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HIGH TEMPERATURE AND HIGH PRESSURE NANOCLAY MODIFIED DRILLING FLUIDS

M. Danish Haneef, Jamil Abdo, Abdullah Al-Shabibi(*)

Mechanical and Industrial Engineering Department, Sultan Qaboos University, Muscat, Sultanate of Oman
(*)ashabibi@squ.edu.om

ABSTRACT

Projections of continued growth in hydrocarbon demand are driving the oil and gas industry to explore new or under-explored areas that are often challenging. High drilling temperature and pressure conditions (HTHP) poses a great challenge for current drilling fluids. The rheological properties of drilling fluids can be favorably modified with the impregnation of nanomaterial.Keeping in view the decisiveness of drilling fluids impact on drilling efficiency, this work presents an approach to stabilize the drilling fluid rheology in high temperature and pressure conditions by making use of modified nano-clays. An abundantly available clay in Oman, attapulgite was tested in purified nano-form (20-30 nm diameter) for its effectiveness to tailor the rheology of drilling fluids swiftly, that are able to retain their properties over a wide range of operating temperatures and pressure (HTHP conditions), thus ensuring efficient operation in versatile formations and operating conditions. To study the impact of reducing size to nano-level for stability at HTHP and improving the performance of drilling fluids is the main target.Sufficient experiments were performed to compare the rheology of drilling fluids containing Bentonite only, which is a common drilling fluid additive, with drilling fluids containing bentonite in presence of small quantities of attapulgite nanoparticles. After successive laboratory investigations an absolute proportion of water, bentonite and attapulgite nanoparticles was found out that gives consistent results at various temperatures and pressure i.e. stable drilling fluid rheologyat HTHP environment. The best recorded results are reported in this paper and the properties focused here are the plastic viscosity, yield point, gel strength, density, shear thining, spurt lost, fluid lost, and Lubricity index.

Keywords: Drilling Fluids, Nanoparticles, Rheology, High temperature and Pressure

INTRODUCTION

Over the next three decades, global energy demand is projected to rise almost 60%, a challenging trend that may be met only by revolutionary breakthroughs in energy science and technology (Saeed M. et. al., 2006). The demand is widespread geographically and impacts all energy sources. Projections of contined growth in hydrocarbon demand are driving the oil and gas industry to explore new or under-explored areas. The industry needs stunning discoveries in underlying core science and engineering as the search for petroleum become more extreme in terms of depth, hence presure and temperature.

The benefits of improving tools, materials, skills, use of down-hole rotation tools and any other innovation for improving drilling operations is almost ineffectual if they are not used in presence of an accurate drilling fluid. The drilling fluid circulation has to be maintained throughout the drilling process during which it has to perform certain crucial tasks like: hole cleaning, provide effective lubrication between the bore-hole and drill string, cooling of the bit and maintaining appropriate drilling pressure hence weight on bit, and these functions has to be performed consistently throughout the operation regardless of the type of formation and operating conditions. These functions are purely dependent on the rheological properties of the drilling fluids mainly the viscosity, density and gel strength and lack in performance in any of these functions leads to severe drilling problems like: lost circulation, high torque and drag, instability with changing conditions and stuck pipe events (Yarim et. al., 2007, Adriana et. al., 2009, George et. al., 1951, Ryan &Douglas, 2008, Mendes et. al., 2003). The control and prevention of lost circulation of drilling mud is a problem frequently encountered during drilling of oil and gas wells (George et. al., 1951). Often, loss is induced due to the use of improper mud weight (density) in formation with narrow mud weight windows. That's why in deep wells induced loss of circulation is very common due to little difference between the upper bound and lower bound mud weights limits. In addition the lack in tendency to form a thin mud cake further adds to the problem of lost circulation and this is due to the in appropriate viscosity of the drilling fluid. In extended reach drilling there is a dramatic increase in torque and drag problems while drilling. The major component of these torque and drag problems is the friction between the drill string & the bore wall. Drilling fluid play an important role in reducing the torque & drag problem. Torque and drag are caused by numerous factors including cuttings bed, filter cake, hole stability, doglegs, key seats, bit balling & most important the drilling fluid coefficient of friction. Drilling fluid lubricants are used to treat these problems because they supposedly lower the coefficient of friction, improve filter cake, stabilize the well bore, & eliminate bit balling (Quigley, 1989). Stuck pipe incidents have been one of the major technical challenges of the drilling industry & events typically result in a significant amount of downtime & remedial costs. The recent increase in drilling activity, shortage of experienced personnel & equipment, & drilling in higher risk areas, has increased the risk of stuck pipe events in all drilling operations (Yarim et. al., 2007).

