International Journal of NanoScience and Nanotechnology.
ISSN 0974-3081 Volume 10, Number 1 (2019), pp. 21-31
© International Research Publication House
http://www.irphouse.com

Characterization of the MWCNT-Duovis polymer composite effects on laboratory water based drilling fluid

Christian Riise
University of Stavanger
Stavanger, Norway

Mesfin Belayneh
University of Stavanger
Stavanger, Norway

ABSTRACT

This paper reports the effect of multi-walled carbon nanotubes (MWCNT) on the laboratory water based drilling fluid properties.

The experimental test results showed that addition of 0.1 wt. % and 0.29wt. % MWCNT reduced the friction coefficient of drilling fluid by 27 % and 34 %, respectively. MWCNT concentration and particles dispersion have shown a significant impact on the drilling fluid rheological properties of the drilling fluids.

1 INTRODUCTION

Properly designed drilling fluid is a key for the successful drilling operation. Prior to drilling, it is important to evaluate drilling fluid with respect to its performance, environmental impacts and cost as well. The main function of drilling fluid among others is to bring cutting to surface, to maintain well pressure, to lubricate and cool well/drill bit. Oil based drilling fluid (OBM) is better than water based mud (WBM) in terms of shale swelling control and lubricity. However, OBM is expensive and environmental unfriendly. It is therefore important to improve the performance of water based drilling fluid.

Nanotechnology (1-100nm size) have shown proven solutions in the field of electronics, biomedical and material science. Nanotechnology creates materials with improved properties due to their physical, chemical, electrical, thermal, mechanical and optical properties. [1].

In the recent years, nanoparticle research results on drilling fluids have shown positive impacts. For instance, nanoparticles improve rheological properties of drilling fluid [2, 3], reduce filtrate loss and mud cake thickness [2-5], reduce permeability of the shale [6, 7], increase lubricity [8-13] and increase well strength [14].

Multiwall carbon nanotube (MWCNT) has shown improved rheological properties of drilling fluid [4] and in cement [15, 16]. Awais et al. [12] and Afiya et al. [13] have studied the effect of MWCNT in CMC and XG biopolymers, respectively. Results showed that the performance of MWCNT is different in the two polymer types. Therefore, this paper presents the experimental investigation of the effect of MWCNT on Duovis biopolymer based laboratory water based drilling fluid properties.

2 EXPERIMENTAL INVESTIGATION

Base fluid (control) laboratory drilling fluid was formulated by mixing bentonite, salt and Duo-vis biopolymer with tap water. The impact of nanoparticle on the reference system were studied by adding 0.0095-0.29wt% nanoparticle. The following section presents the description of drilling fluid formulation, testing and characterization.

2.1 Materials and Methods

2.1.1 MWCNT nanoparticle description

Carbon nanotube (CNT) is a cylindrical molecule composed of carbon atoms. In carbon nanotubes, each neighboring atoms bonded with strong covalent bond. CNT's are lightweight materials having good electrical, thermal and mechanical properties as well as shows resistance to corrosion. [17] The MWCNT used in this study is purchased from EPRUI Nanoparticles and Microspheres Co. Ltd. [18] **Figure 1** shows the SEM image of MWCNT and **Table 1** provides its **c**haracterization. [18]

