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Effect of Nanotechnology in improving the conventional drilling mud properties in drilling shale of the Kafr El Sheikh Formation in Temsah Field, Mediterranean Sea, Egypt

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Abstract: Wellbore instability in drilling operations account for up to 48% globally. Over 70% of the borehole problems are related to shale instability, in the sametime shales make up over 75% of the drilled formations. The problematic shales in the Mediterranean Sea such as Kafr El-sheikh formation which are encountered in the section above the potential reservoir zone are considered as potential source of borehole instability. Shale cuttings were collected from Temsah -03 well in Mediterranean Sea, Temsah concession. They were evaluated using X-ray diffraction (XRD) for bulk samples to identify the clay minerals and associated ones and the clay minerals percentages (clay fraction <2□), X-ray fluorescence (XRF) and cation exchange capacity (CEC) using Methylene Blue (MB). Nanoparticles used in this study are Nanoshield as inhibitors for swelling of shale cuttings. The inhibitors are added to the conventional drilling fluids instead of potassium chloride (KCl) and compared the rheological and fluid loss test results. Adding 7% KCl caused an increase in API fluid loss from 4 cc/30min to 7.5 cc/30min and this is considered as a negative effect for using KCl. The Nanoshield was changed the value from 4 ml/30min to 3.4, 3.4, 3.4, 3.5, 3.6, 3.8, 3.6 and 4 ml/30min corresponding to 0.15ppb, 0.35ppb, 0.55ppb, 0.75ppb, 1.00ppb, 1.50ppb, 2ppb and 2.5ppb respectively.

keywords: Nanotechnology, shale, drilling, nano-particles, swelling.

1.Introduction

The Temsah concession which comprises the study area is located in the eastern sub-basin, offshore Nile Delta, Egypt and is at about 65 km north-north-west of Port Said city and covers an area of 1155 km^2, with water depth ranging from 70m to 120m. Such area is situated between latitudes 31° 59' 56" N and 31° 34' 57" N and longitudes 32° 00' 05" E and 32° 18' 00" E, [1].

The petroleum industry have disturbed for over 50 years by troublesome shales. The main reason for borehole instability is the drilling of shale formations and the potential event is abandoned and plugged the wells after several weeks of drilling. Generally, the wellbore-stability problems Increases the costs from 10 to 15% of total drilling cost. In the same time from 70 to 90% of the wellbore instabilities problems happened while drilling are as a result of shale formations drilling [2]. The worldwide assessment for the non-productive time cost due to shale problems are from 500$ to 600$ million annually [3].

Kafr El-Sheikh formation is encountered while drilling the Mediterranean Sea wells and is considered as a wellbore instability potential source. It is composed of deep marine shales with local sandstone deposits. There are many drilling problems with this shale. The improper handling including selecting the right fluid to drill these reactive shales has lost completely many wells. So, selecting the right fluid to drill these reactive shales is a must [4].

Nanotechnology involves using additives of 1–100 nm in different sciences and technologies like the drilling fluids. It plays an important role in solving some of the most common drilling problems. Nano-particles have a very high surface area to volume ratio; this will result in high reactivity and reducing the quantity desired for any application which reduces the cost to a great extent [5].

The particle sizes of conventional mud systems additives are much larger than the pore throat sizes of the shale formations [6]. The shale formations with low (nano-darcy) permeabilities, prevent the formation filter cake that causes the fluid invasion to the surrounding formations [7]. The nano-particles size are less than the shale pore throat sizes to plug pore throat in shales and form an intermediate filter cake, which result in reduction of the shale permeability and decreasing of the fluid invasion into the shale formation. So, the drilling fluids with nano-materials will be more efficient to control shale problems and increase wellbore stability [6].

Based on [8], the particle sizes of the lost circulating materials in the range of 0.1 – 100 µm which will be effective to prevent the fluid loss in the porous formation of 0.1 µm – 1 mm pore sizes. The pore throat size in shale formations ranges from 10 nm – 0.1 µm, so the nano-materials are very suitable to enter these pore throats to plug and seal them. While the well completion, the mud cake can easily be removed by conventional cleaning methods.

2. Materials And Experiments

All the chemical materials (bentonite, KCL, PAC LV, Barazan D Plus, Duo Vis, and Barite) used for this research are from MI-Schlumberger and Halliburton-Baroid except the nano-materials; Nanoshield was supplied by Baker Hughes Co. Some of the experiments were carried out in Halliburton-Baroid company laboratory in Cairo, Egypt, and most of these experiments were in MI-Schlumberger company laboratory in 6th October city, Egypt.

