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FULL LENGTH ARTICLE

Enhancing the rheological properties and shale inhibition behavior of water-based mud using nanosilica, multi-walled carbon nanotube, and graphene nanoplatelet

A. Aftab [a,b], A.R. Ismail [a,*], Z.H. Ibupoto [c]

[a] Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Malaysia
[b] Petroleum and Natural Gas Engineering Department, Mehran UETSZAB, Sindh, Pakistan
[c] Department of Chemistry, Sindh University, Pakistan

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Abstract Five different drilling mud systems namely potassium chloride (KCl) as a basic mud, KCl/partial hydrolytic polyacrylamide (PHPA), KCl/graphene nanoplatelet (GNP), KCl/nanosilica and KCl/multi-walled carbon nano tube (MWCNT) were prepared and investigated for enhancement of rheological properties and shale inhibition. Nanoparticles were characterized in drilling mud using transmission electron microscope (TEM) analysis. Mineralogical analysis of shale was examined by X-ray diffraction (XRD). Five shale plugs were prepared using compactor cell for the determination of shale swelling. Shale swelling was determined using the linear swell meter (LSM) for 20 hours. Results revealed that basic mud and KCl/polymer mud systems shows 30% and 24% change in shale volume. MWCNT, nanosilica and GNP were added separately in the KCl mud system. 0.1 ppb of each MWCNT and nanosilica showed 32% and 33% change in shale volume. However, when the shale was interacted with WBM containing 0.1 ppb of GNP, it was found that only 10% change in shale volume occurred. The results showed that the addition of nanoparticles in the KCl mud system improved the shale inhibition. API, HPHT filtrate loss volume, plastic viscosity (PV) and yield point (YP) were improved using GNP. It is learned from the experimental work that small concentration of KCl with GNP can mitigate shale swelling compared to the mud contains higher concentration of KCl and PHPA in WBM. Thus, GNP can be a better choice for enhancement of WBM performance.

* Corresponding author.
E-mail address: razak@utm.my (A.R. Ismail).

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Nomenclature

API	American Petroleum Institute
FW	fresh water
FL	fluid loss
GNP	graphene nano platelet
GS	gel strength
HPHT	high pressure high temperature
KCl	potassium chloride
LSM	linear swell meter
PV	plastic viscosity
MWCNT	multi-walled carbon nano tube
NaOH	sodium hydroxide or caustic soda
OBM	oil-based mud
PAC	poly anionic cellulose
PHPA	poly hydrolytic polyacrylamide
RPM	rotation per minute
SBM	synthetic-based mud
SDS	sodium dodecyl sulfate
TKPP	tetra-potassium pyrophosphate
WBM	water-based mud
YP	yield point

Units

cc	cubic centimeter
cp	centipoise
ft	feet
g	gram
minutes	min
mPa s	milli pascal's
nm	nanometer
ppb	pound per barrel
ppg	pound per gallon
Pa s	pascal's
sec	seconds
μm	micrometer

Units conversion

$\frac{1\ \text{lb}}{100\ \text{ft}^2} = 0.4788\ \text{Pa s}$

$1\ \text{cp} = 1\ \text{mPa s}$

$1\ \text{ppb} = \frac{1\ \text{g}}{350\ \text{cc}}$

1. Introduction

Drilling operation requires an extra care in well monitoring, rig hoisting, rig power, and most importantly well control system. Proper handling of well control system is only possible by well control equipment such as blow-out preventer and proper formulation of drilling muds [1,2]. Functions of drilling mud are to maintain the hydrostatic pressure when formation pressure exceeds the drilling mud pressure, to cool drill bit when drilling in hard geological formations for longer time, and to suspend and transport drilled cuttings from subsurface to surface. However, these functions can be well performed with the proper treatment of drilling muds rheology [3]. Furthermore, rheological properties of drilling muds such as mud density, PV, apparent viscosity (AV), YP, gel strength, mud filtrate loss volume and lubricity are important to maintain for an efficient drilling operation and wellbore stability.

Shale causes world's 70% of wellbore instability problems. Shale instability is caused due to presence of clay minerals into the shale. These clay minerals in particular kaolinite, smectite and montrolite have great affinity with the water [4]. However, clay minerals start to swell after they interact with the water and as a result, clay swelling raised the wellbore instability such as shale sloughing, tight hole, caving and reduce efficiency of mud to lift the drilled cuttings. Clay swelling reduces the rate of penetration (ROP) due to bit balling with sticky clay [5]. Previously, Reid et al. [6] determined shale swelling behavior of north sea fields by interacting with different types of drilling muds. It was found that performance of tetra-potassium pyrophosphate (TKPP) was equivalent to OBM. However, TKPP muds shown mud accretion problems. Traditionally, KCl and PHPA are used to minimize the shale swelling problems. Somehow, KCl mud performance is good for shale swelling inhibition but the use of high concentration of KCl in drilling mud is strictly prohibited due to environmental concerns [7].

Beside that polymers such as acrylamide and PHPA are good heat insulators and used for prevention of mud filtrate, and inhibition of clay swelling [8]. These polymers cannot sustain high pressure high temperature (HPHT) downhole conditions [3]. Oil-based mud (OBM) and synthetic-based mud (SBM) are widely used for shale inhibition and considered as good drilling lubricants. OBM and SBM minimized the shale swelling because of less water content in their composition. Usage of OBM in environmental altered areas is considered to be illegitimate [9]. There is no doubt that OBM came up with excellent shale inhibition properties, but it raised some operational problems such as it disturbed well logging data, and sometimes it raises formation damage [10,11]. Therefore, oil and gas industry is more interested in WBM. It is used to drill almost 80% of all wells. It contains about 80% of water phase and 20% drilling additives. High water content drilling muds normally result in high friction and mud filtrate volume, low PV, and a great affinity with shale which leads to wellbore instability problems. Sehly et al. [12] found the way to minimize the concentration of KCl in WBM and reduced to environmental acceptable limit. Rodrigues et al. [13] used the multi functional polymers to modify rheological and shale inhibition properties of drilling muds. Moreover, Abdou et al. [14] evaluated Egyptian bentonite and nano bentonite as a drilling mud. It was found that use of local bentonite and nano bentonite is not suitable without using necessary drilling mud additives.

Currently, the technical challenge is faced by the oil and gas drilling sector to prepare drilling muds to improve rheological properties and shale inhibition at high temperature conditions. Conventional WBM contained shale stabilizers or conventional inhibitors are heat insulators, macro size and can not plug nanopores of shale. Therefore, water invades into the wellbore, and results in high mud filtrate volume and clay swelling. Nanoparticle can be an excellent solution to plug nano pore size of the shale. Various investigators reported the