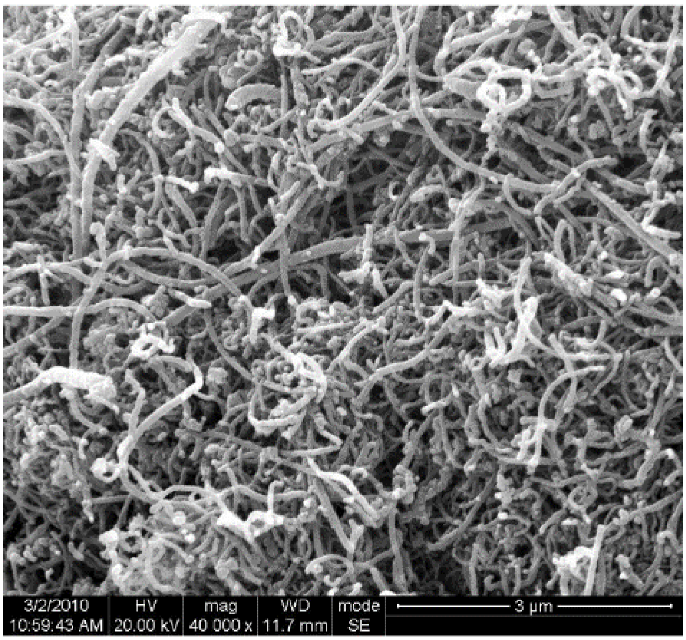

Figure 1: Morphology of MWCNT particles – SEM photograph. [18]

Appearance	OD Particle Size (nm)	ID Particle Size (nm)	Length (μm)	Purity %	Surface Area (m^2/g)	Density (g/cm^3)	Electrical conductivity s/cm
Black powder	20-40	5-10	10-30	>95	>80	2.1	>100

Table 1: Characterization of the used MWCNT. [18]

2.1.2 Duo-vis biopolymer description

DUO-VIS is a dispersible and high-molecular-weight biopolymer, which is an equivalent of xanthan gum (XC Polymer). Its function is to increase the viscosity of water based systems, to provide particles in suspension and hence good for cutting transport. Duo-vis allows fluid with highly shear thinning and thixotropic properties. The product was obtained from MI-SWACO.

2.1.3 Lignosulfonate

Lignosulfonate is water soluble anionic polyelectrolyte polymer. Its function is to deflocculate clay-based drilling fluids. As lignosulfonate adsorbed on clay particles, the attractive force between the clay palate particles will be changed to a repulsive force and results the system being deflocculated. The overall effect is reducing the yield strength of the drilling fluid. The product was obtained from MI-SWACO.

2.1.4 Drilling fluid formulation and results

Ahmed et al's [19] have reviewed several water based drilling fluids and have found out that the concentration of bentonite in average is 5% by weight. In this paper, the laboratory nanoparticle free drilling fluid, also called reference (Ref), was formulated by mixing 500ml of fresh water, 5g of salt (KCl), 0.5g of Duovis polymer and 25g of bentonite (i.e. 5wt.%). Nanoparticle based drilling fluids were prepared by mixing nanoparticle in the base fluid. The drilling fluid ingredients were mixed with a high speed Hamilton beach mixer, and were aged for 48 hours in order to swell bentonite. All the tests were carried-out according to API RP 13B-1 [20]. **Table 2** shows the test matrix of drilling fluids treated with MWCNT.

Additives	Reference (Ref)	Ref + 0.1 g MWCNT	Ref + 0.2 g MWCNT	Ref + 0.5 g MWCNT	Ref + 1.5 g MWCNT
Water [ml]	500	500	500	500	500
Duovis polymer [g]	0.5	0.5	0.5	0.5	0.5
KCl [g]	5	5	5	5	5
MWCNT [g]	0	0.1	0.2	0.5	1.5
Bentonite [g]	25	25	25	25	25
Lignosulfonate [g]	0.2	0.2	0.2	0.2	0.2

Table 2: Drilling fluid formulation

2.2 Results and discussion

2.2.1 Effect of nanoparticle concentration on rheological parameters

Figure 2 shows the viscometer responses of the drilling fluids presented in the **Table 2**. As displayed, the viscosity of the drilling fluids changes nonlinearly as the MWCNT concentration increases.