Characterization of shale samples

Mineralogical Analysis

X-Ray Diffraction (XRD) of shale samples

The shale samples were depicted using X-ray Diffraction (XRD) for bulk samples to identify the clay minerals and associated ones.

These samples contain quartz, feldspars and clay minerals. Kaolinite, illite and smectite are present. Chlorite cannot be verified based on the data given from the XRD. Shale samples show high concentration of barite. This concentration of barite is related to the drilling fluid in the hole while drilling the well as shown in Fig. (1).

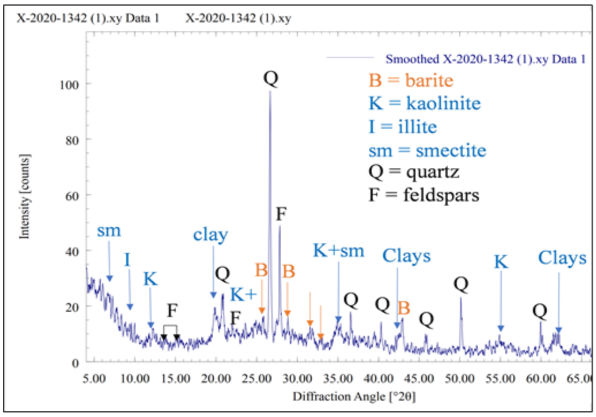

Fig. (1): X-ray diffractogram of shale sample of well Temsah -03

Another quantitative analysis was done on the Kafr Elsheikh shales to identify the clay minerals percentages (clay fraction <2µm). Identification of clay minerals was based upon x-ray diffraction of <2µm fraction (table (1) (Attia et al., 2010).

Table (1): XRD semi-quantitative analysis for Kafr Elsheikh shales

Nile Delta - Kafr El-Sheikh	
Quartz, wt %	11
Potassium feldspar, wt %	---
Plagioclase feldspar, wt %	5
Calcite, wt %	---
Siderite, wt %	---
Sylvite, wt %	3
Barite*, wt %	4
Smectite, wt %	52
Illite, wt %	11
Kaolin, wt %	13
Chlorite, wt %	1
CEC, meq/100g	32

Chemo-physical Analysis

Cation exchange capacity (C.E.C)

The reactive clays (bentonite and/or drilled solids) present in a drilling fluid and the total cation-exchange capacity (CEC) of these solids can be determined by this test.

The CEC can be calculated by Eq. (1):

$$\text{CEC (meq/100g)} = \frac{\text{Methylene Blue (mls)}}{\text{Weight of shale sample (g)}}$$

…. Equation (1)

The (CEC) of the studied sample is 10 meq/100g.

Chemical Analysis

Table (2) shows the chemical composition of the minerals that are present in studied well using Elemental Analysis by Wavelength Dispersive X-Ray Fluorescence Spectrometry (XRF).

Drilling-Fluids Preparation

Preparation of Blank Drilling Fluid

The water-base drilling fluids chemicals used in this study were supplied by Baroid – Halliburton and MI-Schlumberger Companies. All the blank samples of drilling fluid (polymer mud is the blank mud) are based on the formulation of 350 ml (350 ml is equivalent to 1 bbl in laboratory test).) of the fresh water while being stirred at 11000 RPM by a commercial Hamilton Beach mixer then 10 g of bentonite was added while being stirred for 20 minutes to provide primary viscosity and xanthan gum to adjust the viscosity and suspension characteristics for weighting materials of the base fluid.

Polyanionic cellulose low- viscosity was used as a filtration control and shale encapsulation to prevent swelling and disintegration additives. Potassium chloride was used to drill the troublesome "gumbo" shales because it provides potassium ions to inhibit shale swelling and dispersion; it is used here to prepare the conventional fluids with different concentration of 7%. Barite was used as weighting material to increase the drilling fluid density to 13 pound per gallon (ppg). Sodium hydroxide (caustic soda) and sodium carbonate (soda ash) were used as alkalinity agent (the PH was adjusted at 9.5-10) and precipitate magnesium and calcium to reduce the hardness of makeup water.

This mixture was mixed using Hamilton Beach mixer for 30 min. These drilling fluids were made up in accordance with the formulas shown in table (3).