These problems when stumble upon leads to huge financial losses in the form of calling the need for expensive additives, huge non-productive time in resolving the problem and in worst cases may cause to abandonment of the well. The problems becomes more severe when drilling deep due to the considerable increase in temperature and pressure, that results in deterioration of fluid properties, limit tool and dowhole equipment selection, downhole pressure determination, lost circulation, low penetration rates, acid gases, and compliance with saefty and environmental regulations.

Keeping in view the intricacy in the problem of opting a right drilling fluid formulation, there is a strong need to have a healthier knowledge and a timely control on the rheological properties of the drilling fluid so that the properties may be changed to suit any particular type of drilling environment, and this requires a novel solution that is so accurate and punctual in performing its function that it should influence the rheology when added in very small concentration and promptly.

One major emerging application of nanotechnology in oil reservoir engineering are in the sector of developing new types of smart fluids for improved/enhanced oil recovery, and drilling (Igor et. al., 2006). Due to totally different & highly enhanced physio-mechanical, chemical, electrical, thermal, hydrodynamic properties & interaction potential of nano materials compared to their parent materials the nanos are considered the most promising material of choice for smart fluid design for O&G field application (Amanullah & Ashraf, 2009).One of the pioneering work of Paiaman & Duraya (Paiaman & Duraya, 2009) presents useful results by using carbon black nano-particles and reported superior drilling fluid properties. The significance of the use of nanoparticles of clay materials in drilling fluids has also reported first time by Abdo and Danish (Abdo et. al., 2010, Abdo & Danish, 2010, Abdo & Danish, 2012).

The work presents a novel solution to have surprising set of rheological properties by use of combination of regular drilling fluid bentonite and nanoparticles synthesized from a locally abundant material in Oman called atapulgite. A schematic procedure for purification and breaking down particles to nano size for uniform dispersion is tested. The significance of reducing the particle size distribution of attapulgite has been highlighted and its impact on rheology is presented when used in nano size particle distribution. It displayed remarkable gel strength characteristics even though whilst maintaining a low viscosity. The shear thinning behavior was also investigated and showed enviable results. The paper is mainly focused on application of attapulgite nanoparticles in drilling fluids, and stabilizing the recipes at high temperature and pressure, i.e HTHP environment.

EXPECTED PERFORMANCE OF NANO-ENHANCED DRILLING FLUIDS

The onset of nanotechnology has revolutionized the science and engineering faction, and due to its huge domain of applicability, like every other industry, the drilling industry can also pull out terrific benefits from nanotechnology out of which one of the most promising prospects is the use of nanoparticles in drilling mud in order to have a definite operational performance, stability and suitability to adopt well with a wide range of operating conditions with minor changes in composition and sizes (Igor et. al., 2006). The use of nanoparticles in drilling fluids will enable the drilling technologists to swiftly modify the drilling fluid rheology by changing the composition, type or size distribution of nanoparticles to suit any particular situation, discourage use of other expensive additives, and improved functionality. The use of nanoparticles synthesized from different materials has been used to achieve certain targets and are reported in the literature (Paiaman & Duraya, 2009, Jimenez, 2003, Cai et. al., 2012). Hence by controlling the rheology by using nanoparticles, severe drilling problems can be avoided and also enables to conveniently modify the properties to suit particular drilling conditions i.e. type of formation, temperature, formation pressure, required operating pressure etc.

