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Short Communication

Application of Nano-Particles of Clay to Improve Drilling Fluid

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Abstract

Drilling fluids are an essential component of the rotary drilling process used to drill for oil and gas on land and offshore environments. The injection of this nano particle into drilling fluid increases the viscosity levels fluids. In these experiments, the rheological properties of the fluid including apparent viscosity (AV), plastic viscosity (PV), yielding point (YP), mud cake thickness and fluid loss (FL) were studied before and after the addition of the nanoclay with different concentrations. In this study, nano particles of clay were used in order to enhance the rheological properties of drilling fluids. The results showed nanoclay controls the fluid loss and is resistant to high temperatures and also fluid loss. We also found that nanoparticles varying in concentration (0.1 to 1 Wt %) and also size 1, 50 and 500 nm are shown to be effective at improving fluid rheology.

***Keywords**: Water-based drilling mud, Nano-particle, Drilling fluid, Fluid loss.*

1. INRODUCTION

Various kinds of drilling fluids, such as water-based drilling mud (WBM), oil-based drilling mud (OBM) and their derivatives, are being used along with suitable polymer and clay additives. The choice of the base of a drilling fluid greatly influences its behavior during the drilling operation [1]. Oil-based muds have been established as the premier mud system in terms of lubricating properties. The system provides wellbore stability, low torque and drag, excellent fluid loss control and filter cake quality, appropriate rheological properties for cleaning the hole, and temperature stability [1]. Disadvantages are high cost, environmental limitations, disposal problems, health and safety issues, and detrimental effect on drilling and completion pay zone [2-4].

Fluid penetration from water-based muds into shale formations results in swelling and subsequent wellbore instability. Particles in conventional drilling fluids are too large to seal the nano-sized pore throats of shales and to build an effective mud cake on the shale surface and reduce fluid invasion [5]. It is generally accepted that balanced-activity oil-continuous muds offer a good solution to shale-instability problems because there is no interaction between oil and shale [6]. However, for environmental and economical considerations, water-based muds would be much preferred if the interaction between the fluid and the shale could be minimized. Hayatdavoudi and Apande (1986) found that the best possible way of preventing contact between argillaceous rock and water is to seal off exposed clayey surfaces.

Even though some research has focused on improving wellbore stability with specially engineered water-based muds, no such inhibitive mud currently exists [7]. Al-Bazali et al. found that the average pore-throat sizes of a variety of shales range from 10 to 30 nm (0.01 to 0.03 μm). Compared with shale pore-throat sizes,

commonly used drilling-fluid additives such as bentonite and barite have much larger particle diameters, in the range of 100 to 10000 nm. Only nano-sized particles have the possibility of plugging pore throats in shales. Nanotechnology represents the development and application of materials, methods, and devices in which the critical length scale is on the order of 1 to 100 nm [8]. To the best of our knowledge, the use of nanoparticles in drilling fluids is the first potential large-scale application of nanoparticles in the oil and gas industry. Other applications of nanoparticles as tracers for reservoir-engineering and formation evaluation applications have been suggested [9,10].
Nanotechnology may help address some of these challenges. Nanotechnology is the study of science of materials at nanoscale (nanoparticles) which help in enhancing the performance of processes. A nanoparticle is any particle having one or more dimensions of the order of 100 nm or less. Nanoparticles are unique because of their large specific area ratio giving enhanced surface-dependent material properties [11-17]. This concept has initiated the use of nanoparticles in improving the thermal conductivity of the base of mud into which they are dispersed. Thus, stable nanofluids exhibit improved thermal conductivity, parameter most responsible for enhanced heat transfer [18]. Recent studies addressed the use of nanoparticle to solve drilling related issues which include pipe sticking, lost circulation, torque and drag [19-22]. Agarwal et al. [23] worked on the use of nanoclay and nanosilica for high-pressure high-temperature (HPHT) invert emulsion based drilling fluids, and observed their effect on the rheology of the drilling mud. Paiaman and Al-Anazi [24] observed that the addition of nano-carbon black particles into the drilling mud reduced the thickness of the mud cake with increasing pressure and temperature, thus helping in the prevention of stuck-pipe issue. Zakaria et al. [25] used nanoparticles in drilling fluids, and demonstrated a significant reduction in mud cake thickness. Recent investigations on the use of nanoparticles as shale inhibitor in WBM showed reduced fluid (water) penetration into the shale, thus reducing wellbore instability problems [26-28]. Singh and Ahmed [29] described the role and significance of using nanopolymers in drilling applications and validated their use.
In this study, the rheological properties of the fluid including apparent viscosity (AV), plastic viscosity (PV), yielding point (YP), mud cake thickness and fluid loss (FL) were studied before and after the addition of the nanoclay with different concentrations.

