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Comparative Study of Impact of Silicate and Zinc Oxide Nanoparticles on Viscosity of Water Based Drilling Fluid

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ABSTRACT

Drilling fluids, one of many other important things in the petroleum industry that affects the smooth, harmless exploration of oil, when exposed to a high temperature and high pressure situation in drilling lose their rheological properties such as viscosity, etc. to perform their primary purpose of successfully carrying the drill cuttings out of the boreholes or wells been drilled. This research work is aimed at investigating how drilling fluid rheological property can be improved using zinc oxide and Silicate nanoparticles. In order to achieve the objectives of the research work, Water Based Drilling Fluids (WBDF) were prepared using the standard laboratory barrel (350 ml) method from bentonite, xanthan gum and water and the nanoparticles were introduced into the formulation in different concentrations. The rheological properties of the samples were determined using Brookfield rotational viscometer. Also, the structural analysis of the interaction between the nanoparticles and the Xanthan gum were determined using Fourier Transformation Infra-red (FTIR) spectroscopy. The results showed that Zinc oxide and Silicate nanoparticle improved the rheological properties of the water based drilling fluid. The zinc oxide at equal proportion with xanthan gum at 30 rpm shear rate increased the viscosity from 1484.5 to 2752.2mPa.s while the Silicate nanoparticles at equal proportion with xanthan gum at 30 rpm shear rate increased from 1484.5 to 1556.8mPa.s. The results of the structural 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 Zinc oxide (ZnO) nanoparticles improved the rheological performance of water based drilling fluids with xanthan gum additive. However, Zinc oxide (ZnO) nanoparticles exhibited more improvement than the Silicate.

INTRODUCTION

Just as water is important to the human body, a drilling fluid is very important in drilling operations for petroleum resources. Drilling fluid is more or less one of the most crucial parts of any earth excavation. Drilling fluid, often referred to as drilling mud, is an assortment of fluid, basically a mixture of clay, water, minerals and additives. It is pumped through the drill string and continuously introduced to the bottom as it squirts out from the drill nozzles. Drilling fluid has many uses some of which includes; 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 [1-2]. Unfortunately, when drilling fluids are exposed to a high temperature high pressure situation in drilling, they lose their rheological properties such as viscosity, strength etc. Furthermore, one of the challenges related to drilling deep wells is to maintain the desirable rheological properties of the drilling fluid [1, 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-pressure (HP), high-temperature (HT) wells. In an increasing number of areas in the world environmental regulations prohibit the discharge of the oil based drilling fluid and cuttings containing oil-based fluid. These (HP, HT) wells can be defined as those with a bottom hole temperature of between 300 ^{o}F and 500 ^{o}F and an expected shut in pressure from 10,000 psi to 25,000 psi [4]. WBDF are among the most popular drilling fluids; thanks in part to their reputation as easy to maintain, economically competitive drilling fluids [1]. Such fluids can be designed and engineered to be suitable for high temperature and pressure environments. William *et al*. [5] 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 [6] and multiwall carbon nanotube [3, 7]. Some other researcher also investigated impact of nanoparticles on drilling fluid in various other capacities [8-30]. WBDF often contains viscosifying agents such as starches, polyacrylates, xanthan gums and a wide variety of synthetic and natural polymers to establish and control the rheological properties of drilling fluid. During the course of drilling a subterranean well, water based drilling fluids are exposed to temperatures that can be in excess of 300 ^{o}F. Exposure to such temperatures can have a detrimental effect on the viscosifying agents, resulting to loss in velocity of the fluid at high temperatures. A breakdown of the rheology can result in the drilling fluid unable to suspend solid dispersed within it such as the weighting or bridging agent or even the drill cuttings which can lead to severe problems such as settlement, loss in fluid density and possibly a blowout of the well. The use of silicate and zinc oxide nanoparticles to improve the rheological properties such as viscosity etc. of water-based drilling fluids is essential in a drilling process, as drilling fluid must have the correct heat transfer and fluid flow characteristics to function in an effective manner. Thus, in this study, the impact of combination of xanthan gum and nano particles of silicates and Zinc oxide in different ratio on viscosities of WBDF were investigated. Also, the interactions of the structures of the nanopartices with the xanthan gum in different proportions were investigated using FTIR.

2.0 MATERIALS AND METHOD

2.1 Materials

The materials used were of high purity and analytical grade. The bentonite clay used was obtained from standard Nigerian chemicals organization. Xanthan gum, silicate and zinc oxide nanoparticles are products of Sigma-Aldrich. The major pieces of equipment used were Brook-field rotational viscometer (Ndj-8S) and Fourier Transform Infra-Red (FTIR) spectrometer (Agilent; range: 4000-650 cm^{-1}).

2.2. Sample preparation

2.2.1 Sample one

The first basic WBDF 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 10minutes.

