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Effect of Nanomaterial on the Rheology of Drilling Fluids

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Abstract: Good formulations of drilling fluid properties are required in drilling operations. Selection of suitable drilling fluid additives are important criterion in formulating drilling fluid. Nanomaterial is selected in this study due to its extremely high surface area to volume ratio and high thermal conductivity. This research is focused on determining the optimum concentration of multi-walled carbon nanotubes (MWCNTs) to produce better rheological properties in water-based and ester-based drilling fluids at various temperatures. Different concentrations of MWCNTs at various temperature were tested in this study. The results revealed that in water-based drilling fluid, the plastic viscosity, yield point and gel strength are not much affected by different concentration of MWCNTs used. However, 0.01 ppb of MWCNTs gives the lowest filtrate volume at low pressure low temperature and high temperature high pressure condition of 4.4 and 1.9 mL, respectively. In ester-based drilling fluid, gel strength and emulsion stability is slightly increased as MWCNTs concentration increases. This formulation also indicates that MWCNTs can be used together with conventional filtrate loss control agents to improve filtrate loss. It is also found that temperature gives an effect to the drilling fluid rheological properties. In water-based drilling fluid, plastic viscosity, yield point and gel strength are decrease with an increase in temperature. On the contrary, ester-based drilling fluid shows the other way around. Therefore, MWCNTs can be used as an additive in drilling fluid due to its improvement observed in the drilling fluid rheological properties.

Key words: Nanomaterial, drilling fluid, rheology, additives, multiwall carbon nanotube

INTRODUCTION

Currently, drilling scenario face a great challenge especially in the formulation of suitable drilling fluids for a more complicated drilling conditions. High temperature high pressure wells due to deep water operation and highly deviated well may cause difficulty in drilling operation. As such, development of high performance drilling fluid in more extreme conditions such as ultra-deep wells should be designed to withstand temperature of 500°F and 30,000 psi (Tran and Lyons, 2007). Nowadays, drilling fluids in oil and gas exploration and production is designed for mechanically strong, physically small, chemical and thermally stable, biologically degradable, environmentally benign chemicals, polymers or natural products for use in drilling. However, drilling process in offshore reservoir brings greater challenges due to changes in operating conditions such as operational depth, temperature, pressure and shifting in drilling orientation (Amanullah and Al-Tahini, 2009).

Selection of suitable drilling fluids and maintenance of their properties within the specification are critical aspect of successful oil and gas well drilling. Other than the fluid (water or oil or both) phase, the solids, chemicals and polymers that are used in designing a fluid play an important role in the functional behaviour of the fluids. Though the factors that guide the choice of a fluid base and the mud additives are complex, the selection of the additives must consider both technical and environmental challenges of the areas for trouble free and economic drilling and production operations (Azar and Samuel, 2007). This condition was leading to the application of nanotechnology which offer tailored made nanomaterial with specific characteristics properties that is expected to overcome the technical and environmental challenges faced during drilling and production. It may offer better solutions to drilling operation related problems and extend the benefit of petroleum production and development (Kong and Ohadi, 2010).

Nanomaterial is considered the most promising material for smart fluid design for oil and gas field application due to totally different and highly enhanced physio-chemical, mechanical, electrical, thermal, hydrodynamic properties and interaction potential of

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nanomaterial compared to their parent materials. Nanofluids for oil and gas field applications are defined herein as drilling, drill-in, completion, stimulation or any other fluids used in the exploration and exploitation of oil and gas that contain at least one additive with particle size in the range of 1-100 nanometers (Amanullah and Al-Tahini, 2009).

Physically, a nano sized particle has a dimension that is thousand millionths of a meter. Hundred nanometer fibers or particles have diameters that are about 800 to 1000 times smaller than the diameter of a human hair and roughly equal to the width of 10 hydrogen atoms (Mokhatab *et al*., 2006). Based on the No. of nano-sized additives in the fluid, these fluids can be classified as simple nano-fluid and advanced nano-fluid. Nano-fluids with one nano-sized additive are defined as simple nanofluids and nanofluids with more than one nano-sized additive are defined as advanced nanofluids.