ATTAPULGITE NANOPARTICLES SYNTHESIS

Locally available attapulgite was collected which is mainly available in form of solid big chunks in mountains and then the attapulgite chunks were crushed in the crusher to obtain coarse particles so that it can be taken for fine milling. Fritsch attrition milling machine was used to mill the coarse grains to obtain fine powder for several hours. After milling for several hours the fine powder was sieved to obtain particles of mesh size ≤ 20 μm. The fine powder of mesh size ≤ 20 μm was carried for further processing. The fine powder is washed thoroughly by distilled water and ethanol after centrifuging to remove all insoluble impurities. High power sonicator was used to impart high frequency ultrasonic vibrations to suspensions of attapulgite fine powder in ethanol. This causes the separation of needle like chains and clusters and further breaking down of the material to smaller size without damaging the morphology. The ethanol environment serves as a chemical shield to protect against flocculation during the sonication process. This occurs due to the formation of a charged layer over the surface of the particles thus repelling each other hence facilitating the dispersion process. The process was carried out at different frequencies of vibration and different number of hours to find the optimum size range and dispersion. They remain suspended without flocculation and settling to the bottom, due to the fact that at nano-level the surface forces become more dominant than the gravity forces. Figure 1 Shows the uniformly dispersed attapulgite nanoparticles with diameters as small as 20 nm.

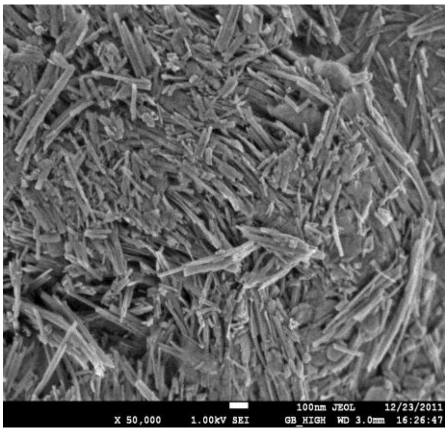

Figure 1: Uniformly dispersed attapulgite nanoparticles

USE OF ATTAPULGITE IN DRILLING FLUIDS

Bentonite based drilling fluids have the limitation of flocculation and limited functionality at high pressure and pressure conditions. Because of high water absorption capability and swelling characteristics the dispersion behavior of bentonite is non uniform and have huge problem of flocculation which results in insufficient and inconsistent rheology of drilling fluids.

On the other hand, attapulgite has very good colloidal properties such as: specific features in dispersion, high temperature endurance, salt and alkali resistance, and also high adsorbing and de-coloring capabilities. The special nanorods structure and large specific surface area can endow attapulgite with many unique physical and chemical properties; therefore, attapulgiteattracted the interest to be used as efficient and stable rheology modifier for drilling fluids.

RESULTS AND DISCUSSION

In order to investigate the effect of drilling fluids enhanced by inclusion of nanoparticles, and to have a better insight into how the rheological properties can be tailored to meet certain operational requirements, the following tasks are carried out and reported in the following sections:

Effect of size reduction of attapulgite:

Initial studies revealed that a material called attapulgite which is abundant in Oman, have good Fann viscosity for the use in drilling fluid and is a prospective material to use in nano form to improve rheological properties. XRD tests were carried out and the material was found to be consisting mainly of Montmorillonite [Nax (Al,Mg) 2Si4O10 (OH)], Quartz low (SiO2) and Clinochlore-IIb [Mg5Al (Si3Al) O10 (OH)8] (Abdo et. al., 2010, Abdo & Danish, 2010, Abdo & Danish, 2011). The material was used in different sizes (micro & nano) to illustrate the tailoring of rheological properties of drilling fluids without using other additives.

Samples of drilling fluids containing 40 gms of attapulgite in different sizes with 500 ml of water were prepared and viscosity measurements carried out by Fann 35 Viscometer. Table-1 shows the effect of different particle size distributions (PSD) of attapulgite on plactic viscosity (PV) and yield point (YP).

		P.V (cp)	YP lb/100 sq ft
Sample 1	Fine grinded	9	7.5
Sample 2	Size ≤63 μm	9	7.5
Sample 3	Size ≤20 μm	9.5	7.5
Sample 4	Size = 20-30 nm diameter	11	8

Table-1: PV and YP of samples containing different PSD of attapulgite

It can be observed from the results presented in table-1, that the reduction of PSD from sample 1 to sample 3 (Micro or greater) does not impart any significant improvement in the plastic viscosity and yield point of the drilling fluid samples and gives almost similar values at different RPMs. For sample 4 (nano-size) the viscosity began to deviate from the trend than what was observed in size reduction from sample 1 to sample 3. This shows that the functionality of nano sized particles now came into play and thus showed high viscosity. Even though improvement in viscosity is quite obvious but the constant yield point has to be justified by measuring gel strength for scrutinizing the carrying capacity of the fluid. Table-2 presents the 10 sec and 10 min gel strengths and densities measured at 3 rpm for above four samples.

