International Journal of NanoScience and Nanotechnology.
ISSN 0974-3081 Volume 8, Number 1 (2017), pp. 49-58

http://www.irphouse.com

# The Effect Of $MoS_2$ Nanoparticle On The Properties & Performance Of XG Polymer /Salt Treated Bentonite Drilling Fluid

**Shirin Forthun**
University of Stavanger
Stavanger, Norway

**Mesfin Belayneh**
University of Stavanger
Stavanger, Norway

## ABSTRACT

In literature, several nano-material application research results have shown positive impacts on the performance of cement, drilling fluid and Enhanced Oil Recovery.

This paper evaluates the effect of Molybdenum disulfide ($MoS_2$) nanoparticle in Xanthan gum (XG) polymer treated bentonite drilling fluid.

The results show that the addition of 0.15 wt. % $MoS_2$ reduced the friction coefficient of the conventional nano-free drilling fluid by an average of -45 %. The torque and drag simulation results show that the reduction of coefficient of frictions increases drilling depth by +26 %.

## 1 INTRODUCTION

In rotary drilling operations, drilling fluid is used, among others, to maintain well pressure, to transport cutting and cool well & drill bit and formation of filter cake around the borehole. Properly formulated drilling fluid reduces fluid loss by forming good mud cake and increase well strength. The quality of the filter cake depends on its porosity, permeability and mechanical properties. A typical conventional drilling fluid contain viscosity, density and fluid-loss control additives. However, the conventional water based drilling fluid does not completely solve drilling related problems such as shale swelling and formation damage.

Nanotechnology (particles in the size range of 1nm -100 nm) has proven to be useful in biomedicine and electronics engineering. This technology is believed to have a potential of solving technical challenges of the conventional technology in the Oil and Gas industry. Through chemical and physical processes, nanomaterials have shown an ability to create materials with improved properties such as thermal, mechanical, electrical, and rheological properties. The surface area to volume ratio of the nano-system is significantly higher than the micro/macro sized particles systems, Amanullah et al, (2009) [1]. The positive effect of different types of nano particles on the properties of drilling fluids are documented in Riley et al, (2012)[2], Hareland, et al (2012) [3], Li et al, (2012) [4], Nwaoji, et al (2013) [5], Abdo et al (2013) [6], Fakoya et al. (2013) [7], Sadeghalvaad, et al. (2015) [8], Krishnan et al, 2016 [9]. Similarly, the effect of nano on the conventional cement slurry with regards to fluid loss reduction and improved cement properties are also documented (Ruhal et al, 2012 [10], Ershadi, et al (2011) [11] , Vipulanandan, et al (2015) [12]).

The performance of nano-systems in water based drilling fluid has shown good potential in shale formations stability. The main mechanism is that the nano-system reduces the shale permeability through physical plugging the nanometer sized pores Katherine et al (2012) [13]. The authors also indicated that right sized nanoparticles in combination with the correct fluid loss system can minimize the fluid-rock interaction

This paper presents the impact of Molybdenum disulfide ($MoS_2$) nanoparticle in a conventional water based drilling fluid. The evaluation of the formulated drilling fluids have been by using experimental and performance simulation studies.

# 2 EXPERIMENTAL INVESTIGATION

Conventional nano-free water based drilling fluid was formulated as a reference system. The impact of nano-particle additives on the reference system has been studied by adding a 0.01-0.15 wt % spectrum of nano particle. This section presents the description of drilling fluid additives, drilling fluid formulation, measurement and characterization.