2. MATERIALS AND METHODOLOGY

2.1. Materials

Potassium chloride (KCl), potassium hydroxide (KOH), calcium hydroxide ($Ca(OH)_2$), calcium carbonate ($CaCO_3$) and sodium sulfite (Na_2SO_3) were obtained from Merck Chemicals with 85%, 99.5%, 80%, 95% and 85% purity, respectively. Polyanionic cellulose, XG and starch were supplied by Sinocmc co..
In this study, sodium bentonite (made in Iran) was used as clay. The bentonite was produced in Iran and amended with the chemicals shown in Table 1. Oxford-ED2000 XRF and GC-2550TG (Teif Gostar Faraz Company, Iran) were used for all chemical analyses.
After the preparation and analysis of the raw materials, the clay was purified using a 2 inch hydrocyclon apparatus. To accomplish this, a suspension of 3 wt.% clay in distilled water was prepared and then passed through the cyclone at a pressure of 0.15 MPa. This resulted in the removal of impure and large particles. To ensure compatibility following the dispersion of clay in distilled water, a clay suspension was prepared and amended

***Table 1**. Chemical composition of bentonite*

Formula	Wt. %
L.O.I	13.2
Na_2O	2.04
MgO	2.22
$Al2O_3$	14.59
SiO_2	61.03
SO_2	0.37
Cl	0.46
K_2O	0.76
CaO	0.77
TiO_2	0.22
Fe_2O_3	2.09
BaO	0.11

with 10, 20, 30, 40 or 50 wt% of the modifier materials "silane". The mixtures were then heated at 80°C for 6 hours, after which the products were washed with distilled water and dried.

The distribution of clay particle sizes was measured before and after purification using a Laser Particle Size Analyzer. In addition, clay particles in the colloid state were analyzed by SEM. The intercalation of the samples was evaluated using an X-ray diffraction.

The results of the XRD analysis revealed that most of the impurities, which included quartz, cristobalite, calcite, gibbsite and feldspar, were removed from the clay by the purification process. Finally, the thickness of the layers in the crystal structure of montmorillonite and the patterns generated by XRD indicate that the clay was comprised of crystal layers on top of each other following purification (Figure 1).

The size distribution of various samples clay nanoparticles are shown in Figure 1. The size of the diameter for nano particles was determined. The volume percentage distribution shows size with mean particle diameters of less than 1, 50 and 500 nm for NPs clay. Water-based drilling mud using the polymeric component of the drilling fluid as the base fluid for nanoparticles will help ensure better distribution throughout the drilling fluid composition, and it enables