		10 sec	10 min	% Increase	Density (gm/cm^3)
1	Fine grinded	0.2	0.3	50	1.015
2	Size ≤63 μm	0.6	0.8	33.4	1.020
3	Size ≤20 μm	0.5	0.65	30	1.030
4	Size = 20 -30nm diameter	1.5	4.5	200	1.055

Table-2: 10 sec and 10 min gel strengths and densities of samples 1 to 4

Thus from the gel strength measurements the effectiveness of nano-sized attapulgite clay in terms of its carrying capacity is very well justified. It displayed an improvement of about 200% in terms of its gelling characteristics thus confirming its superior performance in holding on the drill cuttings when in static condition. It is convenient to conclude that the problem of poor hole cleaning can be tackled well by this recipe. The high gelling characteristics of the fluids may demand a high starting torque which needs to be justified by investigating the shear thinning behavior of the fluid. In addition to the properties discussed above it is also crucial to keep an eye on the density of the drilling fluid because if formation pressure increases, mud density should also be increased, often with barite (or other weighting materials) to balance pressure and keep the wellbore stable. Thus it is vital to maintain a density suitable enough to fulfill the above mentioned requirements while varying the viscosity, yield point and gel strength. Keeping in view this fact, density tests carried out on the same samples by using mud density balance revealed noteworthy results in the form of displaying significant changes with changing size. It is thus evident that any of the rheological parameters can be tailored by changing the size to suit any type of drilling environment. Density test results are also presented in table-2.It is evident from the results in table-2, that reducing the particle size has a considerable effect on the mud density.

Effect of Composition of Attapulgite:

The crystal structure of bentonite is 3-layer sheet and forms particles in form of flakes thus having a medium ranged surface area. Flocculation is one of the major drawbacks of bentonite. Whereas, attapulgite which has a chain like crystal structure forms particles in form of needles thus have a high surface area and hence increased reactivity. Attapulgite forms gel structures in fresh and salt water by establishing a lattice structure of particles connected through hydrogen bonds.

After successive testing it is found that the use of attapulgite alone with reduced PSD imparts superior rheological properties to the samples, but lacks in maintaining high yield point values. Thus based on the fact that bentonite have capability of forming thick drilling fluids (high yield points) it is recommended to use small composition of attapulgite nanoparticles in precence of bentonite. Table 3 and Figures 2-4, demonstrates the variation in rheological properties with increasing quantity of attapulgite.

Bentonite (gms)	**Attapulgite (gms)**	**Gel Strength (10 min)**	**Viscosity (cp)**	**Y.P**
40	0	40	18	45
40	2	35	17	32
40	4	29	15.5	18
40	6	21.5	14	11
40	8	16	12	7

Table 3: Change in rheological properties with increasing attapulgite nanoparticles

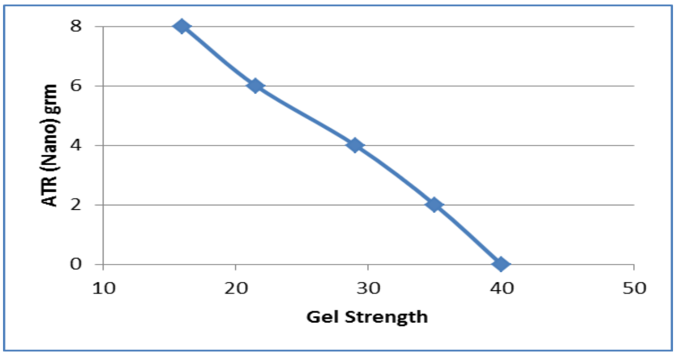

Figure 2: Decrease in Gel strengthwith increasing quantity of attapulgite nanoparticles