## 2.1 Material description

### *2.1.1 Molybdenum disulfide ($MoS_2$) nanoparticle*

Molybdenum disulfide ($MoS_2$) is an inorganic compound. It is composed of molybdenum and sulfur elements. It is used as solid lubricant, since it has low friction properties [14]. However, up to the knowledge of the authors, this particle has not been tested in drilling fluid. Therefore, in this paper, the performance of the particle is tested in polymer/salt based drilling fluid. **Figure 1** shows the SEM photograph of

$MoS_2$, which was purchased from EPRUI Nanoparticles and Microspheres Co. Ltd [15 ]

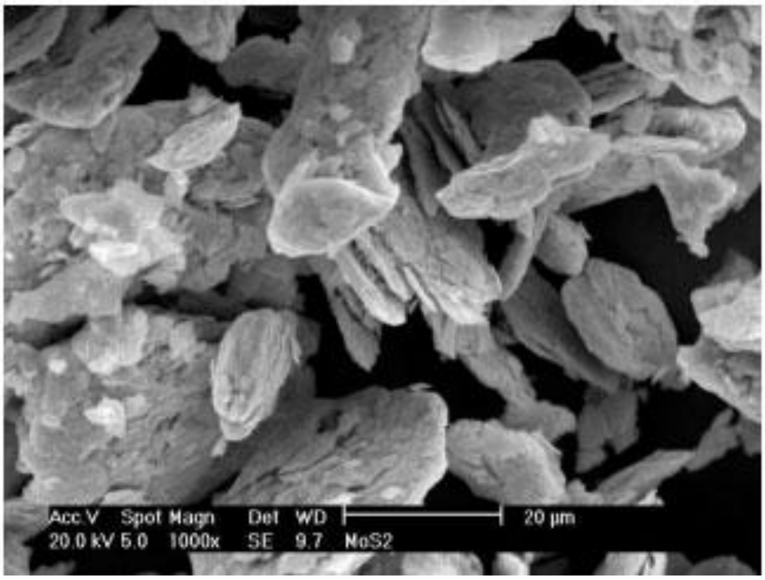


**Figure 1:** Morphology of $MoS_2$ particles – SEM photograph.

#### *2.1.3 Bentonite*

Bentonite is used as viscosifier additive in water-based mud. Bentonite is a clay mineral and has a crystalline nature. The atomic structures of clay crystals are the prime factor to determine their properties. Most clay has a mica-type structure, with flakes composed of tiny crystal platelets. A single platelet, called a unit layer, consists of an octahedral sheet and one or two silica tetrahedral sheets [16]. Oxygen atoms tie the sheets together by covalent bonds as shown in. The aggregation of clay platelet is related to rheology and filtrate loss properties of drilling fluid. The effect of nano, polymer and salt on the aggregation of clay will be studied later.

#### *2.1.4 Xanthan gum -XG*

Xanthan gum is a water soluble polymer. It is used to thicken water based drilling fluid due to its viscous properties. Xanthan gum composes of a five-ring structure: A three-ring side chain with a two-ring backbone. Coupled to the side chain are different functional groups such as carbonyl and hydroxyl. This unique branching structure gives Xanthan gum thixotropic properties. The polymer branches will connect by hydrogen bonding. Since the hydrogen bondings are weak, they will break when shear is applied to the system. Under low shear rate conditions, the hydrogen bonding will again connect, and viscosity goes back to initial state. [17]

#### *2.1.5 Salt-KCl*

Potassium based water based drilling fluids are the most widely used for water sensitive shale formation. Potassium chloride is more effective in reducing swelling than other salts such as sodium chloride (NaCl) at the same concentration [18]. The $K^+$ ions attach to clay surfaces and the size can fit the plates of clay.

### 2.2 Nano-$MoS_2$ & Graphene treated drilling fluid formulation and Characterization

Out of 200-field water based drilling fluid, Ahmed et al's [19] study showed that the amount of bentonite used in drilling mud varied up to 14% and the most of the fluids used 6% bentonite. The average was found out to be 5%.

In this paper, several screening test was performed to obtain a fluid system, which can easily flow. From the study, we have found that the 0.5gm CMC was suitable in the considered 5%wt bentonite system.