From functional points of view, a nanomaterial could be single functional or multifunctional. A multifunctional nano-additive can perform several jobs in the fluids systems to complete the functional tasks of the fluid with a dramatic reduction in total solids and/or chemical content of a mud and also the overall fluid cost. The significantly higher functional ability with a reduction in overall fluid cost in spite of high cost of individual additive is expected to be one of the characteristic features of nano-based smart fluids. In addition, the natures of nanomaterial which is very fine but have very high specific surface area with enormous area interactions just require very low concentration of nanomaterial to provide great enhancement in fluid properties.

In this study, the optimum concentration of multi-walled carbon nanotubes (MWCNTs) to generate better rheological properties in water-based drilling fluid and ester-based drilling fluid at different temperatures is investigate.

MATERIALS AND METHOD

For the preparation of both drilling fluid MWCNTs in powder form is used. Figure 1 show the average diameters of the MWCNTs used were 30 nm. These particular MWCNTs then were weighted by using micro-scale electronic balance at different concentration of 0.001, 0.01 and 0.1 ppb. Then each drilling fluid was prepared and test according to the standard procedures (API, 2000). Basic rheological properties were carried out such as mud weight, plastic viscosity, apparent viscosity, gel strength and filtrate loss at low pressure and high pressure and high temperature. The tests were also conducted at various temperatures of 80 F, 200 F and 250°F.

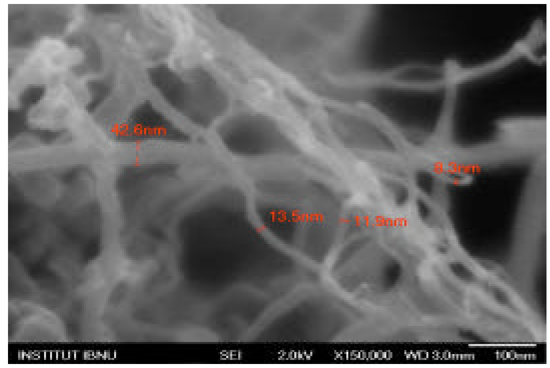

Fig. 1: Multi-walled carbon nanotube diameter under field emission scanning electron microscopy (FESEM)

RESEARCH FINDINGS

Rheological properties of water-based drilling fluid: The experimental observation shown that not much significant variance of plastic viscosity, yield point and gel strength in water-based drilling fluid (WBDF). Figure 2 depicts that different concentration of MWCNTs used was not much affected the rheological properties of the drilling fluid.

API filtrate loss after aging at different concentration of MWCNTs used is shiwn in Fig. 3. From the Fig. 3 it revealed that 0.01 ppb addition of MWCNTs gives the lowest filtrate volume.

Rheological properties of ester-based drilling fluid: Figure 4a illustrate the effect of different concentration of MWNTs to the gel strength before aging for Ester-Based Drilling Fluid (EBDF). At 10 seconds and 10 min gel strength, the value is gradually increased. Before aging, controlled sample and 0.001 ppb are lower than acceptable range but as concentration MWNTs increase to 0.01 and 0.1 ppb the value move within the range. Sample without MWNTs gives a high value and over the range which is in between 10-20 lb/100ft^2.

Figure 4b shows the comparison of ES of controlled sample and different MWNTs concentration before and after aging. From the graph, it shows that increase in concentration does not affect the emulsion stability reading. All samples including controlled sample is within the acceptable limit which should be higher than 400 V. Sample with nanomaterial gives the higher initial value at 2048 V.

Effect of combination of MWCNTs with conventional fluid loss additive in WBDF and EBDF: In WBDF, conventional fluid loss, Pac UL with different concentration of 0.0, 0.5 and 1.0 ppb was used in order to