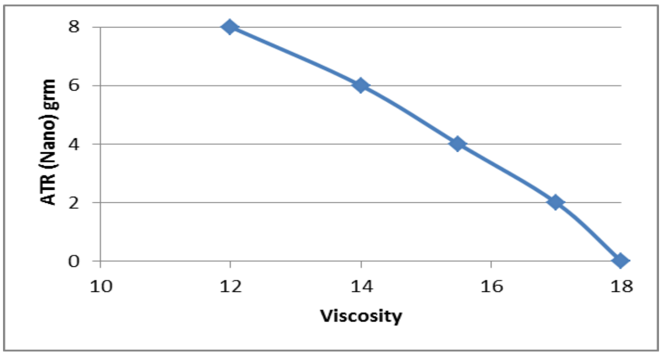

Figure 3: Decrease in viscositywith increasing quantity of attapulgite nanoparticles

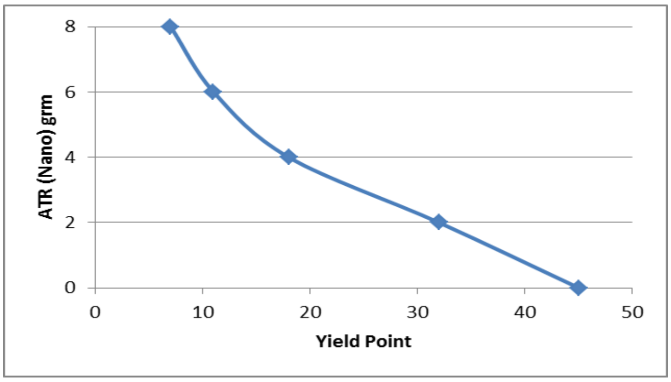

Figure 4: Decrease in YP with increasing quantity of attapulgite nanoparticles

Drilling Fluid Stable Recipes:

As discussed earlier that the dimishing of conventional oil and gas reserves have urged the industry to go beyond conventional ways to extract oil from more challenging deep lying reservoirs. The major issue to confront in doing so is the deterioration of drilling fluid performance due to high temperature and pressure (HTHP) environment faced during extended reach drilling operations. For a mud to work well in high temperature bottom-hole conditions it must be rheologically stable over the entire range of temperatures and pressures to which it will be exposed. The rheological stability of a mud is monitored by measuring its yield point and gel strengths, in accordance with standard drilling fluid tests, before and after circulation down the well bore (Elward & Julianne, 1993). It is thus vital to assess the drilling fluid stability at changing conditions to ensure its performance throughout the drilling operation. Based on this concern, after confirming the effectiveness of composition and size of nanoparticles (as explained in sections 5.1 and 5.2), various recipes were formulated to check for the stability of the samples. Different sizes and compositions of attapulgite nanoparticles were tested with and without bentonite, while changing the water proportion concurrently. Each experiment was repeated to check for accuracy of results. After testing several recipes, it was found that a certain proportion of water in presence of bentonite and a certain quantity of attapulgite nanoparticles yeilds perfect stability at temperatures of as high as 150 ºC. Out of the various proportions tested, most of the samples failed to sustain the temperatures of 100 ºC. Only a certain recipe succesfully sustain temperature of 150 ºC. This paper discusses the recipe that was able to sustain the highest degree of temperature.

Shear Thining Behavior

Another important task is to confirm the shear thinning behavior of the sample. As explained earlier the shear thinning behavior of the drilling fluid contribute towards efficient cuttings transports. The shear thinning behavior of drilling fluids containing attapulgite nanoparticles was investigated in (Abdo & Haneef, 2012). The results confirmed the use of bentonite and ATR nano together have a remarkable versatility and control over the rheological due to combination of the advantages of both materials together. The shear thining behavior for the stable receipe (a recipe containing 5.9 gms of attapulgite in presence of 40 gms bentonite and 570 ml water) are presented in Figures table 4. The resuls confirm the drilling fluid functionality for eliminating the problem of mechanical and differential pipe sticking.

Rotational speed	600	300	200	100	6	3
Shear Rate	**1028**	**514.04**	**343.76**	**168.14**	**9.52**	**4.64**
Shear Stress: 5.9 gm ATR nano 40 gm Bntonite 570 ml Water	13.26	10.2	10.71	7.905	5.355	3.825

Table 4: Shear stress (Pa) at different shear rates for stable receipe

Spurt Loss and Fluid Loss

Spurt loss and fluid loss are major factors that play an important role in causing formation damage. The fluid losses without Nanoparticles and with attapulgite Nanoparticles (a recipe containing 5.9 gms of attapulgite in presence of 40 gms bentonite and 570 ml water) are studied using API Filter press. The prepared samples are poured to a filter press cup. 100 psi of pressure is applied and fluid loss is measured after 1 min, 4 min, 7 min, 10 min, 15, and 30 min. The spurt losses were calculated with extrapolating to zero time. The results in table 5 show that the fluid loss is significontly reduced with the use of attapulgite nanoparticles.

