rpm shear rate increased from 192.3 to 1771.1 mPa.s at 31.5 ^{o}C. The improvement in the rheological properties of the drilling fluids observed resulted from the bonds between these nanoparticles and xanthan gum. Furthermore, introduction of Silicate nanoparticles and CuO nanoparticles improved the rheological performance of water based drilling fluids with xanthan gum additive with CuO nanoparticles exhibiting more improvement than the Silicate. Thus, it is recommended that for optimal improvement in rheological properties of water based drilling fluid CuO nanoparticles combined with xanghan gum be considered in the oil and gas industry.

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