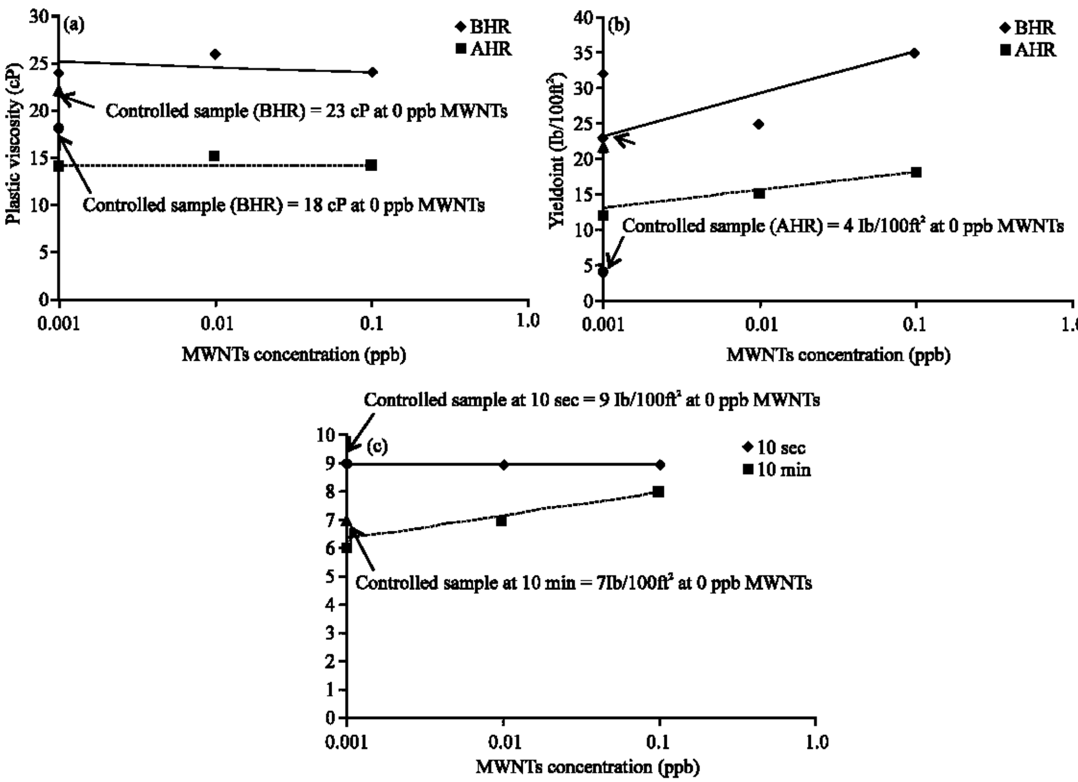

Fig. 2(a-c): Rheological properties of water-based drilling fluid, (a) Plastic viscosity, (b) Yield point and (c) Gel strength

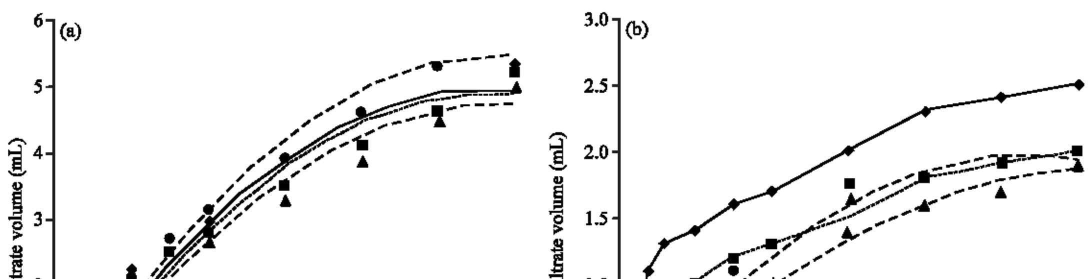

Fig. 3(a-b): (a) API and (b) HTHP filtrate loss after aging at different MWCNTs concentration

see the effect of MWCNTs on mud filtration. Figure 5a displayed the API filtrate loss at different concentration Pac UL and constant concentration of MWCNTs before aging. From the graph is clearly shows that with increasing Pac UL concentration will reduce the filtrate volume. Started with without Pac UL and 0.01 ppb MWCNTs in the sample, filtrate volume is high at around 7 mL. Then, addition of 0.5 ppb Pac UL and MWCNTs, filtrate volume getting reduce to about 6.5 mL. At 1.0 ppb Pac UL combined with MWCNTs gives the lowest filtrate volume of 4.3 mL.