2.2.2 Sample two

The second WBDF 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 minutes 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 minutes was prepared in a beaker. 2 g of Xanthan gum was mixed with the solution for 15 minutes using a magnetic stirrer.

2.2.3 Sample three

The third WBDF 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) 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 Silicate 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. 1.5 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) 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. 1.5 g of Silicate was weighed, added to the solution and mixed thoroughly for 20 minutes.

2.2.4 Sample four

The fourth WBDF involved water, bentonite clay, xanthan gum and Zinc Oxide 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 Zinc Oxide 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 Zinc Oxide 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. 1.5 g of Xanthan was weighed and added to the solution, it was mixed for 20 minutes. 0.5 g of Zinc Oxide 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. 1.5 g of Zinc Oxide was weighed, added to the solution and mixed thoroughly for 20 minutes.

Sample analysis

Test for viscosity

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

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

The viscometer used is a Ndj-8S digital Brookfield viscometer with measuring range of 20-2,000,000 mPa.s, rotational speeds (rpm) of 0.3, 0.6, 1.5, 3, 6, 12, 30, 60 (i.e. eight adjustable speeds), 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 is poured into a beaker and placed under the viscometer. A spindle that suits the sample is used and knotted tight at the joint under the viscometer. The viscometer is then adjusted at the knob to the bottom to make the spindle enter the sample placed; the knob is stopped when the “stop-point mark” on the spindle is no longer visible as this indicates that the spindle is well inserted into the solution. The viscometer is powered on, the speed is picked by pressing a button that reads “speed” on it, it is pressed number of times till the speed used is picked, the thermometer from the viscometer is then inserted into the solution/sample to be examined, the spindle used is selected (i.e. spindle 1, 2, 3 or 4). After all these selections, the run viscometer shows the viscosity value button is pressed and the**,** the temperature of the sample, the speed and spindle used. Before another reading is taken, the spindle is 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 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.

Structure analysis

FTIR equipment was used to carry out the structure analysis of all the 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 Silicate

Sample B: 1g Xanthan gum

Sample C: 1g Zinc Oxide

Sample D: 1g Xanthan gum + 1g Silicate

Sample E: 1.5g Xanthan gum + 0.5g Silicate

Sample F: 1g Xanthan gum + 1g ZnO

Sample G: 1.5g Xanthan gum + 0.5g ZnO

The FTIR analysis was done at the central laboratory of Yaba College of Technology, Lagos, Nigeria. FTIR uses an Infra-Red (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 FTIR 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.

RESULTS

From the results obtained, there is a decrease in the viscosity as there is increase in shear rates for all the samples tested (Figures 1, 2 and 3). This implies that the drilling fluids produced are non- Newtonian. The drilling fluid is shear thinning as the viscosity decreases as the shear rates increases. At different temperatures, the viscosity of the drilling fluids decreases as shear rate increases. At every given temperature, the viscosity of the drilling fluid sample increases with increase composition of xanthan gum (Figures 1, 2, and 3). Thus, the xanthan gum acted as a viscosifier which is in agreement with findings of previous researcher [30]. It was observed that addition of 1g xanthan gum to the water based drilling fluid increased its viscosity sharply and further addition of xanthan gum resulted in slight increase at all temperatures considered (Figures 1, 2, and 3). At 31.5 ^oC, the apparent viscosity of the drilling fluid sample at 30 rpm increased from 192.3 mPa.s to 1484.5 mPa.s on addition of 1g xanthan gum (Figure 1). Further addition of 0.5g xanthan gum increased the apparent viscosity to 1914.2 mPa.s and increasing the xanthan gum composition to 2 g only increased the apparent viscosity to 2100.4 mPa.s under the same condition (Figure 1). It was further observed that as the shear rate increases above 30rpm the increment in apparent viscosity reduces. This is trend subsist at 40^oC and at 45^oC (Figures 2 and 3). Also, as the temperature increases the viscosity of the drilling fluid reduces. This is in agreement with the findings of other previous researchers [2].

From Figure 4, it was observed that addition of silica nanoparticles to the xanthan gum bentonte mixture formulated drilling fluid had impact on the viscosity of the fluid. Concentration of 1 g silica 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. However, samples with 0.5 g silica and 1.5 g xanthan gave a better increase in viscosity than that of 1 g: 1 g concentration. Thus, the performance of the viscofier (xanthan gum) can be improved by appreciable addition of the silica nanoparticles. These observations are in agreement with the findings of other previous researchers [30]. 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. Hence, the silica nanoparticle alone may not be able to improve the viscosity of the WBDF without the xanthan gum or any other vioscosifier.