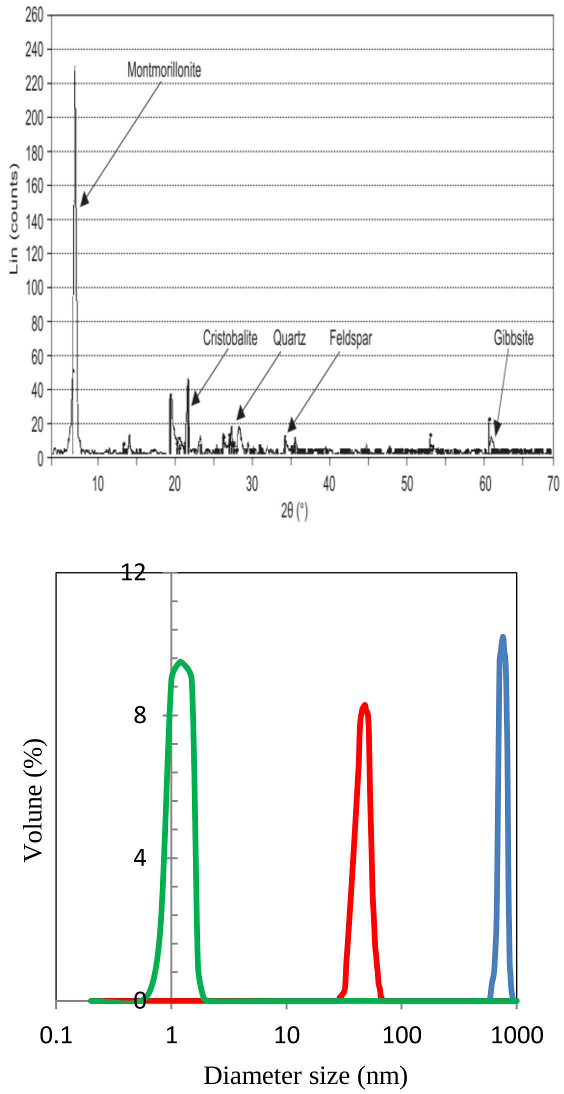


Figure 1. *XRD pattern, local pure sample and particle size distribution.*

the effects of the base of the nanofluid into the drilling mud to be neglected as a constraint in its working [30]. In order to ensure that the XG polymer solutions do not degrade due to bacterial action. Table 2 shows the formulation of water-based drilling fluid. The nanofluids are prepared using nano particles. The composition of water based fluid is based on the API standard specification for WB mud fluid [31]. This consists of introducing clay nanoparticles (size 1,50 and 500 nm) in concentrations of 0.1 and 1.0 wt% into a base fluid (Table 3).

Table 2. Formulation of water-based drilling fluid.

Component	Amount Added
Deionized Water	287.7 cm^3
Bentonite	18 g
XG Polymer	3 g
Starch	6 g
Polyanionic cellulose	0.75 g
KCl	41 g
KOH	0.5 g
$Ca(OH)_2$	0.25 g
$CaCO_3$	4.5 g
Na_2SO_3	0.75 g

Table 3. Formulation of Nano Drilling Fluid.

Sample No.	Drilling fluid sample
S1	WBD
S2	WBD + 0.1 Wt% nanoclay (1nm)
S3	WBD + 0.1 Wt% nanoclay (50nm)
S4	WBD + 0.1 Wt% nanoclay (500nm)
S5	WBD + 1.0 Wt% nanoclay (1nm)
S6	WBD + 1.0 Wt% nanoclay (50nm)
S7	WBD + 1.0 Wt% nanoclay (500nm)

2.2. Methodology

Viscosity of sample was used to assess its pumpability. Shear stress and shear rate were measured by use of concentric cylinder geometry on an Anton Paar MCR 501 advanced rheometer at room temperature. Viscosity at different shear rates was measured and depicted in Figure 2. FANN 35 viscometer equivalent rheology data have been generated by the Anton Paar readings.

Static fluid-loss testing was performed on fluid by use of a filter press. Next, flow was started through the gel with a 100-psi differential pressure, on the volume of fluid was collected and recorded as a function of time at 25°C. Fluid loss tests were run for 6 hours. The same experimental procedure was used to measure the fluid loss at 25 and 90°C temperatures.

To test the thermal stability of both oil base mud and nano water base mud and the rate of deterioration of its filtration and rheology properties under the condition of high temperature, and continuous circulation, the following test was carried out. Samples prepared according to the above procedure and placed in a rolling oven operating at 350ºF with continuous circulation for 16 h; samples were then removed and cooled for 20 min in a cold water bath. Samples were then banded in a high speed blender for 5 min and the AV, PV, YP, gel strength for 10 sec, gel strength for 10 min, and fluid loss (FL) were determined [32].

3. RESULTS AND DISCUSSION

There was a comparison between the newly developed nano drilling fluid and the traditional one such in rheological properties, temperature tolerance, and fluid loss performance.

Effect of Nanoparticle Concentration. For a drilling mud, filtration and rheology properties need to be suitable to fulfill drilling requirements. The following tests were performed to study the effect of nanoparticle concentration in muds. Table 4 and Figure 4 show a summary of results.

The filtration properties of nanoparticle-containing muds are shown in Tables 4 and figure 3. Nano-sized clay could plug the throats of the filter paper and formed a thin and hard mud cake, which led to a decline in the API filtration [5].