In EBDF, confitrol was used as filtration control agent and tested in HTHP condition. In this study, 0.01 ppb of MWCNTs combined with different

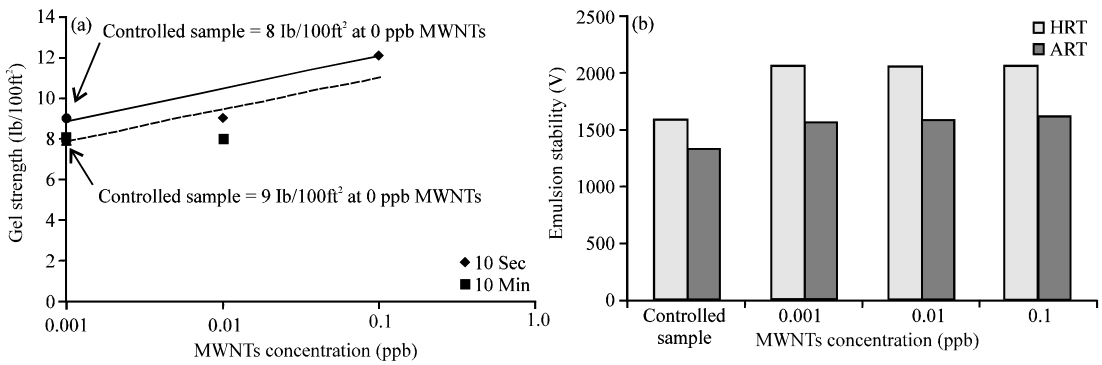

Fig. 4(a-b): Rheological properties of ester-based drilling fluid, (a) Gel strength and (b) Emulsion stability

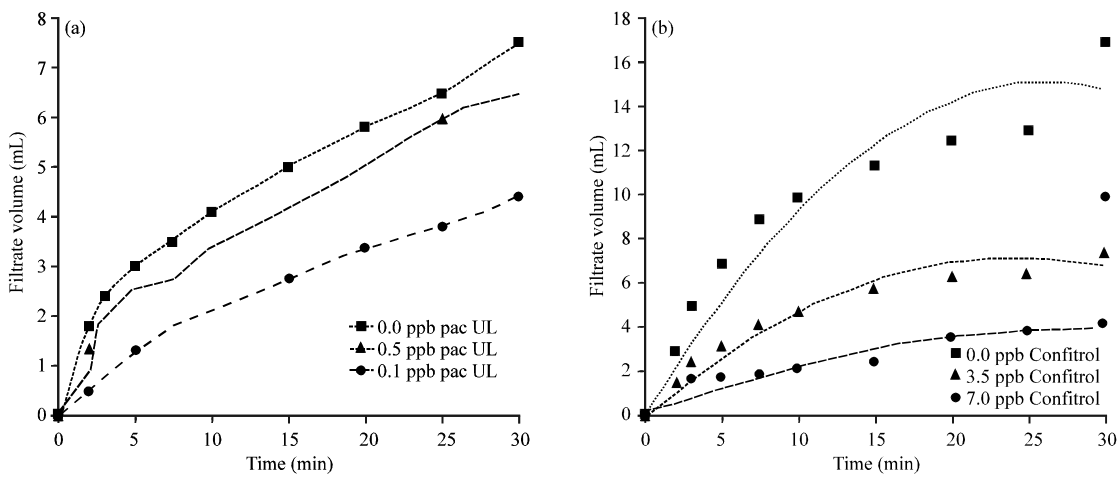

Fig. 5(a-b): Combination of MWCNTs and conventional fluid loss, Filtrate volume of (a) WBDF and (b) EBDF

concentration of confitrol of 0.0, 3.5 and 7.0 ppb was used. The effect of MWCNTs on mud filtration in EBDF before aging is given in Fig. 5b. This graph shows that filtrate volume is decrease as confitrol concentration increase at constant MWCNTs concentration.