The conventional drilling fluids have been formulated by mixing 500g fresh water ($H_2O$), 2.5gm salt (KCl), 0.5gm polymer (Xanthan Gum (XG) and 25g bentonite. This was considered as reference –nano free fluid (**Ref**). Nano-based drilling fluids have been prepared by mixing nano-particles in the reference fluid formulation. The drilling fluids were mixed with a Hamilton beach mixer, and were aged for 48 hours in order for the bentonite to swell. All the tests were carried-out according to API RP 13B-1 [20] standard. **Table 1** shows the test matrix of $MoS_2$ treated drilling fluids. The formulation of the fluids:

- Reference fluid (1) = 500gm $H_2O$ + 2gm KCl + 0.5g Xanthan gum (XG) + 25gm Bentonite
- Nano-treated fluids (2-5) = Reference fluid (1) + (0.1 - 1.25)gm $MoS_2$

| Ingredient | Fluid 1 Ref | Fluid 2 Ref + 0.05gm MoS2 | Fluid 3 Ref + 0.10gm MoS2 | Fluid 4 Ref + 0.15gm MoS2 | Fluid 5 Ref + 0.20gm MoS2 |
|---|---|---|---|---|---|
| $H_2O$[g]m | 500 | 500 | 500 | 500 | 500 |
| Nano – MoS2[gm] | 0 | 0,1 | 0,2 | 0,3 | 0,4 |
| XG[gm] | 0,5 | 0,5 | 0,5 | 0,5 | 0,5 |
| KCl[gm] | 2,5 | 2,5 | 2,5 | 2,5 | 2,5 |
| Bentonite[gm] | 25 | 25 | 25 | 25 | 25 |

**Table 1**: Test matrix of nano- $MoS_2$+ XG polymers

### 2.2.1 Rheology and filtrate loss evaluation

**Figure 2** displays the Fann© model 35 Viscometer responses of the formulated mud systems provided in Table 1. As can be shown, the performance of nano Molybdenum disulfide ($MoS_2$) additives do not show any significant effect. For all nano-$MoS_2$ additive systems, the measured rheology values are higher than the nano-free system.