Nano-materials Water-Base Drilling Fluids Preparation

By using the blank drilling fluid sample (without KCl) and replacing the KCl with different concentrations from Nanoshield nano-particles (0.15 ppb, 0.35 ppb, 0.55 ppb, 0.75 ppb, 1.00 ppb, 1.50 ppb, 2.00 ppb, 2.50 ppb) and by a slow addition while being stirred at 11000 RPM by a commercial Hamilton Beach mixer over 30 min for dispersion to obtain the nano-fluids. In this regard, all the samples at pH of around 9.5, KCl and nano-materials concentrations were selected randomly.

Table (2): Chemical analysis results for shale sample (XRF)

Main Constituents, wt%		**Traces Constituents, ppm**	
SiO_2	36.10	S	16600
TiO_2	1.60	Cr	227
Al_2O_3	9.43	Ni	42
$Fe_2O_3^{tot.}$	11.80	Cu	227
MgO	1.53	Sr	634
CaO	5.91	Zn	204
N_2O	1.86	Zr	854
K_2O	1.90	Br	35
P_2O_5	0.170	Ru	750
MnO	0.113	Rh	4450
Cl	1.92	Rb	64
Ba	0.490	Ag	855
L.O.I	19.80	Co	52
		Y	30
		Nb	52
		Pd	4690
		Pa	59
		Pa	30

Table (3): Barrel formulation of water base mud without nano-materials

Product Name	**Concentration** (Ib/bbl) - gm	**Density** (ppg)	**Volume** (ml)
Water		8.30	349.38
Barite	245.2	35	0.17
PAC Low Vis	4	1.5	0.06
Nano-Material	0	1.5	0.00
Potassium Chloride	24.5	2.0	0.29
Barazan D Plus/Duo Vis	0.15	1.5	0.00
Soda Ash	0.5	20.9	0.00
Caustic Soda	0.5	17.8	0.00
Bentonite	10	20.8	0.10
one lab. bbl			350

3. Results and discussion

By formulating a sample of blank drilling mud, a sample of KCl polymer mud and others from each concentration from Nanoshield nano-particle and testing their rheological properties, API Fluid Loss and Mud Weight as criteria to select the most suitable and advanced drilling fluid in order to be chosen finally as a suitable replacement for the conventional drilling fluid.

Rheological properties measurement

The rheological properties such as apparent viscosity, plastic viscosity, yield point and gel strength were measured using fann viscometer shown in Fig. (2) and according to API specifications at 120 F^0.

Fig. (2): VG Meter at Schlumberger Co. Lab

Adding KCl on the blank fluid caused a progressive reduction in rheological properties. The variations in rheological properties of the drilling fluids with 7% KCl can be summarized in the following as shown in table (4):

Table (4): Rheological results of the blank fluid and KCl base mud

	Rheological Properties					
	Apparent Viscosity	Plastic Viscosity	Yield Point	Gel Strength 10"	Gel Strength 10'	YP/PV Ratio
blank fluid	54	39	30	6	12	0.77
KCl 7%	29.5	25	9	3	5	0.36

The apparent viscosity was decreased from 54 (for the blank fluid) to 51cp, the plastic viscosity from 39cp to 25cp, the 10-second and 10-minute gel strength values from 6 to 3 $Ib/100ft^2$ and from 12 to 5 $Ib/100\ ft^2$ respectively, the yield point from 30 $Ib/100\ ft^2$ to 9 $Ib/100\ ft^2$ and YP/PV ratio from 0.77 $Ib/100ft^2/cp$ to 0.36 $Ib/100ft^2/cp$.

The rheological results of the Nanoshield base mud are illustrated in Table (5).

Table (5): Rheological results of the Nanoshield base mud

Rheological Properties		Nanoshield Concentration							
		0.15	0.35	0.55	0.75	1.00	1.5	2.00	2.5
Apparent Viscosity		55	56	56.5	60	56.5	61	55	62
Plastic Viscosity		40	41	41	43	42	43	41	43
Yield Point		30	30	31	34	29	36	28	38
Gel Strength	10"	8	8	6	6	5	5	5	5
	10'	16	16	14	14	13	13	13	13
YP/PV Ratio		0.75	0.73	0.76	0.79	0.69	0.84	0.68	0.88

Using different concentrations of Nanoshield ranged from 0.15 up to 2.5 pound per barrel (ppb) caused more or less changes in rheological values of the blank fluid as explained below:

Nanoshield caused slightly changes in the apparent viscosity of the blank fluid from 54cp to 55cp, 56cp, 56.5cp, 60cp, 56.5cp, 61cp, 55cp and 62cp corresponding to 0.15ppb, 0.35ppb, 0.55ppb, 0.75ppb, 1.00ppb, 1.50ppb, 2ppb and 2.5ppb respectively as shown in Fig. (3).