Table 4. Rheological properties of the nanoclay drilling mud and base mud at 25°C and 90°C.

Sample at 90°C	Yield Point ($lb/100ft^2$)	Plastic Viscosity (cP)	Thickness of Mud Cake (in)
S1	19	5	0.137
S2	27	12	0.066
S3	25	11	0.066
S4	22	10	0.071
S5	32	16	0.052
S6	30	15	0.061
S7	25	11	0.067

Sample at 25°C	*Initial Gel Strength* ($lb/100ft^2$)	*Final Gel Strength* ($lb/100ft^2$)	Apparent Viscosity (cP)
S1	10	28	20
S2	12	30	25
S3	12	29	23
S4	11	29	21
S5	18	38	32
S6	17	35	30

S7	13	30	24

Sample at 90°C	Yield Point ($lb/100ft^2$)	Plastic Viscosity (cP)	Thickness of Mud Cake (in)
S1	9	3	0.149
S2	24	9	0.068
S3	22	8	0.069
S4	19	7	0.075
S5	31	15	0.053
S6	29	15	0.063
S7	23	10	0.070

Sample at 90°C	Initial Gel Strength ($lb/100ft^2$)	Final Gel Strength ($lb/100ft^2$)	Apparent Viscosity (cP)
S1	5	15	8
S2	7	16	21
S3	7	16	19
S4	7	16	16
S5	14	19	30
S6	13	18	29
S7	8	17	21

Table 5. *Effect of temperature on apparent viscosity.*

Sample	T25	T50	T70	T90
S1	20	13	9	7
S2	26	23	20	19
S3	24	22	20	18
S4	22	19	17	16
S5	33	31	30	28
S6	31	30	29	27
S7	24	23	22	20

From the tables shown above, it can be seen that both nanoclay concentration additives actually increased the viscosity of the mud, but in different capacities. The reduction in the viscosity dial readings after each 0.1%wt added is more with nanoclay than it is with 1 %wt nanoclay. Similar effects can also be noticed with the yield points and plastic viscosities. The total percentage enhancement in yield point and plastic viscosities at 25°C after addition of the 1 weight percent of nanoclay are 40% and 68% respectively, while that after addition of the 0.1 of weight percent of nanoclay are 24% and 50% respectively, so 1 %wt of nano clay shows a higher level of increment, but generally, both concentration of nano enhancement yield point more than they did plastic viscosity.

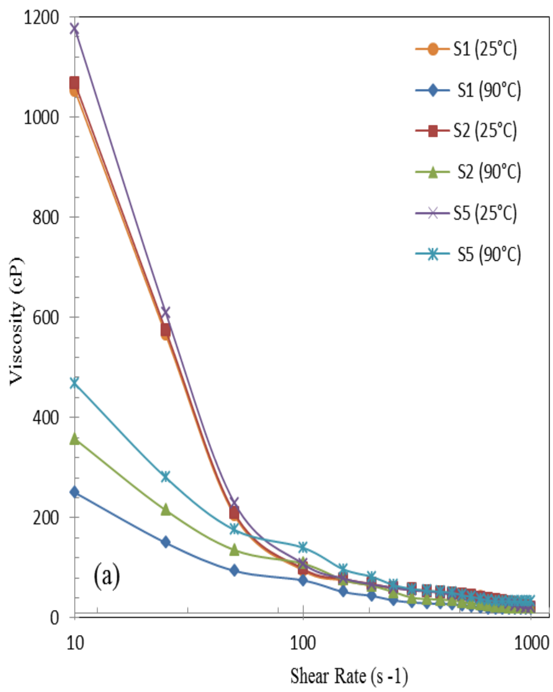
Also, The total percentage enhancement in yield point and plastic viscosities at 90°C after addition of the 1 weight percent of nanoclay are 71% and 80% respectively, while that after addition of the 0.1 of weight percent of nanoclay are 52% and 57% respectively, so the thermal increase parameters yield point and plastic viscosity nanoclay water base fluid. higher level of reduction, but generally, both phosphates reduced yield point more than they did plastic viscosity.