It was observed from Figure 5 that the little quantity of xanthan gum (0.5g) and 15 g of ZnO had very little impact on the viscosity of the WBDF sample, which implied that ZnO nanoparticles may not be able to increase the viscosity of the WBDF. However, the results showed that 1g of xanthan gum and 1g of ZnO had appreciable impact on the viscosity of the drilling fluid and even better than 1.5 g xanthan gum to 0.5 g ZnO concentration. The impact of the 1.5 g xanthan gum to 0.5 g ZnO in the viscosity was even greater than that of sample containing only 2 g xanthan. Thus, the ZnO and xanthan gum mixed in ratio 1 g :1 g can improved the rheological performance of the water based drilling fluid appreciably for a 350 ml volume. This can be scale-up for larger volume production of WBDF. Comparison of the impacts of the xanthan gum, silicate and zinc oxide on the viscosity of the WBDF showed that as the concentration of the xanthan gum increased in the WBDF without nanoparticles, the viscosity of the fluid increases but the rate of increment reduces as the concentration increases

(Figure 6). The mixture of 1g xanthan gum and 1 g nanoparticles also increased the viscosity of the WBDF, but the ZnO nano particles performed better than the silicate nano particles.

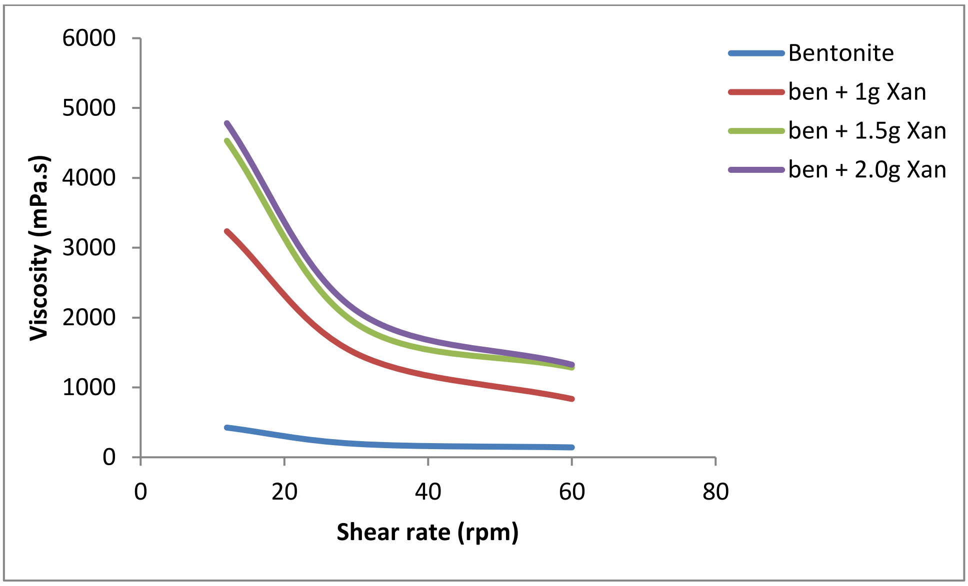

Figure 1: Viscosity against shear rate of drilling fluid for different concentration of xanthan gum at 31.5°C

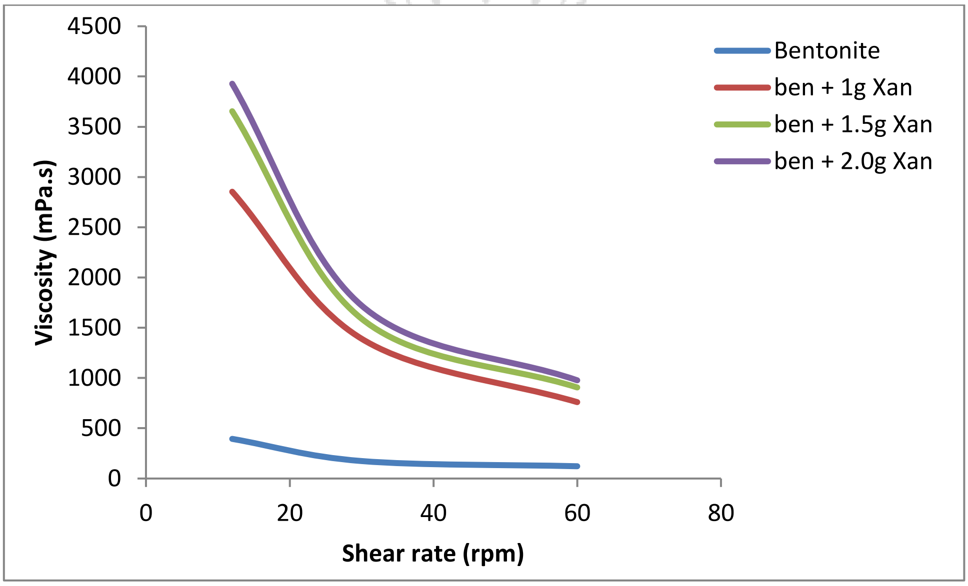

Figure 2: Viscosity against shear rate of drilling fluid for different concentration of xanthan gum at 40°C