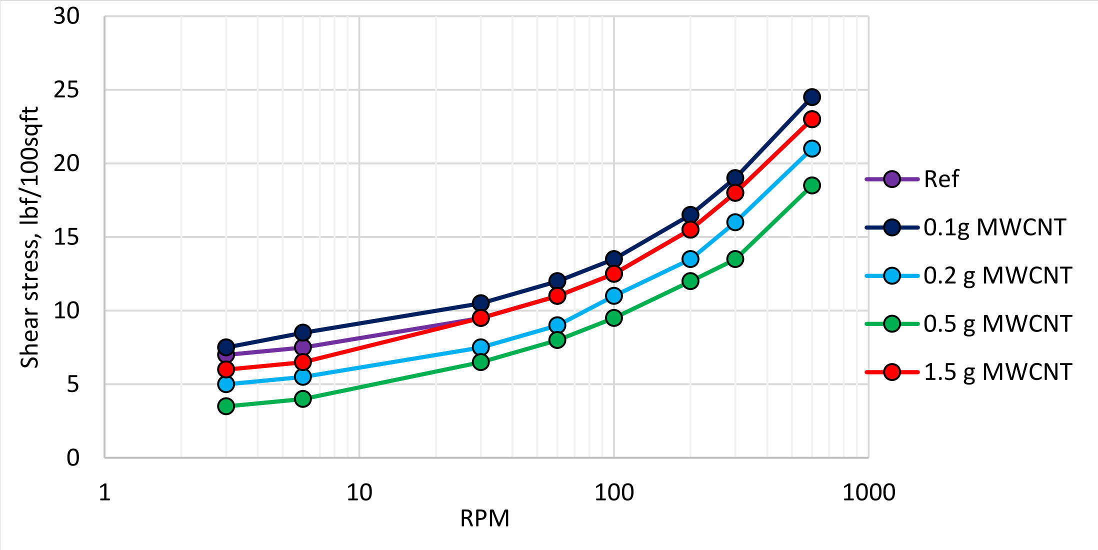

Figure 2: Viscometer measurement of test matrix –Table 2

The rheological properties are quantified from the viscometer data. The rheological parameters determine the drilling fluid performance efficiency concerning hydraulics and cutting transport phenomenon.

There several rheological models used to characterize the shear-deformation rate of drilling fluid. For the evaluation of the formulated drilling fluid, Herschel-Bulkley (H-B) model is used in this paper. The model a three parameters model, which reads [21]:

$$\tau = \tau_o + k\gamma^n \qquad 1$$

Where, the flow index (n) and the consistency (k) are determined from curve fitting with the measurement provided that the yield stress (τ_o) is approximated first.

Kok and Alikaya evaluated the rheological properties of KCl/Polymer type drilling fluids. The yield stress (τ_o) is determined by using [22]:

$$\tau_o = \frac{\tau^{*2} - \tau_{max}\tau_{min}}{\tau^* - \tau_{max} - \tau_{min}} \qquad 2$$

τ_{max} and τ_{min} are the maximum and minimum measured shear stresses. The shear stress (τ^*) is determined by interpolation from the corresponding geometric mean of the shear rate $\gamma^* = \sqrt{\gamma_{max}\gamma_{min}} = 72.25s^{-1}$.

The calculated H-B model parameters are presented in **Table 3.** As shown, except for the 0.1g MWCNT, the higher concentrations reduced the yield stress significantly. The lower concentration (0.1, 0.2 and 0.5g) nanoparticles reduced the flow index and increased the consistency index. On the other hand, the higher concentration (1.5g) nanoparticle shows an increasing and decreasing effect, respectively. From the results, one can observe a nonlinear effect of concentration on the rheological parameters.

Model	Parameters	Ref	Ref + 0.1 g MWCNT	Ref + 0.2 g MWCNT	Ref + 0.5 g MWCNT	Ref + 1.5 g MWCNT
Herschel Bulkley	τ_o (lbf/100ft^2)	6.90	7.18	4.71	2.82	5.52
	% Deviation		4.00	-31.67	-59.07	-20.02
	k (bfs^n/100ft^2)	0.23	0.41	0.32	0.39	0.21
	% Deviation		82.47	39.90	72.11	-4.76
	n [-]	0.64	0.56	0.60	0.56	0.67
	% Deviation		-13.23	-7.49	-12.22	4.34

Table 3: Computed H-B rheological parameters of drilling fluids formulated in **Table 2**

2.2.2 Effect of pH on the coefficient of friction

The lubricity of the drilling fluids on 6-chromium steel ball-plate surface were measured with CSM tribometer. The ball rotated with a linear speed of 3m/s and lasted for 10min. The normal force of 5N was applied on the tribometer arm. The lubricity of the formulated drilling fluids have been measured at 22^0C. Repeat tests were performed to achieve reproducable results and the average values are reported as shown in the **Figure 3**.

