e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-10, Issue-4 (August 2020)
https://doi.org/10.31033/ijemr.10.4.11

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

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ABSTRACT

Drilling fluids play very important roles in the oil and gas industry hence the need to get method of improving their rheological properties cannot be over emphasized. In this study how drilling fluid rheological property can be improved using zinc oxide and copper (II) oxide nanoparticles were investigated. To achieve these objectives, water based drilling fluids (WBDF) were prepared using the standard laboratory barrel (350 ml) method from bentonite, xanthan gum and water. The Zinc oxide and Copper (II) nanoparticles were introduced into the formulation in different proportions. Brookfield rotational viscometer was used to determine the rheological properties of the samples while Fourier Transformation Infra-red (FTIR) spectroscopy was used to determine the structural analysis of the interaction between the nanoparticles and the Xanthan gum. The results showed that Zinc oxide and CuO nanoparticle improved the rheological properties of the water based drilling fluid. The zinc oxide at equal proportion with xanthan gum at 60 rpm shear rate increased the viscosity from 834.7 to 1597.3 mPa.s while the copper (II) oxide nanoparticles at equal proportion with xanthan gum at 60 rpm shear rate increased from 834.7 to 1452.3 mPa.s at low temperature of 31.5°C. The FTIR analysis of the nanoparticles and xanthan gum revealed that the interactions of the bonds between the nanoparticles and xanthan gum contributed to the improvement in the rheological properties of the drilling fluids. It is concluded that introduction of ZnO nanoparticles and CuO nanoparticles improved the rheological performance of water based drilling fluids with xanthan gum. The ZnO nanoparticles, however, exhibited better improvement than the CuO.

Keywords-- Water Based Drilling Fluid, Nanoparticles, Xanthan, Zinc Oxide, Copper Oxide

I. INTRODUCTION

Drilling fluid has vital role in oil and gas industry during drilling operations. It is pumped through the drill string and continuously introduced to the bottom as it squirts out from the drill nozzles. Among other uses, drilling fluid is used in drilling of deep wells to clean and transport th2e rock cuttings, maintain the whole integrity, control the formation pressures and lubricate and cool the drill bit (Akinyemi and Alausa, 2020; Majid and Younis, 2018). One of the major challenges related to drilling deep wells is to maintain the desirable rheological properties of the drilling fluid (Akinyemi and Kadiri, 2020; Ismail *et al.* 2014).

There had been increase in use of water-based drilling fluids in applications where oil based drilling fluid have previously been preferred due to environmental and economic considerations. Partly because of their reputation as easy to maintain, economically competitive drilling fluids, WBDFs are among the most popular drilling fluids and can be designed and engineered to be suitable for high temperature and pressure environments (Majid and Younis, 2018). Various researchers had investigated impact of nanoparticles on drilling fluid in various capacities (Sabori *et al.*, 2012; Fereydouni *et al.*, 2012; Kosynkin *et al.*, 2012; Mao *et al.*, 2015; Ponmani *et al.*, 2015; Balayney *et al.*, 2016; Ismail *et al.*, 2016; Li *et al.*, 2016; Salih *et al.*, 2016; Afolabi *et al.*, 2017; Al-Yasiri *et al.*, 2019). Viscosifying agents such as starches, polyacrylates, xanthan gums and a wide variety of synthetic and natural polymers are included in the production of WBDFs to establish and control the rheological properties of drilling fluid. Water based drilling fluids are exposed to temperatures that can be in excess of 300 °F during the course of drilling a subterranean well and this exposure can have a detrimental effect on the viscosifying agents, resulting to loss in velocity of the fluid at high temperatures.