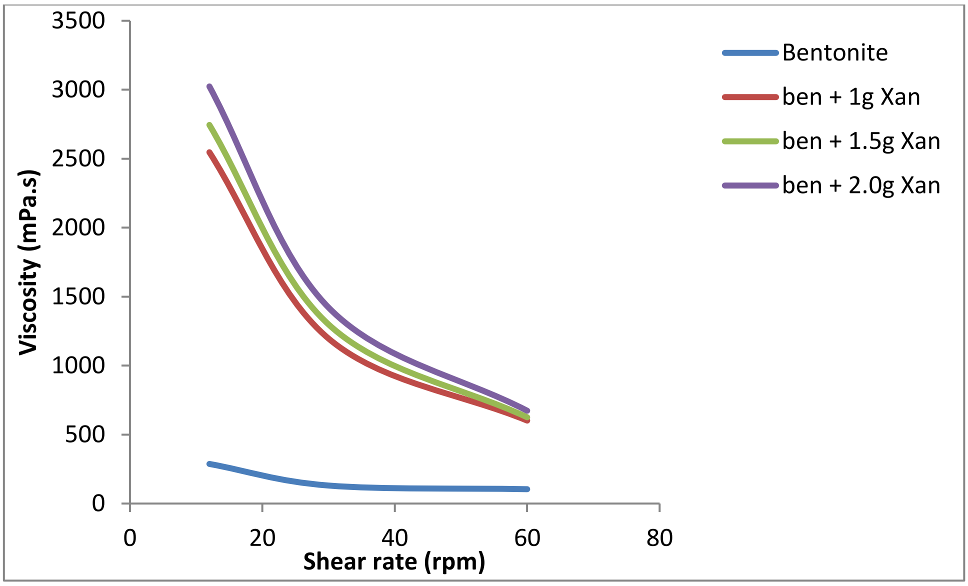

Figure 3: Viscosity against shear rate of drilling fluid for different concentration of xanthan gum at 40ºC

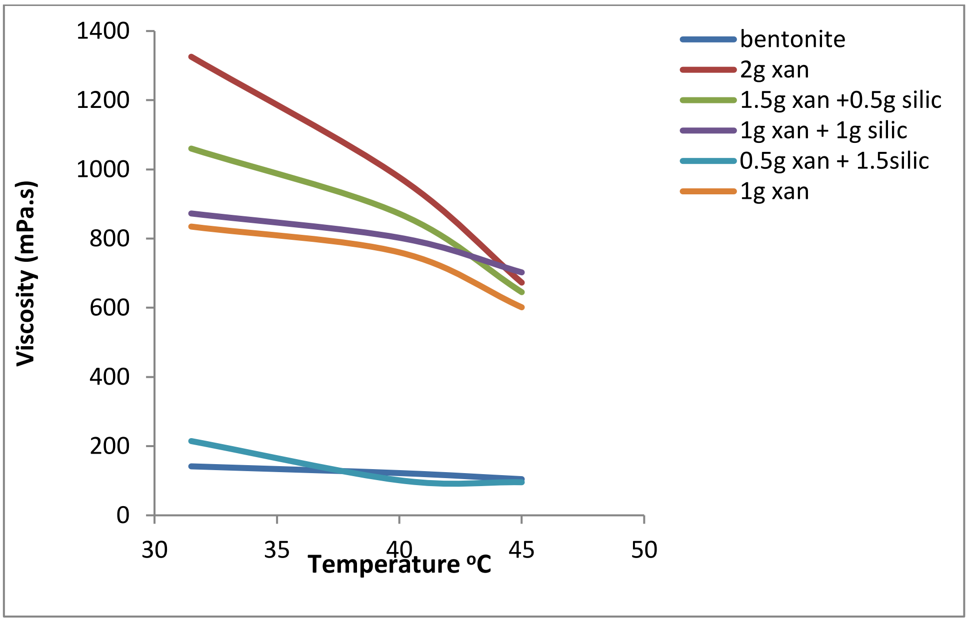

Figure 4: Viscosity against temperature at 60 rpm for drilling fluid containing bentonite, xanthan and silicate in different concentration