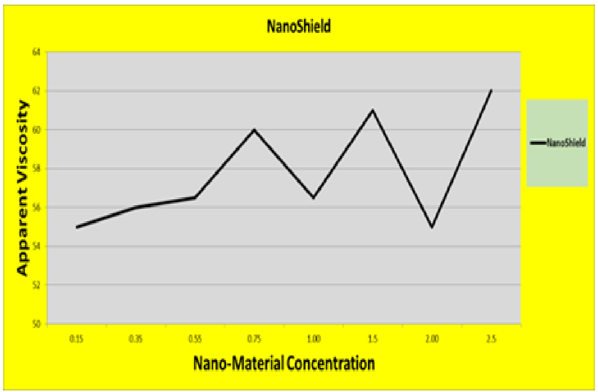

Fig. (3): Apparent Viscosity variation with different concentrations of Nanoshield.

The plastic viscosity value of the blank fluid (39cp) was almost constant with all concentrations; 41cp, 56cp, 41cp, 43cp, 42cp, 43cp, 41cp and 43cp corresponding to 0.15ppb, 0.35ppb, 0.55ppb, 0.75ppb, 1.00ppb, 1.50ppb, 2ppb and 2.5ppb respectively as shown in Fig. (4). Also, the yield point value of the blank fluid (30 $Ib/100ft^2$) was almost constant with all concentrations; 30, 30, 31, 34, 29 and 28 Ib/100ft2 corresponding to 0.15ppb, 0.35ppb, 0.55ppb, 0.75ppb, 1.00ppb, and 2.00ppb respectively. But 1.50ppb and 2.50ppb caused an increase in the yield point value to become 36 and 38 Ib/100ft2 respectively as shown in Fig. (5).

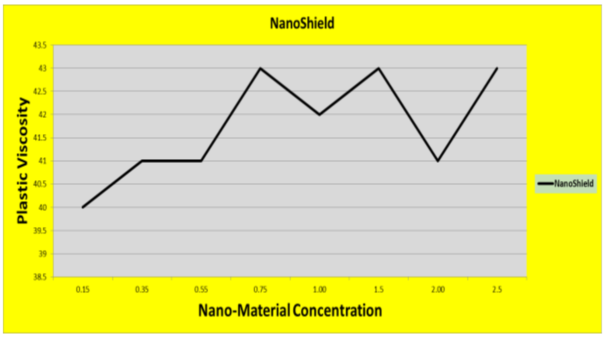

Fig. (4): Plastic Viscosity variation with different concentrations of Nanoshield.

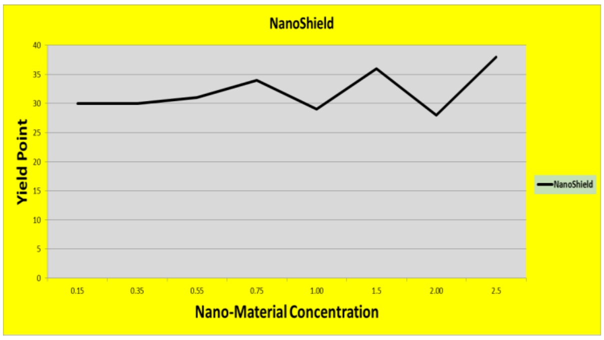

Fig. (5): Plastic Viscosity variation with different concentrations of Nanoshield

The 10-second gel strength values were increased in the first and decreased gradually with increasing concentrations; 8, 8, 6, 6, 5, 5, 5 and 5 Ib/100ft^2 corresponding to 0.15ppb, 0.35ppb, 0.55ppb, 0.75ppb, 1.00ppb, 1.50ppb, 2.00ppb and 2.5ppb respectively. The 10-minute gel strength values were followed the same situation also; 16, 16, 14, 14, 13, 13, 13 and 13 Ib/100ft^2 corresponding to 0.15ppb, 0.35ppb, 0.55ppb, 0.75ppb, 1.00ppb, 1.50ppb, 2ppb and 2.5ppb respectively as shown in Fig. (6).