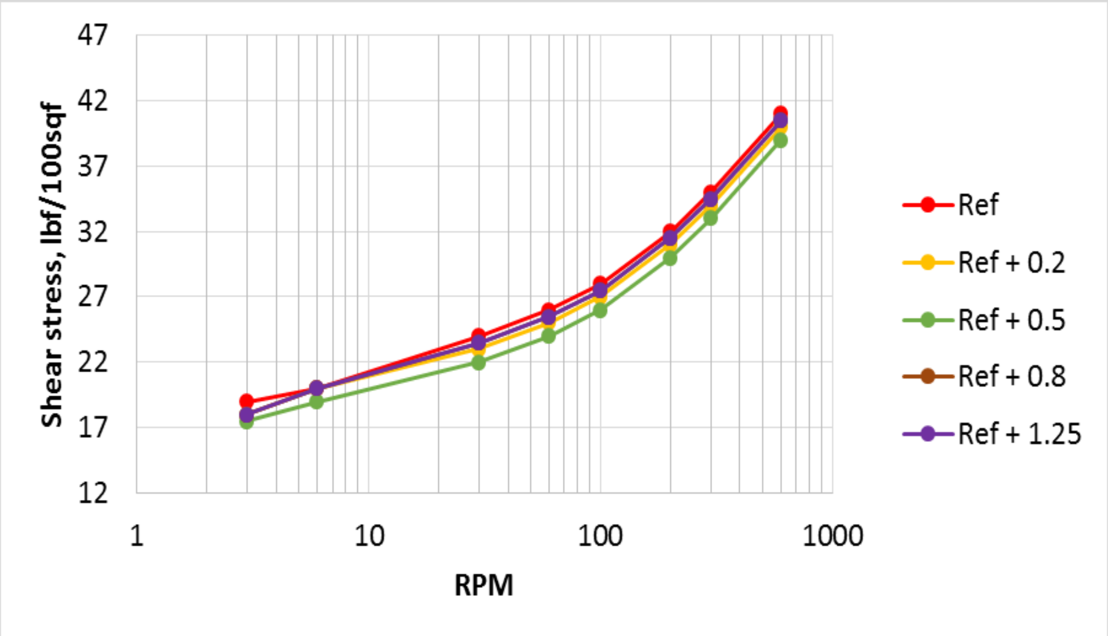


**Figure 2**: Viscometer measurement of test matrix –Table 1- $MoS_2$ system

The effect of Molybdenum disulfide on the rheology of drilling fluids has been evaluated through the the computed Bingham parameters (Yield strength, (YS) and Plastic viscosity (PV)) and the lower shear yield stress (LSYS). In addition, the Power law parameters (i.e. consistency index (k) and flow index (n)) are also calculated.

As shown in **Table 2** and the viscometer responses **(Figure 2),** the Molybdenum disulfide additives do not significantly influence the rheology parameters. This indirectly might have indicated that the additive is less chemically reactive with the other additives. However**,** the addition of 0.2gm $MoS_2$ reduces the filtrate loss by -10.7%. There are two possible explanations for this. As the concentration increase, the system might have been more dispersed/deflocculated and hence allows more filtrate loss**.** The second reason could be as the concentration increases, the additive might have created microbubbles and hence more filtrate losses. The second reason sounds more reasonable since the additives did not show impacts on the rheology parameters**.** As future work, the chemistry of the fluid systems will be studied to describe best the fluid systems.

| Drilling fluids | Drilling fluid parametere | | | | | Filtrate 7.5min % Change |
|---|---|---|---|---|---|---|
| | YS (lbf/100sqft) | PV (cP) | LYSY (lbf/100sqft) | k (lbf.s$^n$/100sqft) | n [-] | |
| Reference | 7 | 5 | 3 | 0.5 | 0.5 | - |
| Ref. +0.05gm Graphene | 13 | 6 | 2.5 | 1.6 | 0.4 | +7.7 |
| Ref +0.1gm Graphene | 17 | 5 | 4,5 | 3,5 | 0,3 | +19.2 |
| Ref +0.2gm Graphene | 7 | 5 | 3 | 0.5 | 0.5 | +3.8 |
| Ref +0.4gm Graphene | 7.5 | 4.5 | 2.5 | 0.7 | 0.46 | +15.4 |

**Table 2**: Rhelogy and fltrate loss parameters of Molybdenum disulfide treated drilling fluids

### 2.2.2 Coefficient of friction evaluation

CSM tribometer [21] was used to measure the lubricity of the drilling fluids. The measurement was on ball and plate surface contact in the presence of drilling fluid. The steel ball is an alloy of 6-chromium and 6mm diameter. The experiments have been lasted for 8.35min and with the linear speed of 4cm/s, which corresponds a linear distance of 20m. For all tests, a constant normal force of 10N was applied on the tribometer arm. The lubricity of the formulated drilling fluids have been measured at 20, 50 and 70 deg centigrades. Repeat tests have been performed with the objective of obtaining a representative average value. **Figure 3 & Figure** 4 are the test results.