Furthermore, any breakdown of the rheology of the drilling fluid can cause inability to suspend solid dispersed within it such as the weighting or bridging agent or even the drill cuttings. This can lead to severe problems such as settlement, loss in fluid density and possibly a blowout of the well. The use of zinc oxide and copper (II) oxide nanoparticles to improve the rheological properties such as viscosity etc. of water-based drilling fluids is essential in a drilling process. Hence, this study focused on the impact of combination of xanthan gum and nanoparticles of zinc oxide and copper oxide in different ratio on viscosities of water-based drilling fluids. The interactions of the structures of the nanopartices with the xanthan gum in different proportions were also investigated

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using FTIR. This study is a follow-up to the previous one done by the members of this research team.

II. MATERIALS AND METHOD

Materials

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

Sample Preparation

Sample One

Basic water based drilling fluid was prepared as sample one using of water and bentonite clay:

Measuring cylinder was used to measure 350ml of water and put in a 500ml beaker. Using weigh balance 15 grams of bentonite clay was weighed and poured into the beaker containing 350ml of water. The 15g of bentonite clay and 350ml of water were mixed for 10mins using a magnetic stirrer.

Sample Two

Sample two was prepared using water, bentonite clay and Xanthan gum only following the procedure described in Akinyemi and Alausa, 2020.

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

Sample Three

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

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

Sample Four

The fourth water based drilling fluid prepared involved water, bentonite clay, xanthan gum and copper (II) oxide nanoparticle. 350 ml of water was measured using a measuring cylinder and was put into a beaker. 15g of bentonite clay was measured using weigh balance. Different proportions of Xanthan gum and copper (II) oxide were used for this experiment.

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

Sample Analysis

Test for viscosity

Brookfield rotational viscometer was used to determine the viscosity of the prepared water based drilling fluid samples. The Ndj-8S digital Brookfield viscometer has measuring range of 20-2,000,000mPa.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)

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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 is 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 is 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**,** the temperature of the sample, the speed and spindle used. 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 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

The structure analysis of all the additives and their blends in different ratios were carried out using Fourier transform infra-red (FTIR) equipment 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 in the following order:

Sample A: 1g ZnO
Sample B: 1g Xanthan gum
Sample C: 1g copper (II) Oxide
Sample D: 1g Xanthan gum + 1g ZnO
Sample E: 1.5g Xanthan gum + 0.5g ZnO
Sample F: 1g Xanthan gum + 1g Copper (II) oxide
Sample G: 1.5g Xanthan gum + 0.5g Copper (II) oxide

The Fourier transform infra-red analyses were carried out at the central laboratory of Yaba College of Technology, Lagos, Nigeria. The 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 and 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. The Agilent Fourier transform infra-red spectroscope was used to obtain the infrared radiation for the sample and the result is plotted on a graph of transmittance against wavelength.

III. RESULTS

At every given temperature it was observed from Figure 1 that viscosity of water based drilling fluid with increase in xanthan gum concentration (1.5g to 2g) although the increment was not so much. Thus, the xanthan gum acted as a viscosifier which is in agreement with findings of previous researcher (Al-Yasira *et al.*, 2019). Addition of ZnO and xanthan gum in equal proportion increased the viscosity of the WBDF and exhibited the highest increment of the viscosity of all the samples of xanthan gum mixed nanoparticles tested at any given temperature (Figure 1). The next proportion of mixture that gave appreciable increment in viscosity to the WBDF is the mixture of ZnO and xanthan gum in ration 1:3 (0.5 g ZnO and 1.5 g xanthan gum) followed by the WDBF containing mixture CuO and xanthan gum in ratio 1:3. The positive impacts of the nanoparticles on the viscosities of the drilling fluid may have been due to interaction between the molecules of the xanthan gum and those of the nanoparticles. This is in agreement with the findings of previous researchers (Akinyemi and Alausa 2020). It was further observed that addition of CuO and xanthan gum in equal proportion displayed decrease in viscosity of the WBDF when compared with when it was containing only xanthan gum of either 1.5g or 2.0g in the standard quantity tested (Figure 1). Thus, only addition of very small quantity

e-ISSN: 2250-0758 | p-ISSN: 2394-6962
Volume-10, Issue-4 (August 2020)
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of CuO can have positive effect on the rheological property of the WBDF and any further addition may result in negative impact on the drilling fluid. Also, it was observed that the viscosity of the drilling fluid generally reduces as the temperature increases. This is in agreement with the findings of other previous Vryzas and Kelessidis, 2017.