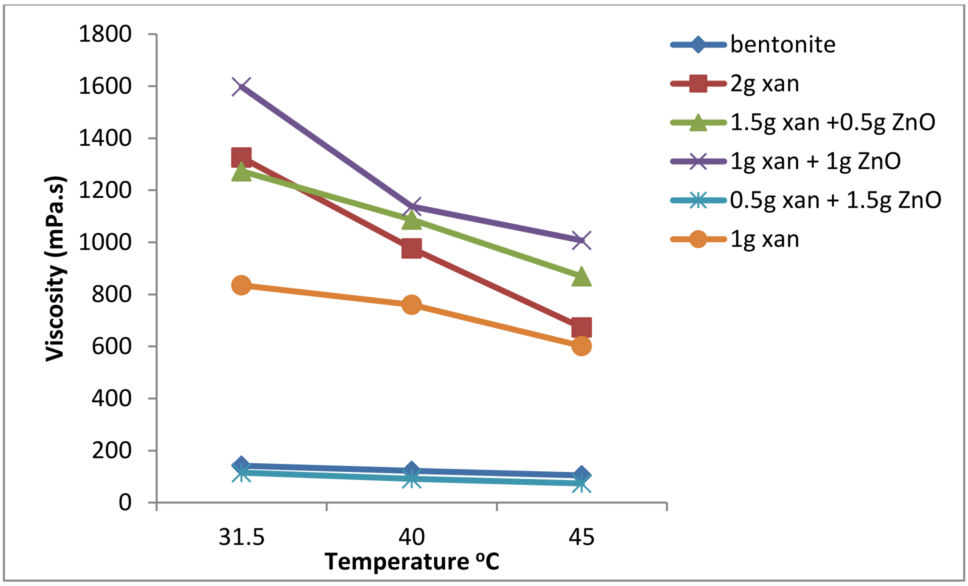

Figure 5: Viscosity against temperature at 60 rpm for drilling fluid containing bentonite, xanthan and zinc oxide in different concentration

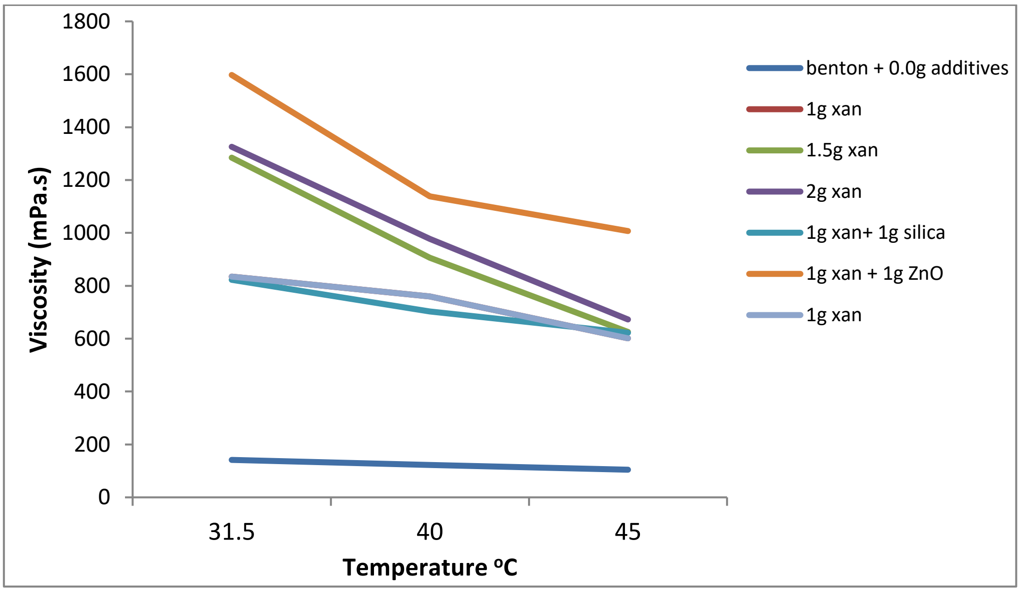

Figure 6: Viscosity against temperature at 60 rpm for drilling fluid containing bentonite, xanthan, silicate and zinc oxide in different concentration

The result of the structural analysis of the xanthan gum and its mixture with the nano particles using FTIR revealed that there were some interaction between the xanthan gum and the nanoparticles. The FTIR spectrum of the xanthan gum showed various peaks/bands (Figure 7): the band at 3418.0 cm^{-1} indicate the presence of a stretching of strong hydroxyl groups, also, 3354.6 cm^{-1}, 3291.2 cm^{-1} and 2877.5 cm^{-1} indicates O-H functional group, the band at 1714.6 cm^{-1} is assigned to carbonyl group C=O stretching, 1599.0 cm^{-1} indicates C-C (ring) stretch, 1401.5 cm^{-1} indicates C-C (ring) stretch. The band at 1367.9 cm^{-1} is assigned to –C-H bending. Furthermore, the band at 1244.9 cm^{-1} corresponds to C-O stretching, 1155.5 cm^{-1} indicates C-O stretch, the band at 1017.6 cm^{-1} represents C-OR stretching, and the band at 786.5cm^{-1} is assigned to aromatic group C-H. These observations are in agreement with the finding of previous researchers [30].

The FTIR spectrum of the silicate revealed some peaks/bands (Figure 8): the band at 797.7 cm^{-1} indicates the Si-OH-Si bending while the 965.4 cm^{-1} infrared band indicates Si-O stretching; furthermore, the band at 1077.2 cm^{-1} represents Si-O-Si bond stretching, and the band in the region at 1632.6 cm^{-1} corresponds to hydrogen bond O-H groups.