To study the effect of pH on the lubricity, the formulated drilling fluids were treated with NaOH to obtain 10 pH. For instance, as shown in the figure, addition of 0.1wt % and 0.29wt. % MWCNT in pH =10 drilling fluid increased the lubricity by 27% and 34% respectively. The main mechanisms for the reduction of coefficient of friction are categorized into three [23]. These are rolling, sliding, and exfoliation/transfer of thin film. A possible explanation for higher lubricity could be due to the MWCNT-Duovis polymer composites along with Lignite created a thin film layer. The formation of film on the harder solid shears easily at the sliding contact interface and hence offers low friction. This has positive impact on torque and drag load reductions. Moreover, one can also observe that lubricity of water the nanoparticle based drilling fluid depends on the pH level. The higher pH reduced the coefficient of friction, which may have something to do the stability/dispersion of the fluid system. However, up to this level of research the mechanism for the performance was not further analyzed with zeta potential measurement.

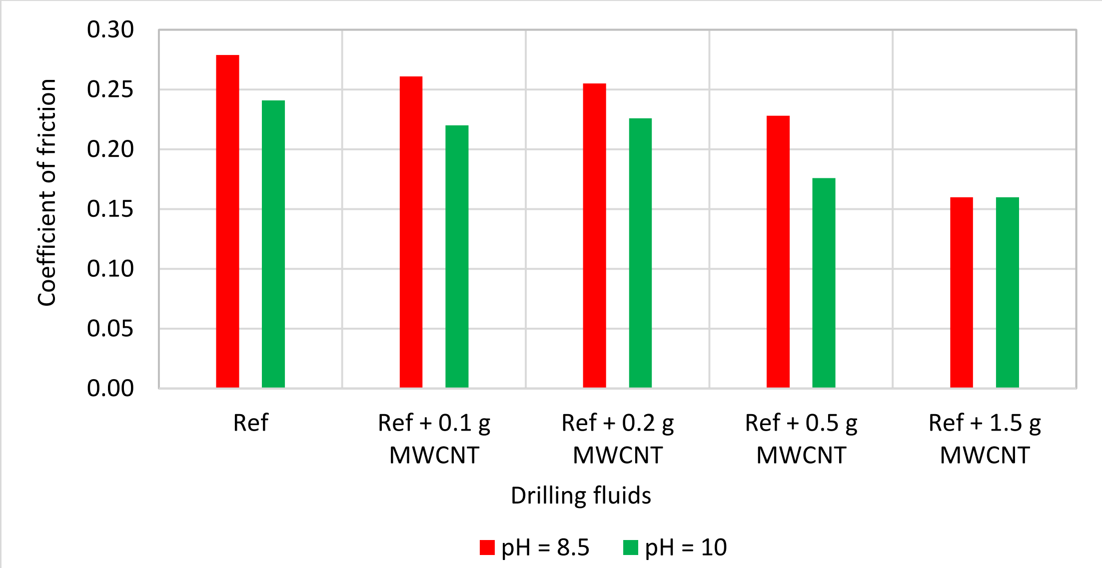

Figure 3: Drilling fluid's coefficient of friction

2.2.3 Effect of Mixing on drilling fluid properties

As shown in **Figure 2 and Table 3**, the reason for the nonlinear rheological property with respect to MWCNT concentration increase is not explained yet. All the fluid systems were mixed with mechanical mixer and the dispersion of nanoparticle in the fluids system might not be homogeneous. However, in order to investigate the effect of mixing, in this section, the 0.5 g MWCNT additive drilling fluid formulated in **Table 1** was considered. Except for bentonite, the two fluid specimens to be used for the dispersion evaluation were prepared by mixing 1.5 MWCNT, 0.5g Duovis, 5 g KCL and 500 ml water.