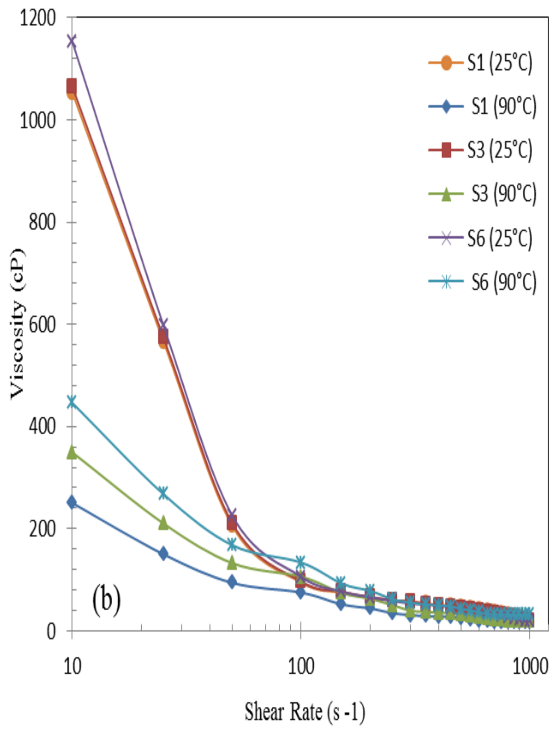
The gel strength of nano water mud and base mud are illustrated in Table 4. Test results for gel strength for both nano water mud and base mud under varying temperature conditions from 25°C to 90°C indicated that they ware premier results compared to water base mud.

In general, it is observed that for fluids in whose nanoparticles are used (Figure 5), YP is significantly higher than basic fluid. Regarding Tables 4, it can be seen that fluids YP having clay nanoparticles is higher than the other fluids, when nanoclay (1Wt% with 1nm size) is used in fluid. YP difference between nanofluids and basic fluids is considerably higher than the time the matter is not applied in the fluid structure. Also, sodium hydroxide results in higher YP fluid with 1weight percent nanoparticles compared to 0.1 nanoparticles with fluids.

Effect of temperature on viscosity of nano water base fluid is shown in figure 2. The concentration of nanoclay solutions are 0.1 and 1 wt% and the size of particles are 1, 50 and 500 nanometer. The measurement temperature varies from 25 to 90°C. It is indicated that viscosity of solutions always desreased but this decrease rate change with add nanoparticles. From Figure 2 it may be observed that the viscosity decreases with increase in temperature at a given pressure. It is observed that the effect of pressure on the viscosity enhancement is not significant even at lower temperatures, as is seen in the base drilling fluid. The viscosity variation from 90°C to 25°C at any given shear rate is more at lower shear rate than at higher shear rate for a given pressure. Although, the effect of clay nanoparticles improved viscosity water base mud as compared to conventional base fluid.

Figure 2 shows the drilling fluid rheology for nano sample fluids S.2 and S.3, respectively (as in Table 5), and showed a similar trend of the effect of temperature on the rheology as the case with S.1. Figure 2 also show the effect of clay nanoparticles (S.4 to S.6) on the behavior of nano water base fluid (S.4 to S.6). According to these figures, the rheological properties of the drilling fluid have been enhanced in the presence of nano particles. One of the important parameters in evaluating the efficiency of nano is the amount of fluid loss. In Figure 3, the fluid loss of nano water base muds and water base are shown at different temperatures. fluid loss controlling role up to 90°C in the presence of component water based fluids,





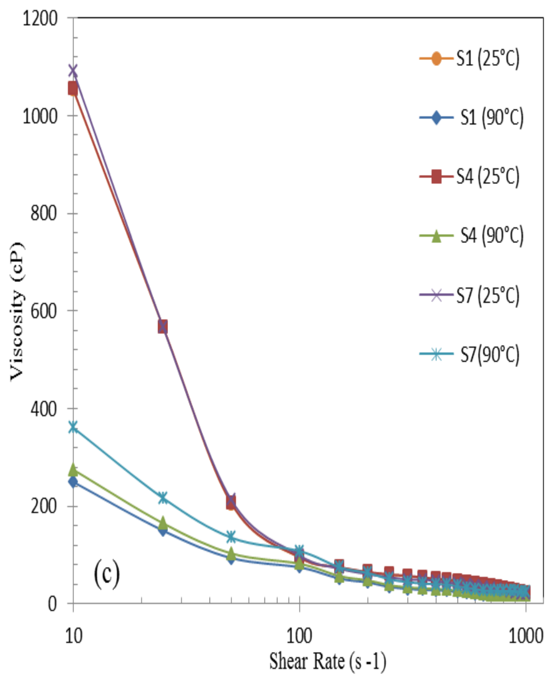


***Figure** 2. Effect of temperature on the viscosity of nanoclay drilling fluids a)1nm, b)50 nm and c)500nm size, Compared with base fluid*