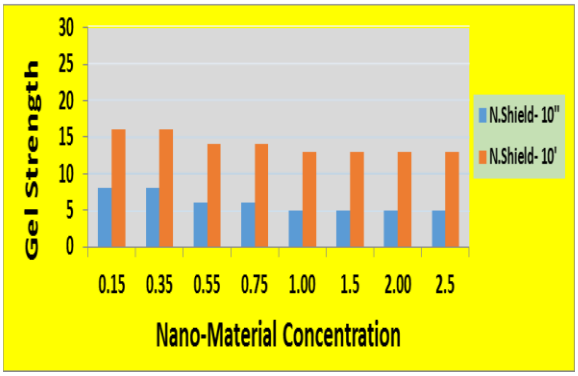

Fig. (6): 10" and 10' Gel Strength variation with different concentrations of Nanoshield.

The YP/PV ratio of the blank fluid was changed with increasing the concentration in up and down trend; 0.75, 0.73, 0.76, 0.79, 0.69, 0.84, 0.68 and 0.88 corresponding to 0.15ppb, 0.35ppb, 0.55ppb, 0.75ppb, 1.00ppb, 1.50ppb, 2ppb and 2.5ppb respectively as shown in Fig. (7).

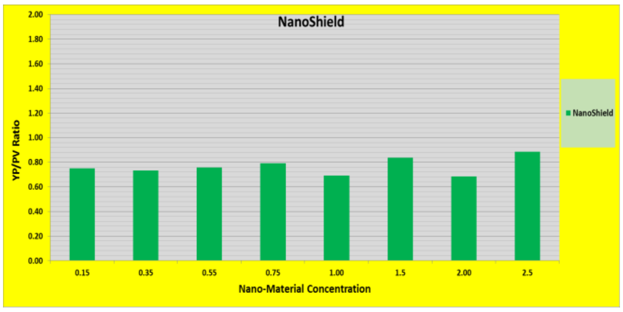

Fig. (7): 10" and 10' Gel Strength variation with different concentrations of Nanoshield.

API Fluid Loss measurement

Filtrate loss of blank fluid increased from 4cc/30min to 7.5cc/30min with using 7% KCl.

Nanoshield decreased the filtration volume of the blank fluid with a constant value of 3.4 ml/30min with the concentrations from 0.15 to 0.55g and began to slightly increase up to 2.5g except for the concentration of 2.00g, the filtrate volume slightly decreased to 3.6 ml/30min as shown in table (6) and Fig. (8).

Mud Weight measurement

The mud weight remains almost constant with all the blends. The addition of nano-particles does not significantly increase the mud weight.

Table (6): The filtration volume Variation versus different concentrations of Nanoshield

	Blank Fluid	7% KCl	Nanoshield Concentration							
			0.15	0.35	0.55	0.75	1.00	1.5	2.00	2.5
Filtrate loss (cc/30min)	4	7.5	3.4	3.4	3.4	3.5	3.6	3.8	3.6	4

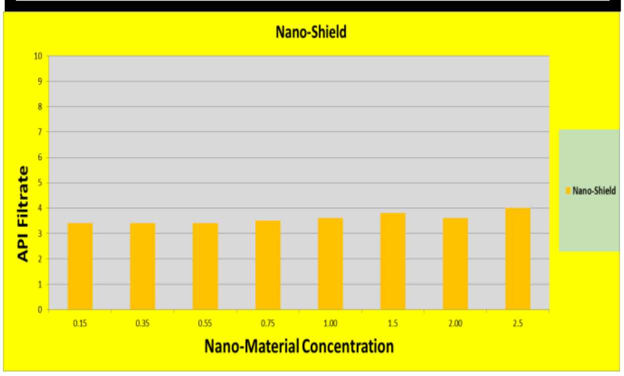

Fig. (8): The filtration volume variation with different concentrations of Nanoshield

Conclusions

The experimental work showed that the KCl decreased the rheological properties of the blank fluid in comparison to Nanoshield which will lead to more treatment with drilling fluids chemicals to adjust the mud properties to be suitable for the drilling operations (more cost). Also, it I found that the KCl increased the fluid loss volume of the blank fluid. So, it is considered from the side effects of using the KCl in drilling fluids to check the rheology and fluid loss properties carefully before drilling process.

The overall comparison showed Nanoshield can be applicable as a substitute to KCl in water base mud.

Further studies need to be conducted on different concentrations of KCl and on different kinds of nano-materials.

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