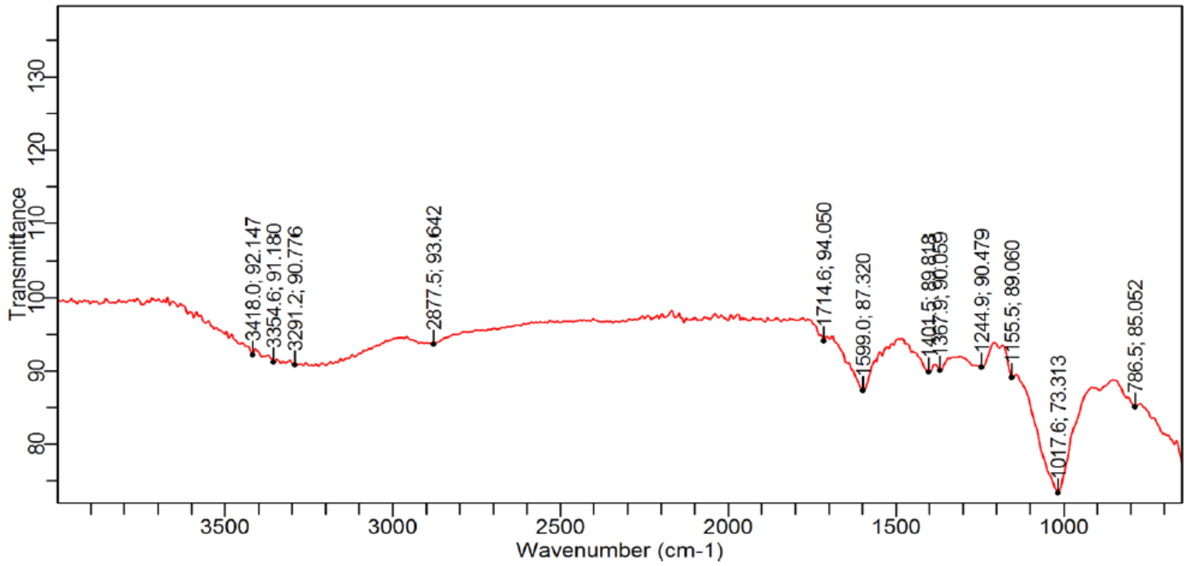

Figure 7: FTIR spectrum for xanthan gum

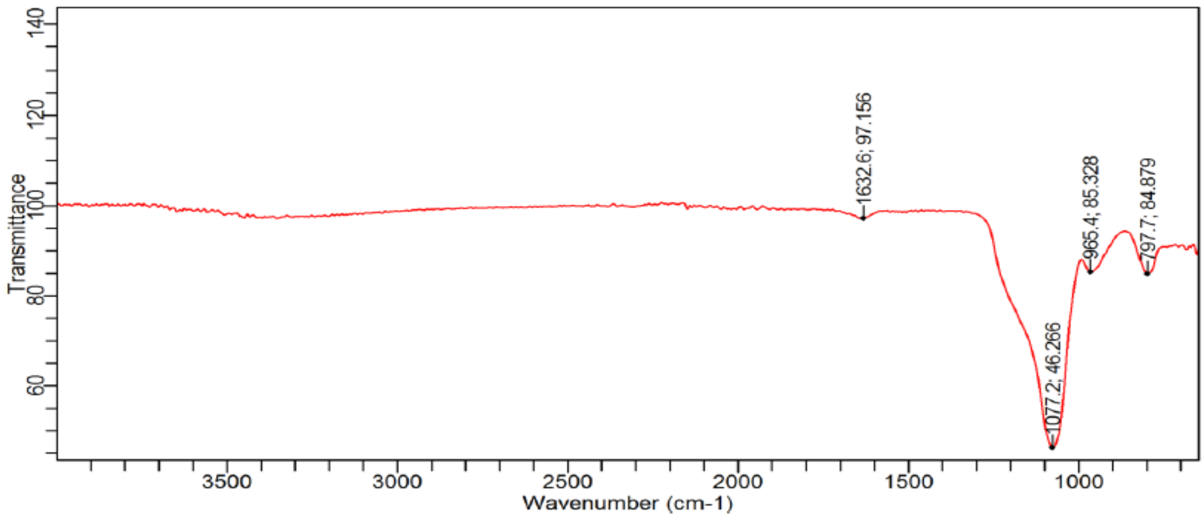

Figure 8: FTIR Spectrum of silicate nanoparticles

The FTIR spectrum for the blend of 1g xanthan with 1 g silicate showed about five bands (Figure 9): Comparing Figures 7, 8 & 9, it is observed that the peaks present in the xanthan gum individual structure are not present in silicate & 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 from3406.8 cm^{-1} to 793.9 cm^{-1}. However, the few interactions 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 4).