As observed, the fluid loss of nano water mud after thermal test at different temperatures is more than that of conventional mud. According to Figure 3, the nanoclay (1 and 50 nm) maintains its while the thermal effect the clay (0.5µ)

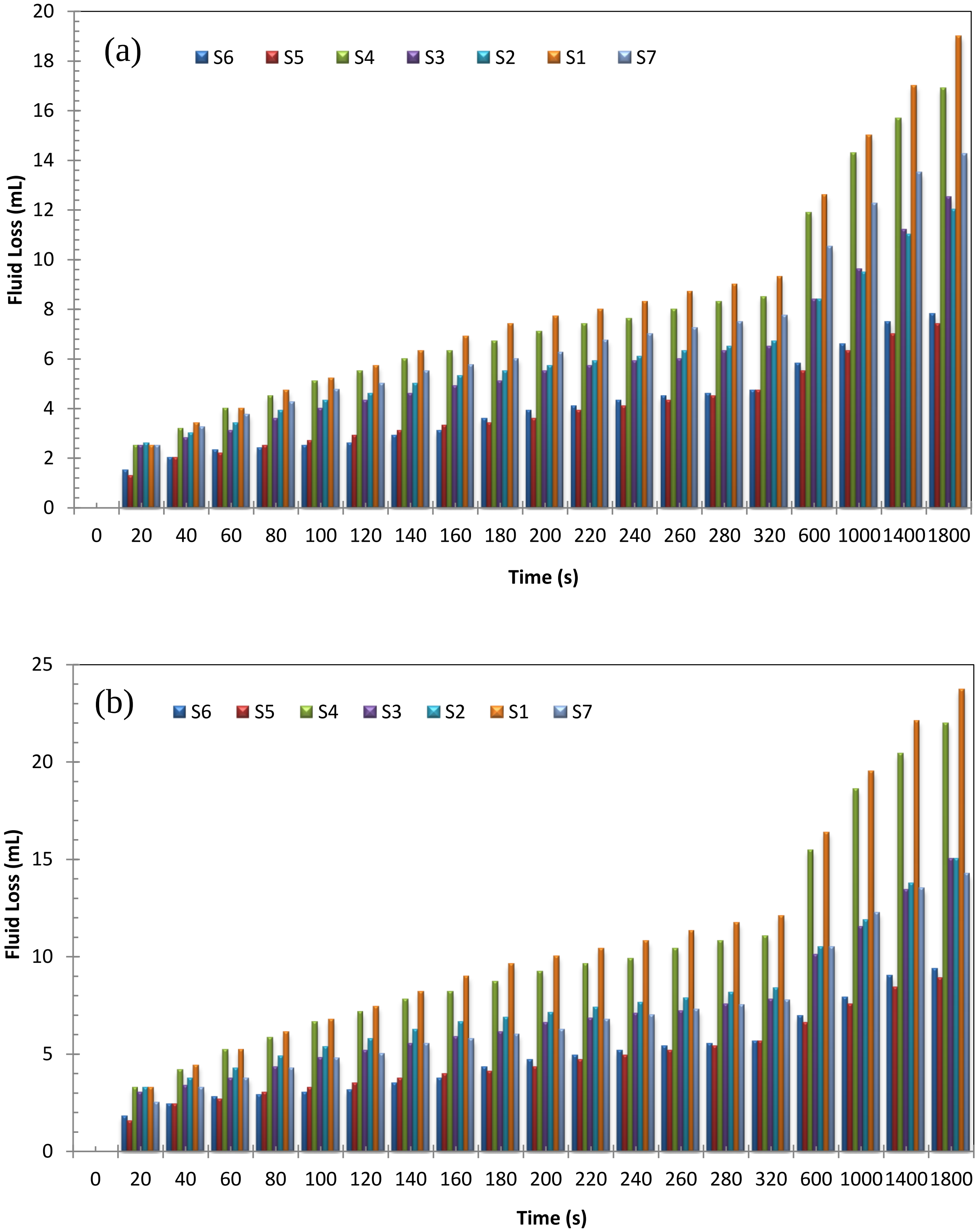


***Figure 3**. Filtrate volume results for fluid-loss samples at a) 25°C and b) 90°C.*

Reduce at temperatures above 130 °C in the water base mud.