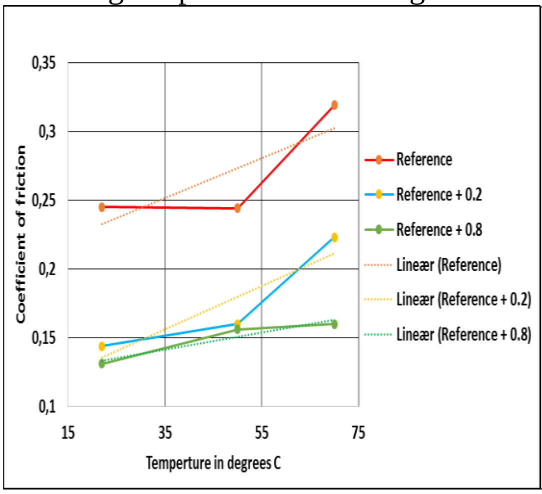


**Figure 3:** Friction coefficient of Molybdenum disulfide treated- and nano free drillig fluid

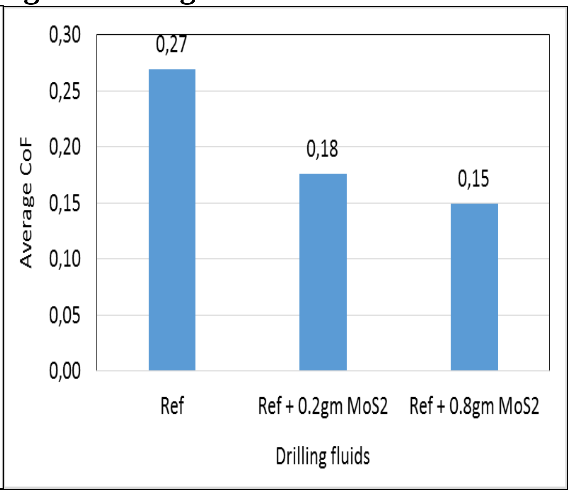


**Figure 4**: Mean coefficient of friction of Molybdenum disulfide based drilling measured at 20$^o$, 50$^o$ and 70$^o$C

**Figure 3** shows the average coefficient of frictions obtained from the nano Molybdenum disulfide treaed drilling fluid comparing with the nano free system. All the drilling fluids have been measured, but the 0.2gm and 0.8gm nano were found out to be the best in terms of higher lubricity. Like the rheology properties, the lubricity is a non-linear function of nano- Molybdenum disulfide concentration. For comparison purpose, the average coefficent of frictions obtained from the three temperature were computed and plotted in F**igure 4.** The results show that the 0.2gm and the 0.8gm $MoS_2$ reduced the coefficent of friction by about -35% and -45%, respectively. These values will be used later for torque and drag simulations.

## 3 NANO-FLUIDS DRILLING PERFORMANCE SIMULATION

The performance of the drilling fluids were evaluated through drill-string mechanics simulation studies.

Using Landmark/Wellplan$^{TM}$ software [22], drill string mechanics simulation has been performed to evaluate how far we can drill with the the formulated nano fluids. The safe operational window is determined when the torque and drag forces, and Von-mises stress in the drill string are found out to be safe within the maximum drilling depth. The simulation well is a deviated well drilled in Bangladesh. Among the three simulation results the torque was found out to be reaching to the torque makeup limit and hence will only be presented. The simulation operational parameters were 60 ft/min tripping in / out speeds and drill string rotation 40 RPM. The 5" OD size of E-75 grade drill string was used for the simulation. The drilling fluids have been pumped in the simulation well at the rate of 500gpm. The coefficient of friction between the drill string and the casing, drill string and the open hole were assumed to be constant.

**Figure 5 & Figure 6** show the simulation results obtaind from the $MoS_2$ nano treated drilling fluid. For the simulation, the 0.2gm and 0.8gm $MoS_2$ systems average coefficient of friction values displayed on Figure 4 were used.

As shown on **Figure 5**, since the tripping out torque reaches the maximum alllowable makeup torque, one can not drill with the nano free drilling fluid system for more than 9923ft of measured depth.

The nano treated drilling fluid values are far from the make up toque, which suggest one can increase the measured drilling depth. The measured drilling depth is increased as long as the torque, stresses and drag plots are within an allowable operational window. Out of theses, as shown on **Figure 6,** the torque load reaches the makeup torque as the measured depth increased to 16523ft when drilling with the 0.8gm $MoS_2$ drilling fluid. Similary, the 0.2gm $MoS_2$ allows to drill up to 15231ft of drillling depth. As shown, the addtion of 0.2gm $MoS_2$ increases the drilling depth by +15.2% and the 0.8gm MoS2 increase the depth by 25.9%. The results presented here illlstrate the huge potential of nano technology in improving drilling performance.