Figure 4a shows the first fluid (Fluid A), which was mixed mechanically with high speed Hamilton beach mixer. The second batch (Fluid B) was mixed mechanically and then sonicated for 2 hr (see **Figure 4b)**. The fluid specimens labelled as Fluid A-(1) and Fluid B-(3) show dark in color, which was due to the MWCNT pigment and the pictures were taken right after mixing. The specimens were then aged for 24 hrs. at room temperature to evaluate the dispersion/suspension of the solution. Using light at the backside, photograph picture of the fluids were taken again. As shown, the nanoparticle in fluid A-(2) were settled out at the bottom with a clear particle free fluid at the top, which is entirely different from the Fluid A-(1). On the other hand, Fluid B-(4) shows a dark solution as Fluid B-(3) (i.e. as it was before 24 hr.). This shows that the sonicator might have provided sufficient energy and created a good stability with a better particle dispersion/suspension in the solution. Both nanoparticle solutions were then mechanically mixed with 25g bentonite. The drilling fluids were aged again for 24 hrs. for the bentonite get swell.

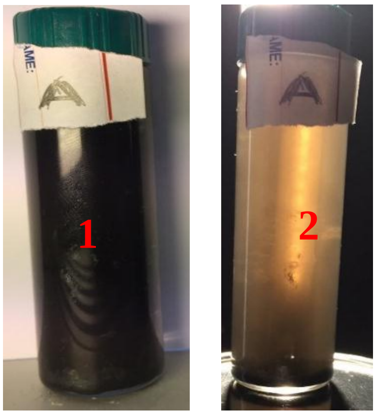

Figure 4a: Fluid A: Mechanically mixed (1) Right after mixing (2) After 24 hr.

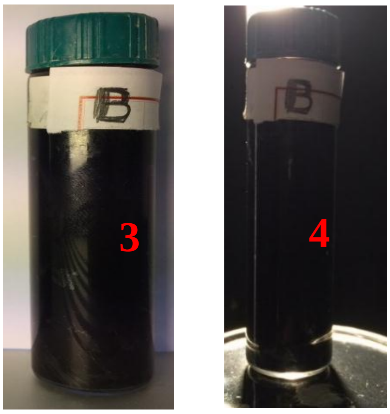

Figure 4b: Fluid B: Mixed mechanically and sonication (3)Right after mixing (4)After 24 hr.

Figure 5 shows the viscometer data, of the drilling fluids mixed with different methods. As shown, fluid B VG-response is higher than fluid A, which reflect dispersion performance of the nanoparticles in the system. Due to the stable system, the interaction of the particles with drilling fluid might have created a better gel structures.