From Figure 2 revealed that the viscosity of the water based drilling fluid with or without ZnO decreases with increase in share rate at any given temperature. This implies that the drilling fluids produced are non- Newtonian and it is shear thinning. It was observed that the WDBF

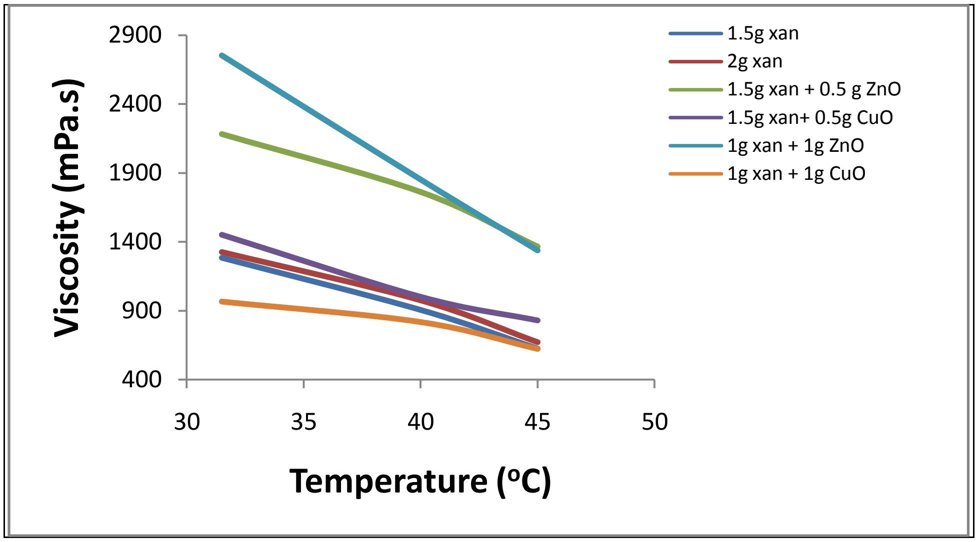

Figure 1: Viscosity against temperature at 60 rpm for drilling fluid containing bentonite, xanthan and nanoparticle in different proportion

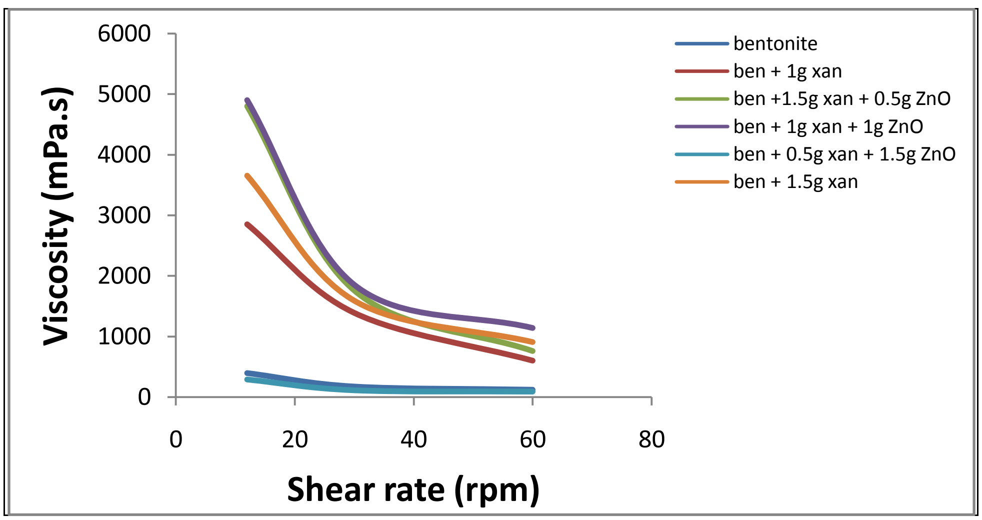

Figure 2: Viscosity against shear rate of drilling fluid for different concentration of xanthan gum and ZnO nanoparticle at 40°C