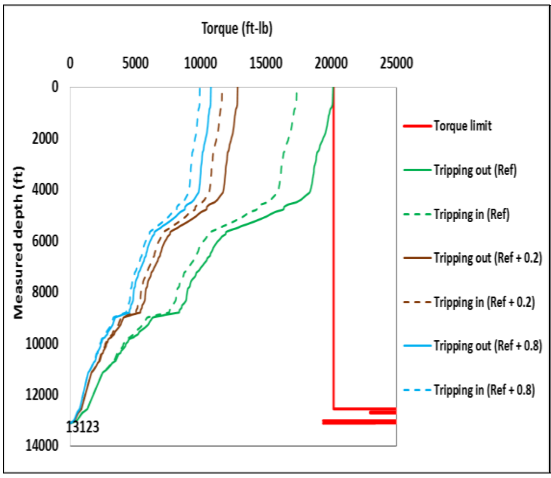


**Figure 5**: Maximum length drilling with the **reference fluid** without exceeding the torque limit

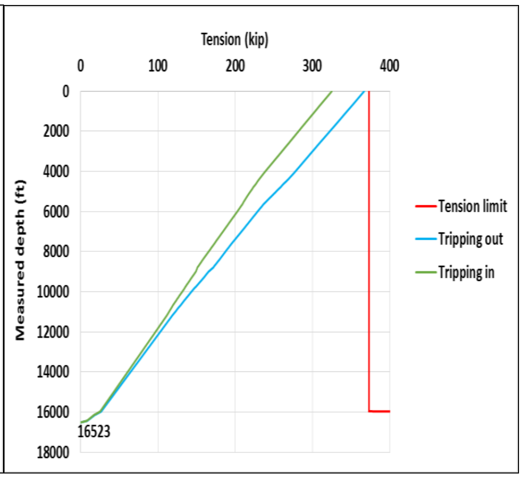


**Figure 6**: Maximum length drilling with the 0.8gm **$MoS_2$ treated** fluid without exceeding the torque limit

## 4 SUMMARY

In this paper, the effect of nano-$MoS_2$ in 25gm bentonite /500 gm $H_2O$ treated with Xanthan gum (XG) polymers and salts have been evaluated. The rheology at room temperature and the lubricity at $20^0$, $50^0$ and $70^0$ C have been measured. Based on the mean coefficient of friction and drilling fluids parameters obtained from the considered fluids, the main observations can be summarized as:

- The addition of 0.15% wt. $MoS_2$ reduces the average coefficient of friction by -45 %. The simulation results show that the nano additive allows to drill about +26 % more, but didn't show any impact on filtrate loss.
- The addition of 0.038 % wt. $MoS_2$ reduces the average coefficient of friction by -35 % and this increases the drilling depth by about +15 % more and reduces filtrate loss by -10.7%. In addition, the nano additive increases the viscolasticity parameters.
- Molybdenum disulfide additives do not significantly influence the rheology parameters.

One clear observation is that the performance of nano- is a non-linear effect as the concentration increases.

Although nano based drilling fluids can be more expensive than conventional one, nano- based drilling fluids may have the potential to reduce drilling related problems and improve performances.

## References


[1] Md. Amanullah, and Ashraf M. Al-Tahini: (2009)// **Nano-Technology-Its Significance in Smart Fluid Development for Oil and Gas Field Application**// SPE 126102 Alkhobar, Saudi Arabia, 09-11 May 2009

[2] Riley, M., Young, S., Stamatakis, E., Guo, Q., Ji, L., De Stefano, G., Hoelscher, K. P., De Stefano, G., Ji, L., and Friedheim, J. "**Wellbore Stability in Unconventional Shale – The Design of a Nano-Particle Fluid**". SPE 153729, Mumbai, India 28-30 March 2012.