SEM. The SEM scan was performed on the filter cake to determine the morphology of each layer. It was noticed that there was a difference in the particle-size distribution in each layer, as shown in Figure 4. Grain size was measured using a Leica microscope. The obtained results showed that drilling fluid contained a mixture of grains of of a large size, in the range of 1–50 n. Figure 4a and 4b show the morphology of the nano clay particles by SEM which were dispersed by drilling fluid on mud cake in 1nm size for 4a, 50nm for 4b and 0.5µ size for 4c. Obviously, the nano clay particles in 1nm size dispersed completely on mud cake surface and create new nano structure on well surface (impervious Porous media). The nano clay particles in 0.5µ size (Figure 4c) particles were not dispersed completely, so this matter can decrease mud performance.

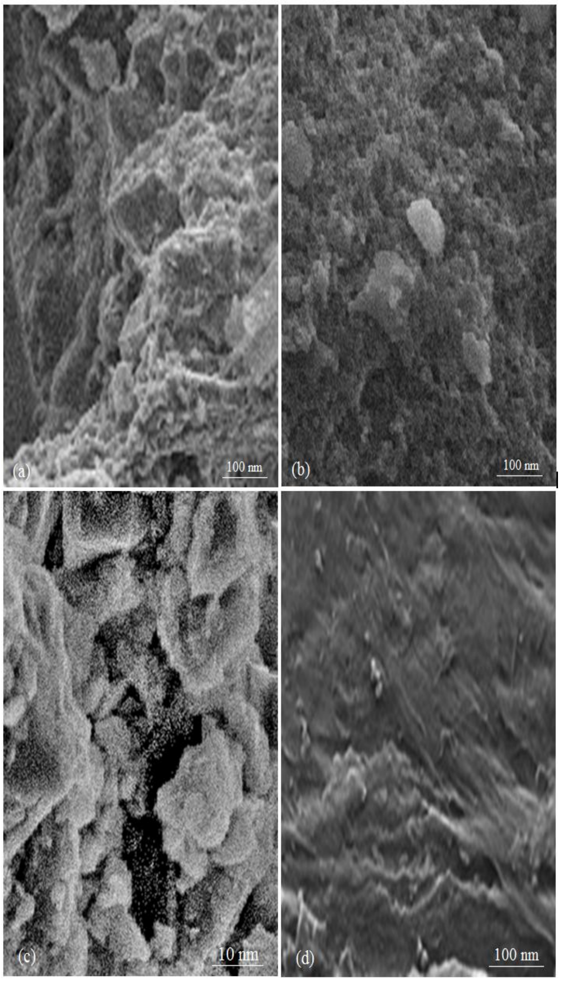


Figure 4. *SEM photomicrograph of the filter cake with different nano particles size of (a) 1nm (b) 50nm (c) 500nm and (d) without nano particles*

4. CONCLUSIONS

In the present work, a new nano WBM was reported. This novel system had good rheological properties and fluid loss performance.

Nano sample fluids are more significant at higher temperatures, results in better rheological stability in case of nano sample fluids. The most significant role that the nanofluids play is in stabilizing the viscosity at higher temperatures. The effect of temperature on rheological properties of nano water based mud show a slight decrease by increasing temperature compared to the base fluid. An increased concentration of nanoparticles further enhances thermal properties of drilling fluids. The nano sample fluids based on clay nanoparticles show improved thermal properties and are more resistant to thermal condition than water base muds.

Nanoparticles varying in size from 1 to 500 nm and at a concentration of 0.1 and 1 wt% are shown to be effective at reducing fluid loss, thereby reducing the interaction between the shale and a water-based fluids. The materials used to formulate the drilling fluids in this study act to create dispersion with good structure properties, though at conventional scale, the additives are not more efficient; the gel strength increases when adding a small amount of nanoclay, then remains constant when increasing the amount of it.

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