Containing 1g ZnO nanoparticles and 1g xanthan gum exhibited the highest viscosity among the samples tested with different proportions of ZnO and xantahn gum at any given share rate (Figure 2). However, addition of more ZnO nanoparticles to the ratio of 1.5g ZnO to 0.5g xanthan gum reduces the viscosity of the drilling fluid appreciable. Thus, the optimum proportion of ZnO nanoparticles to xanthan gum in the water based drilling fluid may be regarded as ratio 1:1.

Investigation of the structures of the blend of the nanoparticles with xanthan gum used in the production of the WBDF samples as revealed by the FTIR analysis further confirm that ZnO nanoparticles blended with the xanthan gum in equal proportion (1:1) yielded more

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interactions of bonds than other proportions of nanoparticles/xanthan gum mixture in this study (Figures 3, 4, 5). The number of peaks/bands in WBDF containing xanthan gum without any nanoparticles was twelve (12) as shown in Figure 3. There were obviously some interaction between the xanthan gum and the nanoparticles as shown in FTIR spectra of the blends of the nanoparticles and xanthan gum (Figures 4 and 5). The blend of ZnO nanoparticles and xanthan gum in equal proportion revealed thirteen (13) peaks/bands with new peaks/bands as shown in Figure 4: In comparison there are more peak/bands in this spectrum when compared with that for pure xanthan gum contained WBDF (Figure 3). This implies the molecules of xanthan and zinc oxide at equal proportion shows a network of their structures i.e. bonds well. The presence of peaks 1021.3 cm^{-1}, 1159.2 cm^{-1}, 33621 cm^{-1} and 3570.8 cm^{-1} in Figure 4 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 present in xanthan (e.g. 1714.6 cm^{-1} and 1599.0 cm^{-1}) indicate the interaction of the two compounds to form the xanthan-zinc oxide nanocomposite (Figures 3 and 4). Hence, 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 Figures 1 and 2.

The band at 3418.0 cm^{-1} indicate the presence of a stretching of strong hydroxyl groups, and bands 3354.6 cm^{-1}, 3291.2 cm^{-1} and 2877.5 cm^{-1} indicates O-H functional group (Figures 3 and 4). 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 (Figure 3). 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 (Akinyemi and Alausa 2020; Akinyemi and Kadiri 2020; Al-Yasiri *et al.*, 2019).