[3] Mohammad F. Zakaria, Maen Husein, Geir Hareland, 2012// **Novel Nanoparticle-Based Drilling Fluid with Improved Characteristics**// SPE 156992-MS, 12-14 June 2012, Noordwijk, The Netherlands

[4] Gongrang Li, Jinghui Zhang, Huaizhen Zhao, Yegui Hou. Shengli Drilling Technology Institute, Sinopec, 2012// **Nanotechnology to Improve Sealing Ability of Drilling Fluids for Shale with Micro-cracks During Drilling**// SPE 156997-MS 12-14 June 2012, Noordwijk, The Netherlands

[5] 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 Mar 05 - 07, 2013 2013, Amsterdam, The Netherlands

[6] J. Abdo , M.D. Haneef **//Clay nanoparticles modified drilling fluids for drilling of deep hydrocarbon wells//** Applied Clay Science Volume 86, December 2013, Pages 76–82

[7] Muili Feyisitan Fakoya , Subhash Nandlal Shah, //**Rheological Properties of Surfactant-Based and Polymeric Nano-Fluids**// SPE-163921-MS SPE/ICoTA Coiled Tubing & Well Intervention Conference & Exhibition, 26-27 March 2013, The Woodlands, Texas, USA

[8] Mehran Sadeghalvaad, Samad Sabbaghi//**The effect of the $TiO_2$/polyacrylamide nanocomposite on water-based drilling fluid properties**// Powder Technology Volume 272, March 2015, Pages 113–119

[9] Shutesh Krishnan, Zahra Abyat, Calvin Chok //**Characterization of Boron-Based Nanomaterial Enhanced Additive in Water-Based Drilling Fluids: A study on Lubricity, Drag, ROP and Fluid Loss Improvement**// SPE-178240-MS SPE/IADC Middle East Drilling Technology Conference and Exhibition, 26-28 January 2016, Abu Dhabi, UAE

[10] Rahul C. Patil, Abhimanyu Deshpande 2012 //**Use of Nanomaterials in Cementing Applications**// SPE-155607, 12-14 June, Noordwijk, The Netherlands 2012

[11] Ershadi, V. et al (2011) **The Effect of Nano silica on Cement Matrix Permeability in Oil Well to Decrease the Pollution of Receptive Environment**. International Journal of Environmental Science and Development, Vol. 2, No. 2, April 2011.

[12] C. Vipulanandan , R. Krishnamoorti, A. Mohammed, V. Boncan, G. Narvaez, B. Head , J. M. Pappas (2015)// **Nano Graphene Application Improving Drilling Fluids Performance**// IPTC-18539-MS Offshore Technology Conference, 04-07 May, Houston, Texas, USA

[13] Katherine Price Hoelscher, Guido De Stefano, Meghan Riley, Steve Young, M-I SWACO 2012//**Application of Nanotechnology in Drilling Fluids**// SPE 157031, 12-14 June 2012, Noordwijk, The Netherlands

[14] W. 0. WINER //**Molybdenum Disulfide As A Lubricant: A Review Of The Fundamental Knowledge** // Wear, 10 (1967) 422-452

[15] EPRUI Nanoparticles and Microspheres Co. Ltd. http://www.nanoparticles-microspheres.com

[16] Olaf Skjeggestad//**Boreslamteknologi : teori og praksis**// ISBN8241900104, 1989 Bergen

[17] MISwaco Manual "Drilling Fluids Engineering Manual, Polymer chemistry and Applications". Chapter 6, 1998.

[18] Caenn, R. et al. (2011) Compostion and properties of drilling and completion fluids. USA: Elsevier Inc.

[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, R**ecommend Practice for Field Testing Water-Based Drilling Fluids**, third edition. 2003. Washington, DC: API.

[21] CSM Instruments http://www.csm-instruments.com

[22] http://www.halliburton.com/