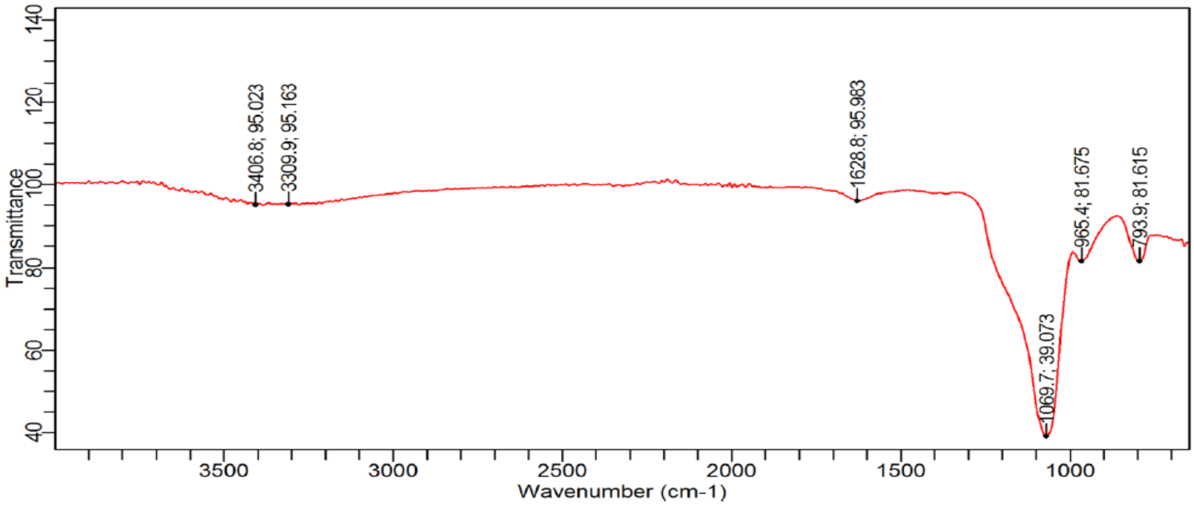

Figure 9: Spectrum of xanthan gum blend with equal proportion of silicate nanoparticles