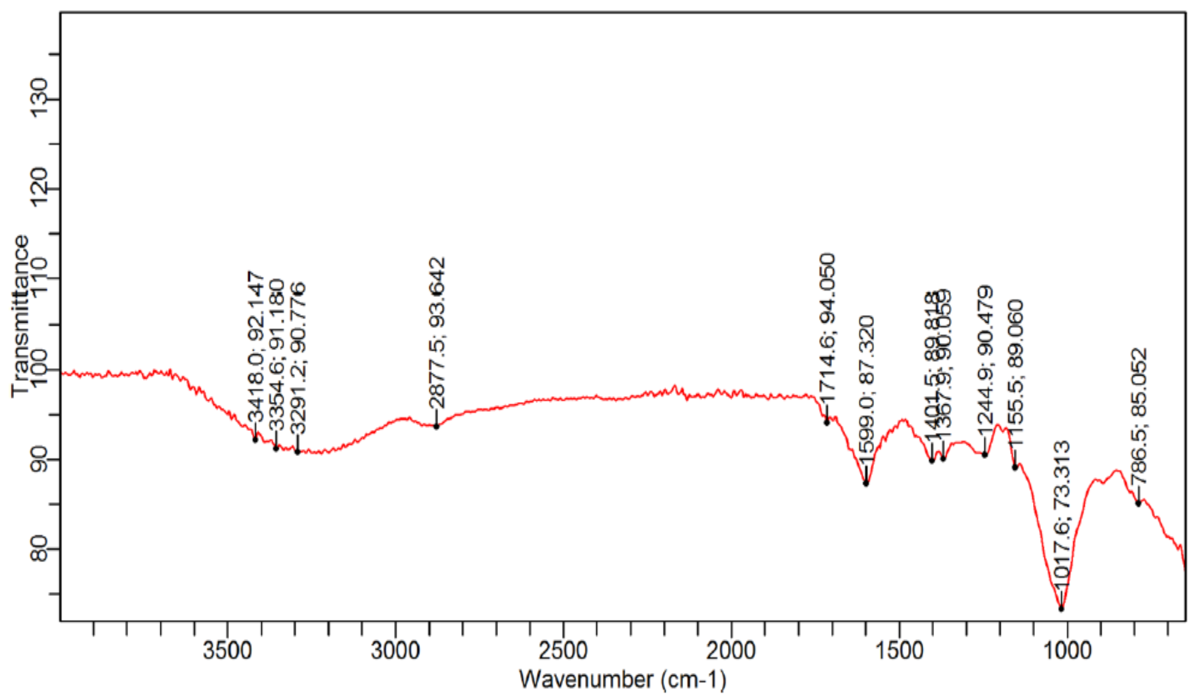

Figure 3: FTIR spectrum for xanthan gum

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Volume-10, Issue-4 (August 2020)
https://doi.org/10.31033/ijemr.10.4.11

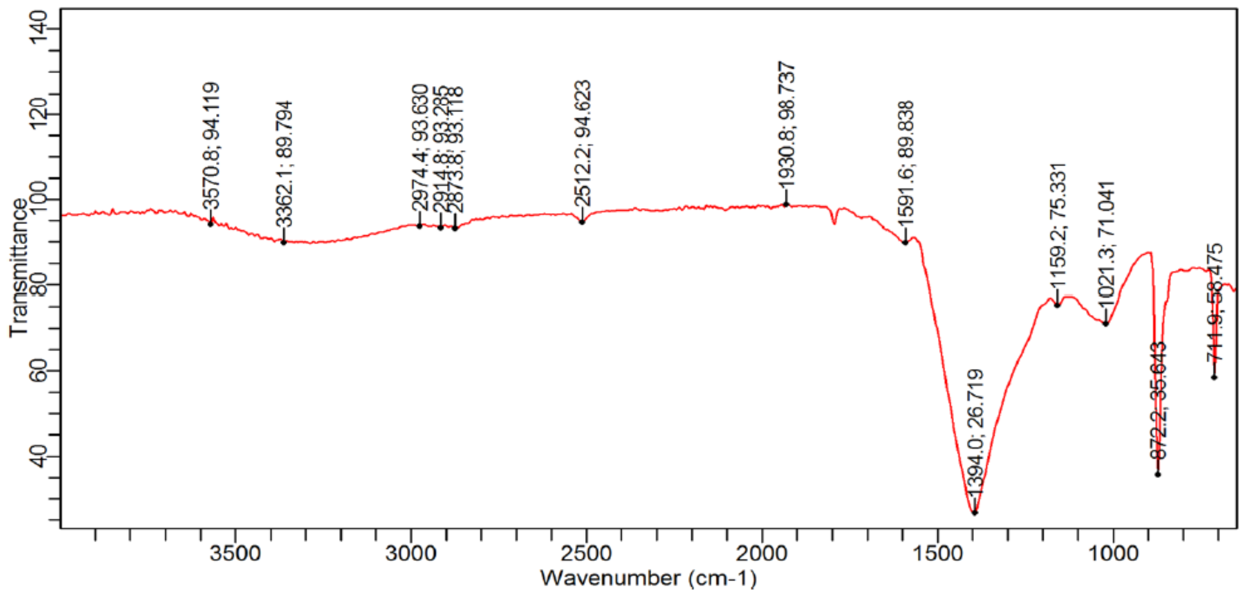

Figure 4: Spectrum of blend of ZnO nanoparticles and xanthan gum in equal proportion