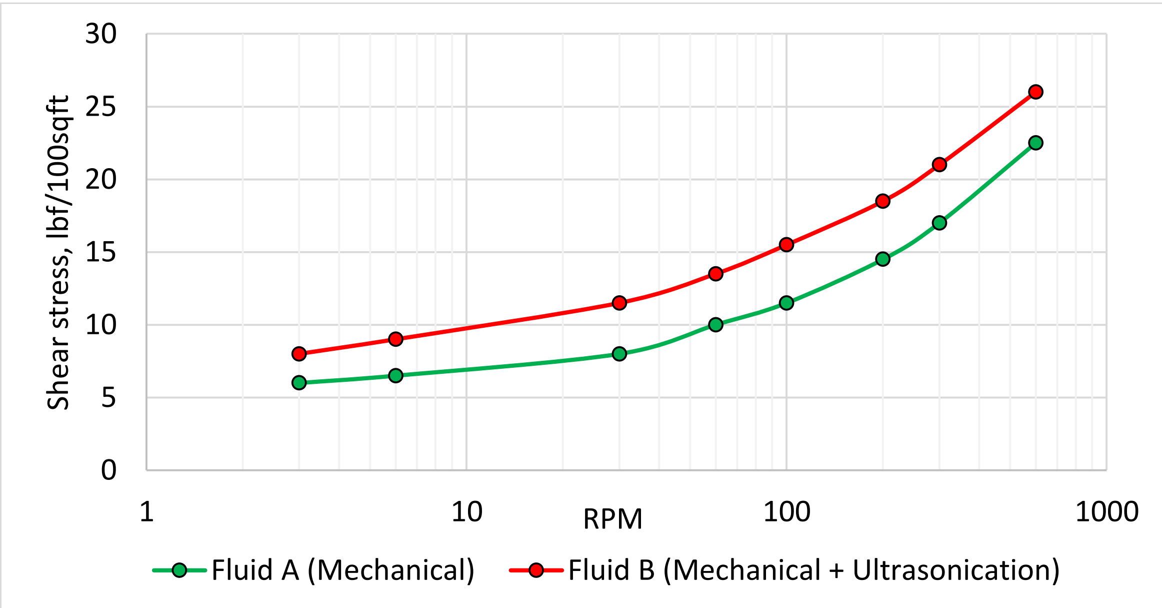

Figure 5: Viscometer data to evaluate mixing effect.

The effect of mix on the Power law, Bingham plastic and Herschel-Bulkely rheological parameters are provided in **Table 4.** In general, the sonicated system increased the consistency index, yield strength and the lower yield strength. On the other hand, the flow index, plastic viscosity shows reduction. Moreover, the lubricity of the fluid B system increased by 2.9 %, which is insignificant. For this particular system, one of the reasons could be due to the low concentration of MWCNT, which may not have created sufficient film for ball and plate contact despite of the mixing effects.

Mix methods	**Power law**		**Bingham Plastic**			**Herschel-Bulkley**		
	n [-]	k $lbfs^n/100ft^2$	PV cP	YS $lbf/100ft^2$	LSYS $lbf/100ft^2$	τ_o $lbf/100ft^2$	k $lbfs^n/100ft^2$	n [-]
Mechanical	0.4	1.37	5.5	11.5	5.5	5.86	0.21	0.65
Mechanical + Sonication	0.31	1.83	5	16	7	7.33	0.60	0.52
% Change	-22.5	34	-9	39	27	25	180	-20

Table 4: Mix effect on Power law, Bingham Plastic and H-B rheological parameters

2.2.4 SEM evaluation of mud cake structure

The structure of the 1.5 g MWCNT treated drilling fluid's mud cake was analysed through Scanning Electron Microscope (SEM). **Figure 6** shows the SEM picture of the surface of the mud cake. As displayed, nanoparticles are distributed and deposited unevenly. The particle clustering could due to the mechanical mixer, which was not strong enough to create a well-dispersed solution, and also could be due to the particle interaction with Duovis polymer. Moreover, the considered MWCNT was not sufficient as compared with the bulk drilling fluid volume so that one can observe particle free space on the surface of the cake. Despite the 1.5 g MWCNT showed a significant impact on the rheological and lubricity, the particle was not able to reduce the filtrate loss. One of the reason could be due to poor mud cake structure to hinder filtrate loss. Inductively Coupled Plasma-Optical Emission spectrometry (ICP-OES) filtrate loss analysis showed that the ionic concentration obtained from the reference and the MWCNT treated drilling fluids are almost the same.