Samples	**Stable Recipe With nanoparticles**	**Without nanoparticles**
Time	**Fluid Loss (ml)**	
Spurt	0.94	0.76
1 min	1.6	2.6
4 min	2.7	4.2
7 min	3.8	5.6
10 min	4.4	7.1
15 min	4.9	9.4
30 min	7.1	13.1

Table 5: Spur loss and Fluid loss over a period of 30 min for stable receipe

Lubricating quality of drilling fluids

The lubricating quality of the stable receipe is measured by OFI Lubricity Tester. Frictional resistance to rotation of the drill string is called torque and frictional resistance to hoisting and lowering the drill string is called drag. The coefficient of friction (CF) is defined as

$$CF = F/W \tag{1}$$

where F is frictional force and W is the force applied normal to the two surfaces. Lubricity measurements of drilling fluids generally report torque reduction, where torque reduction is defined as

$$\%\ \text{torque reduction} = (A-B)/A\times 100 \tag{2}$$

where A is CF for water and B is CF for the drilling fluid being tested. CF was measured for deionized water at 60 rpm and was found to be 34. The applied force on the surfaces was removed and a sample of drilling fluid without ATR Nano was placed between the two test surfaces. The force was then reapplied to the steel surfaces, the apparatus was re-immersed in deionized water and CF was recorded at 60 rpm. CF was measured at 22.5 initially but climbed throughout the duration of the test to 34. Using the value of 22.5, torque reduction was calculated as follows: % torque reduction=(34-22.5)/(34)×100=33.8%.

The test was repeated using stable receipe. CF was measured and found to be 10.8 initially but climbed throughout the duration of the test to 34. The torque reduction was calculated as follows: % torque reduction=(34-10.8)/(34)×100=68%. This represents a significant decrease in torque using the stable receipe.

Modified Drilling Fluid at High Temperature and Pressure (HTHP Environments):

Water-based fluids have traditionally been used for drilling HTHP wells. However, standard water-based drilling fluid additives start to degrade thermally at approximately 250°F (121°C). As HTHP drilling continues to move into harsher environments with bottom-hole temperatures and pressures more than 500°F and 20 kpsi, respectively, fluids with higher temperature and pressure stability are needed (Fan et. al., 2012).The nano modified drilling fluids were tested in HTHP environment and showed great rheology stability at high temperature and pressure.

To test the effeciency of the nanoclay modified drilling fluid one of the stable receipes(a recipe containing 5.9 gms of attapulgite in presence of 40 gms bentonite and 570 ml water) were tested in HTHP conditions. The results of constant rheological properties at varying temperature and pressureare shown in Table 6 and Fig. 5. It is important to indicatehere that a flexible water-based drilling fluids is possibleby varying the size and composition of bentonite and attapulgite Nano to suit a wide range of requirements (viscosity, yield point, gel strength, density,etc.).The stable receipe were tested using Grace Instrument M7500 Ultra HPHT Rheometer. The plastic viscocity and yield point at different temperature and pressure were recorded as shown in Table 6. As the instrument has no capability to measure the drilling fluid density of the samples during the elevation of the temperature and pressure, the density was measured before the sample was put in the instrumentand after the sample was removed from it. For the sample under consideration the values were 1.46 gm/cm^3 and 1.48 gm/cm^{3}before the sample was put in the instrument and after the sample was removed from it, respectively. These results indicate that there is no significant change in the density of the drilling fluid that could effect the performance.

HPHT Rheometer:

The Grace Instrument M7500 Ultra HPHT Rheometer is used to test the capability of the nano modified drilling fluid under the elevation of temperature and pressure to simulate the harsh environments encountered during deep drilling. The Grace Instrument M7500 Ultra HPHT Rheometer is utalized to measure the plastic viscosity and the yield point at HTHP enviroment. The instrument consist of three interconnected parts: rheometer, control unit that is connected to a data acquisition system and a display unit. The rheometer contains a coaxial rotational cylinder and has a capability for inducing high pressure and temperature. The instrument is engineered to measure various rheological properties of fluids under a range of pressures and temperatures, up to 30,000 psi and 600 °F.The 7500 HTHP instrument is shown in Fig. 6 and its design specifications are presented in table 7.