Effect of temperature on rheological properties of MWCNTs as additive in WBDF and EBDF: Temperature also becomes an important indicator to show the stability of the properties of drilling mud. In this study, three different temperatures of 80°F, two other temperatures of 200 F and 250°F was evaluated to see the effect of temperature on the MWCNTs as additive in WBDF and EBDF. Figure 6a shows effect of temperature on plastic viscosity of controlled sample and different MWCNTs concentration in WBDF. As temperature increase from 80 F-250°F, plastic viscosity decrease for all sample. Although, the value is decrease but it is still in the acceptable limit. Controlled sample shows a slow decrease in plastic viscosity as compared to others. Sample with MWCNTs gives sharper slope. Besides that, at higher temperature, water viscosity decreases which results lower plastic viscosity of the mud. Temperature really gives significant impact to the plastic viscosity in WBDF. In contrast, plastic viscosity rose sharply when the temperature increase in EBDF Fig. 6c.

As can be seen in Fig. 6b is the effect of temperature to the 10 min gel strength in WBDF. As temperature increase, gel strength is decrease for all samples. In EBDF gel strength also affected by changing in temperature. At elevated temperature, gel strength reading getting higher as shown in Fig. 6d. Although the gel strength of sample with MWNTs is gradually increase as temperature increase but the value is still lower as compared to the controlled sample. Controlled sample gives higher gel strength value at higher temperature which exceed the acceptable limit.

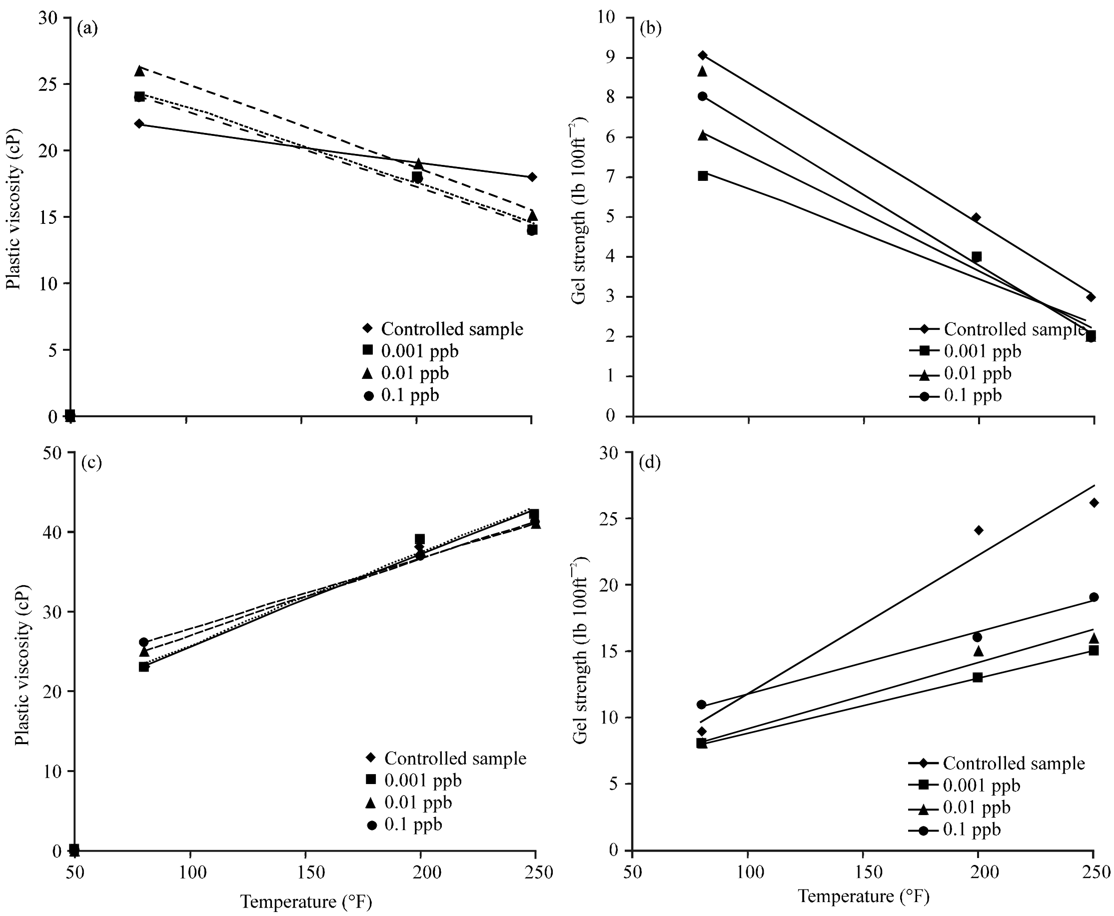

Fig. 6(a-d): Temperature effects on WBDF, (a) Plastic viscosity, (b) Gel strength, EBDF, (c) Plastic viscosity and (d) Gel strength