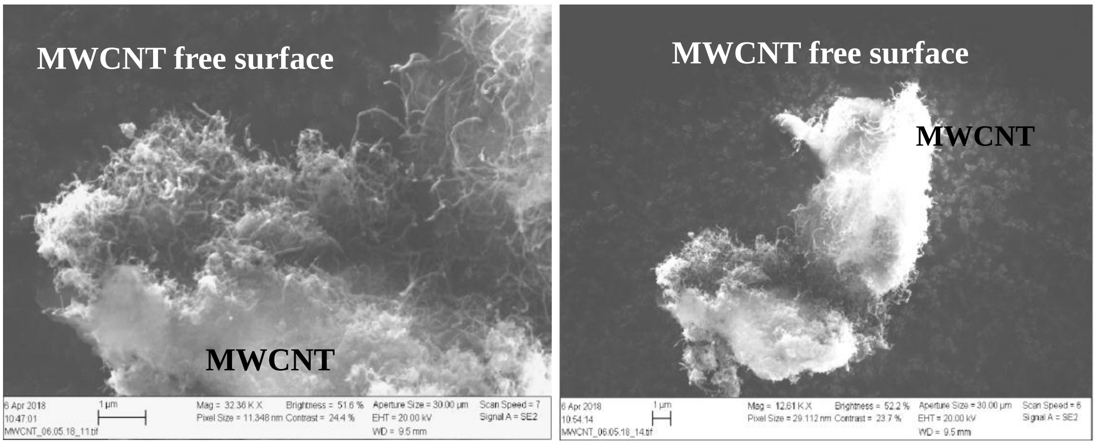

Figure 6: SEM picture of the surface of mud cake (MWCNT-and Particle free surface).

3 SUMMARY

This paper reports the experimental investigation of the effect of MWCNT nanoparticle in a laboratory formulated bentonite water based drilling fluid and characterized at room temperature. Based on the drilling fluid property (rheology, lubricity) results, the main observations can be summarized as:

- Nanoparticle dispersion plays a significant role on the drilling fluid properties.
- Addition of 0.1wt. % and 0.29wt % MWCNT reduced the average coefficient of friction of the laboratory fluid by 27% and 34%, respectively.
- Nanoparticle additives have shown significant impact on the drilling fluid rheological parameters in non-linear manner.
- The performance of nanoparticle depends on several parameters among others, pH, concentration, temperature, and degree of dispersion.
- In general, the considered MWCNT concentrations have increased the filtrate loss of the base fluid.

Please note that the results reported in this paper are based on the considered based fluids and the nanoparticle concentrations. However, changing the composition and temperature and pressure, one may get different results.

References

[1] K. Arivalagan1, S. Ravichandran, K. Rangasamy and E.Karthikeyan //Nanomaterials and its Potential Applications// International Journal of ChemTech Research CODEN (USA): IJCRGG ISSN: 0974-4290 Vol. 3, No.2, pp 534-538, April-June 2011

[2] Z. Vryzas, V. Zaspalis , L. Nalbantian , O. Mahmoud , , H. A. Nasr-El-Din, V. C. Kelessidis, //A Comprehensive Approach for the Development of New Magnetite Nanoparticles Giving Smart Drilling Fluids with Superior Properties for HP/HT Applications //IPTC-18731-MS International Petroleum Technology Conference, 14-16 November, Bangkok, Thailand 2016

[3] A. Parizad, K. Shahbazi, //Experimental investigation of the effects of sno2 nanoparticles and kcl salt on a water base drilling fluid properties//The Canadian Journal of Chemical Engineering 94 (10) (2016) 1924-1938.

[4] Ismail, A. R. (2014). //Improve Performance of Water-based Drilling Fluids// Sriwijaya International Seminar on Energy-Environmental Science and Technology.

[5] Mohammad F. Zakaria, Maen Husein, Geir Hareland, 2012//Novel Nanoparticle-Based Drilling Fluid with Improved Characteristics// SPE 156992-MS, paper presented at the SPE International Oilfield Nanotechnology Conference, 12-14 June 2012, The Netherlands

[6] Mukul M. Sharma, R. Zhang, M.E. Chenevert, L. Ji, Q. Guo, J. Friedheim, 2012 //A New Family of Nanoparticle Based Drilling Fluids// SPE 160045 This paper was prepared for presentation at the SPE Annual Technical Conference and Exhibition held in San Antonio, Texas, USA, 8-10 October 2012.

[7] Hoelscher, K.P., De Stefano,G., Riley, M. and Young, S. 2012"Application of Nanotechnology in Drilling Fluids"SPE 157031, SPE International Oilfield Nanotechnology Conference, 12-14 June 2012, Noordwijk, The Netherlands

[8] N. M. Taha, S. Lee, et al. //Nano graphene application improving drilling fluids performance// In International Petroleum Technology Conference. International Petroleum Technology Conference, 2015.