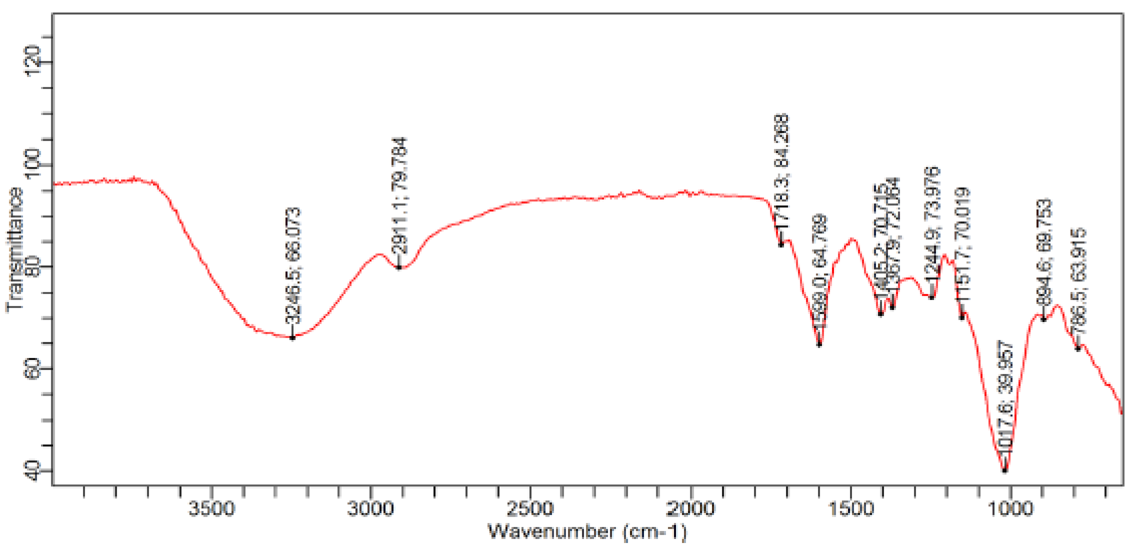

Figure 5: Spectrum of blend of CuO nanoparticles and xanthan gum in equal proportion

A critical look at Figure 5 revealed there are some level of interactions with the CuO nanoparticles and the xanthan gum since some of the peaks/bands in the sample with only xanthan gum are no more reflecting in the spectrum. However, the number of peaks/bands has reduced from twelve (12) to eleven (11). 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 for ZnO and xanthan gum.

IV. CONCLUSION

The impacts of ZnO and CuO on viscosity of water based drilling fluid were investigated in this study. From the result obtained, it is concluded that the rheological properties of water based drilling fluid improved with the addition of zinc oxide and copper (II) oxide nanoparticles. Both zinc oxide and copper (II) oxide nanoparticles mixed with xanthan gum in small quantity improved the drilling fluid viscosity. The structures of the zinc oxide nanoparticle interacted better with the additive than copper (II) oxide). The results of this study indicate that the bonds between

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nanoparticles and xanthan gum help rheological properties of the drilling fluids. Zinc oxide nanoparticle improved the rheological performance of drillings fluids than copper (II) oxide nanoparticle when combined with xanthan gum in appropriate proportion. Therefore, zinc oxide nanoparticles combined with xanthan gum is recommended for use in the oil and gas industry to improve the rheological properties of water based drilling fluid.

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