DISCUSSION

Rheological properties of drilling fluids: Water-based drilling fluid shows not much significant variance of plastic viscosity and yield point. The constant value for the gel strength of water-based drilling fluid gives the same features as the previous report that stated flat type gel strength property of the nano-based drilling fluid indicates superior functional functional behaviour while drilling (Amanullah *et al*., 2011).

Addition of 0.01ppb of MWCNTs gives the lowest filtrate volume as compare to others concentration. Other samples give higher volume than acceptable limit. This condition occur might because of the mud become less stable due to the solid accumulation. As a result, impermeable mudcake with lower porosity is not obtained and more filtrate can pass through the mudcake. In HPHT condition, 0.01 ppb of MWCNTs still gives the lowest filtrate volume. Both API and HTHP condition observed to have no spurt loss especially when adding nanomaterial. This property was very good in reducing the scope of formation damage in damage prone oil and gas reservoir (Amanullah *et al*., 2011).

For ester-based drilling fluid, small difference value of 10 sec and 10 min gel strength gives the shape is almost flat type of gel strength which is same as WBDF. Lower gel strength reading after 10 min may due to reducing in the shear rate of the mud. Moreover, reduction of the yield point may also become another factor that affect the gel strength reading.

Emulsion Stability (ES) is one of the important indicators in EBDF to show that oil and water is well mixed. Higher value of sample with nano material is good in drilling operation because emulsion stability is getting reduced with increasing temperature and pressure. Emulsion stability of the nano-based drilling fluid is relatively high might because of the high electrical stability criteria of MWNTs itself. Small amount of MWNTs is enough to increase the emulsion stability of the mud.

Effect of combination of MWCNTs with conventional fluid loss additive in WBDF and EBDF: Addition of small concentration of MWCNTs in WBDF can help to improve in reducing filtrate loss through the formation. MWCNTs still required conventional filtration control agent to control fluid loss in the mud. Increase in Pac UL concentration results in an increase available binding site on it. These active sites will react with the base oil to form a homogeneous mud system thus reduce the porosity of the filter cake. Besides, increasing Pac UL concentration in the mud is expected to further reduce fluid loss through the filter cake.

Same condition is observed on EBDF. Increase of confitrol concentration gives increase the active sites react with base oil. This homogeneous reaction helps in further reduce the porosity of the filter cake formed. Addition of MWCNTs as additive in this type of mud is not much influence the mud filtration property. Higher concentration of MWCNTs perhaps is required to obtain a better result.

Effect of temperature on rheological properties of MWCNTs as additive in WBDF and EBDF: High temperature leads to reduce in emulsion stability of the mud. This condition is believed to cause solid accumulation. High solid accumulation gives is not favourable as it results high plastic viscosity, reduce the gel strength as well as yield point of the water- based drilling fluids.

In EBDF, high gel strength value in the mud is because of high yield point at higher temperature. Solid accumulate in the mud will increase the attractive force between a particles thus resulting higher gel strength.

CONCLUSIONS

This study shows that MWCNTs can be used as an additive in drilling fluid The following conclusion can be derived from this research:

- Rheological properties (plastic viscosity, gel strength and filtrate loss) show better improvement with the addition of MWCNTs
- Increase concentrations of MWCNTs in ester based drilling fluid provide better result in plastic viscosity, gel strength, emulsion stability and filtrate loss
- Combination of MWCNTs with commercial fluid loss control agent such as Pac UL give better filtrate controller
- An increase in temperature will affect the rheological properties in both water based and ester based drilling fluids. However, an increase in temperature did not give significant impact to the fluid loss and emulsion stability

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