[9] B. Vegard and M. Belayneh, "The Effect Of Titanium Nitride(TiN) Nanoparticle On The Properties & Performance Bentonite Drilling Fluid," International Journal of NanoScience and Nanotechnology, vol. 8, no. 1, pp. 25-35, 2017.

[10] S. Wrobel and M. Belayneh, "The Effect Of MoS2 And Graphene Nanoparticles On The Properties And Performance Of Polymer/Salt Treated Bentonite Drilling Fluid," International Journal of NanoScience and Nanotechnology, vol. 8, no. 1, pp. 59-71, 2017.

[11] Muhammed Awais Ashfaq Alvi, Mesfin Belayneh, Arild Saasen, Bernt S. Aadnøy// The Effect Of Micro-sized Boron Nitride (BN) and Iron trioxide (Fe2O3) Nanoparticles on the Properties of Laboratory Bentonite Drilling Fluid //**Error! Reference source not found.** paper presented at the SPE Norway One Day Seminar held in Bergen, Norway, 18 April 2018.

[12] Muhammed Awais Ashfaq Alvi, Mesfin Belayneh, Arild Saasen, Kjell Kåre Fjelde, Bernt S. Aadnøy//Effect Of MWCNT And MWCNT Functionalized –OH And -COOH Nanoparticles In Laboratory Water Based Drilling Fluid //ASME 37th International Conference on Ocean, Offshore and Arctic Engineering OMAE2018 17-22 June 2018, Madrid, Spain

[13] Afiya Akram, Muhammad Awais Ashfaq Alvi, Mesfin Belayneh// The Impact of MWCNT on XG Polymer /Salt Treated Laboratory Water Based Drilling Fluid // International Journal of NanoScience and Nanotechnology. ISSN 0974-3081 Volume 9, Number 1 (2018), pp. 1-8

[14] Charles O. Nwaoji, Geir Hareland, Maen Husein, Runar Nygaard, and Mohammad Ferdous Zakaria, 2013//Wellbore Strengthening-Nano-Particle Drilling Fluid Experimental Design Using Hydraulic Fracture Apparatus// SPE 163434 SPE / IADC Drilling Conference and Exhibition, Mar 05 -07, 2013 2013, Amsterdam, The Netherlands

[15] Santra, A. K., et al. (2012). Influence of Nanomaterials in Oilwell Cement Hydration and Mechanical Properties. SPE International Oilfield Nanotechnology Conference and Exhibition, Society of Petroleum Engineers.

[16] Shah, S. P., Konsta-Gdoutos, M.S., and Metaxa, Z.S. (2009). //Advanced Cement Based Nanocomposites.// Recent Advances in Mechanics Selected Papers from the Symposium on Recent Advances in Mechanics. Academy of Athens, Athens, Greece.

[17] Rodney S. Ruoff, Dong Qian, Wing Kam Liu //Mechanical properties of carbon nanotubes: theoretical predictions and experimental measurements// C. R. Physique 4 (2003) 993–1008

[18] EPRUI Nanoparticles and Microspheres Co. Ltd.

[19] Ahmed S. Mohammed, C. Vipulanandan., P.E. and D. Richardson//Range of Rheological Properties for Bentonite Drilling Muds // CIGMAT-2013 Conference & Exhibition

[20] API RP 13-B1, Recommend Practice for Field Testing Water-Based Drilling Fluids, third edition. 2003. Washington, DC: API.
[21] Herschel, W.H. and Bulkley, R., Konsistenzmessungen von gummi-benzöllösungen. Kolloid-Z, 39, 291, 1926
[22] Kok, V.M. and Alikaya, T., (2005) "Effect of Polymers on the Rheological Properties of KCl/Polymer Type Drilling Fluids" Energy Sources, 27: 405–415
[23] Tevet, O., Von-Huth, P., Popovitz-Biro, R., Rosentsveig, R., Wagner, H. D., and Tenne, R. “Friction mechanism of individual multilayered Nanoparticles”. PNAS, vol. 108. no. 50. pp.19901–19906, 2011.