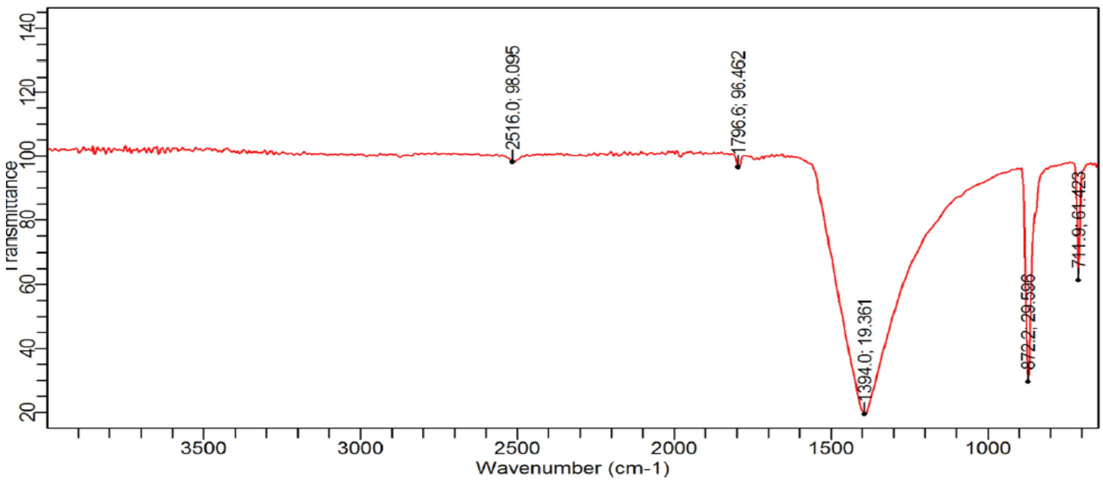

Figure 10: Spectrum of zinc oxide (ZnO) nanoparticles

The bands/peaks for zinc oxide are shown in Figure 10: the band at 2516.0 cm^{-}1 indicates O-H stretching, the band at 1796.6 cm^{-}1 indicate stretching of Zn-H**,** the band at 1394.0 cm^{-}1 is assigned to Zn-H bending**,** the band at 872.2 cm^{-}1 Zn=O stretching, the band at 711.9 cm^{-}1 indicates Zn=O bending. For blend of ZnO nanoparticles and xanthan gum the peaks/bands are shown in Figure 11: In comparison it was observed that the higher intensity represents the absorption of IR spectrum due to some additional bands which is the zinc oxide nanoparticle used (Figures 10 and 11). There's much peak/bands in this spectrum, this implies the molecules of xanthan and zinc oxide at equal proportion shows a network of their structures i.e. bonds well. For instance the presence of peaks 1021.3 cm^{-1}, 1159.2 cm^{-1}, 33621 cm^{-1} and 3570.8 cm^{-1} in Figure 11 showed the formation of xanthan-zinc oxide nanocomposite. Furthermore, the presence of the new bands/peaks (e.g 1591.6 cm^{-1}, 19308 cm^{-1}, 2512.2 cm^{-1}) and the disappearance of some bands/peaks in both xanthan (e.g. 1714.6 cm^{-1} and 1599.0 cm^{-1}) and zinc oxide nanoparticles (e.g. 1796.6 cm^{-1}, 2516.0 cm^{-1}) indicate the interaction of the two compounds to form the xanthan-zinc oxide nanocomposite (Figures 7, 10 and 11). Thus the strong interaction between the xanthan and the zinc oxide must have contributed immensely to the high improvement of the viscosity of the water based drilling fluid as shown in Figure 6.

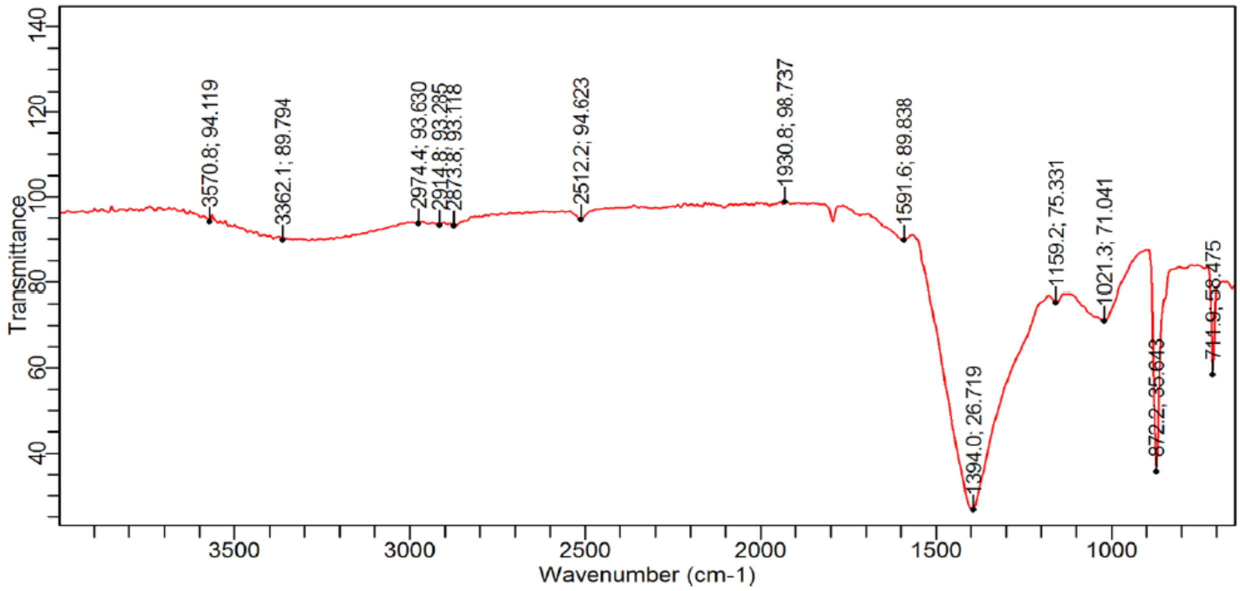

Figure 11: Spectrum of blend of ZnO nanoparticles and xanthan gum in equal proportion

The bands and peaks obtained from the spectra for the FTIR analysis of blending of xanthan gum with other proportions of the nanoparticles investigated also showed some interaction of the nanoparticles with the xanthan but not as much as the ones displayed by the spectra of the equal proportions mentioned.

CONCLUSION

From the result obtained in this study, it is concluded that the rheological properties of water based drilling fluid improved with the addition of zinc oxide and silicate nanoparticles. At equal proportion with xanthan gum, zinc oxide and silicate nanoparticles both improved the drilling fluid viscosity; at different proportions of xanthan gum, zinc oxide nanoparticles improved the drilling fluid viscosity but silicate nanoparticle did not. The structures of the zinc oxide nanoparticle interacted better with the additive than silicate nanoparticle. The results of this study indicate that the bonds between nanoparticles and xanthan gum helps rheological properties of the drilling fluids. Zinc oxide nanoparticle improved the rheological performance of drillings fluids than silicate nanoparticle when appropriately combined with xanthan gum. Hence, for optimal improvement in rheological properties of water based drilling fluid, zinc oxide nanoparticles combined with xanthan gum is recommended for use in the oil and gas industry.

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