Test Conditions			**Dial Readings**						**Plastic Viscosity (cP)**	**Yield Point (lb/100 sq ft)**
Temperature (F^0)	**(C^0)**	**Pressure (psig)**	**600 rpm**	**300 rpm**	**200 rpm**	**100 rpm**	**6 rpm**	**3 rpm**		
100	37.8	100	36	23	13	8	2	1	13	10
131	55	1000	35	22	14	8	3	1	13	9
158	70	2000	36	23	13	9	2	2	13	10
185	85	4000	37	24	15	8	3	1	13	11
212	100	6000	37	24	14	9	3	1	13	11
239	115	8000	38	24	13	9	2	2	14	10
266	130	10000	37	23	14	8	2	2	14	9
293	145	12000	35	22	13	8	3	2	13	9
320	160	14000	35	22	12	8	2	2	13	9
347	175	15000	33	21	12	8	2	2	12	9
365	185	16000	32	20	11	7	2	2	11	9

Table 6: Constant rheological properties at varying temperature and pressure(attapulgite Nano)

Dimensions:	22" x 12" x 24" (cell tower) 12" x 25" x 15.5" (control unit)
Weight:	250 lbs
Construction:	Stainless Steel
Pressure Range:	Atm to 20,000 or 30,000 psi
Temperature Range:	20 °F (w/chiller) to 600 °F
Speed Range:	0.01 to 600 rpm continuous
Viscosity:	0.5 to 5,000,000 Centipoise
Sample Size:	132 ml
Shear Rate Range:	0.0082 to 1020 sec^{-1}
Shear Stress Range:	2 to 1,600 dyn/cm^2
Repeatability:	±1% of full scale range or better
Computer:	PC with Pentium processor
Voltage:	120V or 240V (with transformer)
Frequency:	50 Hz or 60 Hz

Table 7: Grace Instrument M7500 HTHP Rheometer Specifications

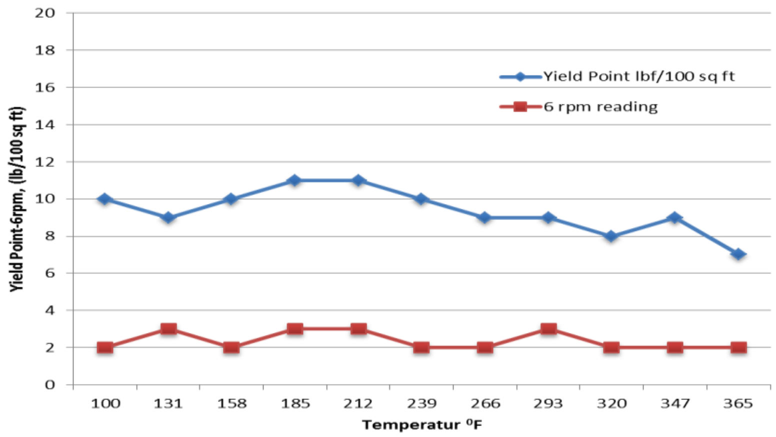

Figure 5: Yield Point and 6 rpm reading vs Temperature

Figure 6: 7500 HTHP instrument

CONCLUSION

A new material attapulgite was tested for use in drilling fluids as a replacement of regular drilling fluid additive bentonite. The material attapulgite was collected and a schematic procedure was developed to purify and breakdown the particles to nanosize. Significant improvement in rheology was observed when using attapulgite nanoparticles in small additive concentration with bentonite and water. Attapulgite have the capability to tailor the properties of drilling fluids by just reducing the particle size. Thus it can be used as a rheology modifier and eliminates the use of other expensive drilling fluid additives. Attapulgite based drilling fluids provides with balanced and optimized set of rheological properties without calling the need for other additives. Another remarkable feature of attapulgite nanoparticles is their stability at high temperature and pressure. Bentonite alone is not found to be stable, while adding small concentration of attapulgite nanoparticles endows the drilling fluid with considerable stablity at high temperature and pressure. Therfore, drilling fluid that include attapulgite nanoparticles could be designed for maximum versatility and delivers and optimized drilling performance, including excellent penetration rates, enhanced lubricity, and superior wellbore stability.

REFERENCES

Abdo J. and Danish M., “Nanoparticles: Promising Solution to Overcome Stern Drilling Problems”, Nanotech Conference and exhibition, Anaheim, California, June, 2010.

Abdo J., Tahat M., Danish M., “Nano-Enhanced Drilling fluids: Capable solution for reducing hight torque and drag in drilling operations”, Eighteenth Annual International Conference on composites/nano engineering (ICCE - 18), Anchorage, Alaska,USA, July, 2010

Abdo J. and Danish M. Haneef, ‘Nanoparticles to Confront Frictional Resistance and Environment in Deep Drilling’, Presented at Ninth AES-ATEMA’2011 International Conference, Montreal, Canada, August 01 – 05, 2011

Abdo J. and Danish M. Haneef, ‘Nano-Enhanced drilling fluids: Pioneering approach to overcome uncompromising drilling problems’, J. Energy Resources Technology (ASME), Volume 134 (1), pp 501-506, 2012.

Adriana M., Johanna N. and Robello S., ‘Pipe Sticking Prediction and Avoidance Using Adaptive Fuzzy Logic and Neural Network Modeling’, SPE Production and Operations Symposium, 4-8 April 2009, Oklahoma City, Oklahoma.

Amanullah M., Ashraf M. Al-Tahini, “Nano-Technology–Its Significance in Smart Fluid Development for Oil and Gas Field Application”, SPE Saudi Arabia Section Technical Symposium, 9-11 May 2009, AlKhobar, Saudi Arabia, 126102-MS.

Cai, J., Chenevert, M.E., Sharma, M.M., and Friedheim, J. 2012. Decreasing Water Invasion Into Atoka Shale Using Nonmodified Silica Nanoparticles. SPE Drilling & Completion 27 (1): 103-112. SPE-146979-PA.

Elward-berry, Julianne, Rheologically stable water-based high temperature drilling fluids, United States Patent 5244877,1993

Fan, C., Shi, W., Zhang, P. et al. 2012. Ultrahigh-Temperature/Ultrahigh-Pressure Scale Control for Deepwater Oil and Gas Production. SPE Journal. 17 (1): 177-186. SPE-141349-PA.

George C. Howard and P.P. Scott Jr., An Analysis and the Control of Lost Circulation, Petroleum Transactions, AIME, Volume 192, 1951, pages 171-182.

Mendes, J.R.P., Morooka, C. K., Guilherme, I. R., Case-based reasoning in offshore well design. Journal of Petroleum Science and Engineering, 2003. 40: p. 47- 60.

Igor N. Evdokimov, Nikolaj Yu. Eliseev, Aleksandr P. Losev, Mikhail A. Novikov, “Emerging Petroleum-Oriented Nanotechnologies for Reservoir Engineering”, SPE Russian Oil and Gas Technical Conference and Exhibition, 3-6 October 2006, Moscow, Russia, 102060-MS.

Jimenez M., ‘Method for treating drilling fluid using nanoparticles, US Patent, US6579832B2, June 17, 2003.

Paiaman A.M., Duraya B. Al-Anazi, “Feasibility of decreasing pipe sticking probability using nanoparticles”, NAFTA,Vol 60 (12), pp. 645-647 (2009).

Quigley, M.C., Advanced Technology for Laboratory Measurements of Drilling Fluid Friction Coefficient, Society of Petroleum Engineers, Inc, 19537-MS,1989.

Ryan E., Douglas J.H, Design of Improved High-Density, Thermally-Stable Drill-In Fluid for HTHP Applications, SPE Annual Technical Conference and Exhibition, 21-24 September 2008, Denver, Colorado, USA

Saeid M., Mariela A.F., and M. Rafiqul Islam, 'Applications of Nanotechnology in Oil and Gas E&P', Journal of petroleum engineering, Vol. 58 No. 4, 2006

Yarim G., May R., Trejo A., Church P., Stuck Pipe Prevention--A Proactive Solution to an Old Problem, SPE Annual Technical Conference and Exhibition, 11-14 November 2007, Anaheim, California, U.S.A.

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