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The novel approach for the enhancement of rheological properties of water-based drilling fluids by using multi-walled carbon nanotube, nanosilica and glass beads

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

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

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ABSTRACT

Nano and micron materials are investigated in water-based drilling fluid (WBDF) to improve its rheological behaviour. Due to the environmental and certain operational concerns, the use of oil-based drilling fluid (OBDF) and synthetic based drilling fluid (SBDF) is restricted that caused the industry seeking for new ways to enhance rheological properties of WBDF. This study was based on investigating the applicability of multi-walled carbon nanotube (MWCNT), nanosilica and glass beads (GBs) as primary additives for enhancing the filtrate volume, lubricity and other rheological properties of WBDF. This study focused on the effect of different concentrations such as 0.001 ppb, 0.002 ppb, 0.01 ppb, 0.02 ppb, 0.1 ppb, and 0.2 ppb of each MWCNT and nanosilica over the rheological performance of WBDF. Effect of GBs of different sizes such as (90–150 μm) and (250–425 μm) was investigated at different concentrations of 2 ppb, 4 ppb, 6 ppb, 8 ppb, 10 ppb, and 12 ppb over rheological performance of WBDF. Results revealed that coefficient of friction (CoF) for drilling fluid without nanoparticles and GBs was 0.238. 0.01 ppb of MWCNT and nanosilica provided 44% and 38% CoF reduction. 4 ppb of GBs (90–150 μm) provided 28% CoF reduction. MWCNT showed 4.5 ml of filtrate volume and 2/32 inch of mud cake thickness. Thus, MWCNT can be a better choice as a drilling fluids additive for WBDF.

1. Introduction

Enhanced formulation and engineering design of drilling fluids system are key to reach target depth of hydrocarbon reservoir. Drilling fluids showed complex behaviour of rheological properties under various drilling conditions (Livescu, 2012; Majidi et al., 2010; Baba Hamed and Belhadri, 2009). Mainly three types of drilling fluids such as OBDF, SBDF and WBDF are used to drill oil and gas wells. Among these drilling fluids WBDF is widely used and considered inexpensive and environmentally friendly (Christiansen, 1991; Mao et al., 2015; Rodrigues et al., 2006; Sadeghalvaad and Sabbaghi, 2015; Tehrani et al., 2009). But it has been also reported that macro, micro and polymer additives based WBDF can raise the problems of unstable rheological properties at high pressure, high temperature (HPHT) down hole conditions (Abdo and Haneef, 2013; Abdo et al., 2014; Mao et al., 2015). WBDF is typically a combination of fresh water and drilling fluids additives such as water activity salts, viscosifiers, filtrate reducers and hydrate resistant polymers.

Addition of potassium chloride (KCl) in WBDF is frequently well accepted and commonly adopted by oil and gas industry to control rheological properties and better hydration-resistance particularly in shale (Khodja et al., 2010). During drilling through water sensitive clays, KCl muds hold drill cuttings together. But a great deal of research has been conducted by Brien apos and Chenevert (1973), Chang and Leong (2014), and Clark et al. (1976) that high concentration of KCl in WBDF caused the problems of accretion. Moreover, it has been also identified that high concentration of KCl raised flocculation in rheological properties of drilling fluid and increased the cutting disposal cost (Chesser, 1987). Therefore, lower concentration of KCl has been recommended with polymers to achieve desired rheological properties.

Polymers are used to improve the rheological performance of the drilling fluids. Various polymers such as poly anionic cellulose (Fritz and Jarrett, 2012; Joel et al., 2012; Van Oort, 2003),

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

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Nomenclature

API	American Petroleum Institute
AV	apparent viscosity
FW	fresh water
CMC	carboxy methyl cellulose
FL	fluid loss
GBs	glass beads
GS	gel strength
HPHT	high pressure high temperature
KCl	potassium chloride
PV	plastic viscosity
MWCNT	multi-walled carbon nanotube
NaOH	sodium hydroxide or caustic soda
OBDF	oil-based drilling fluid
PAC	poly anionic cellulose
PHPA	poly hydrolytic polyacrylamide
RPM	rotation per minute
SBDF	synthetic-based drilling fluid
WBDF	water-based drilling fluid
YP	yield point

Units

cc	cubic centimeter
cp	centipoise
ft	feet
g	gram
mPa s	milli Pascal's second
nm	nanometer
ppb	pound per barrel
ppg	pound per gallon
Pa s	Pascal's second
Φ	dial reading
µm	micrometer

Units conversion

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

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

Xanthan gum (Van Oort, 2003), and carboxy methyl cellulose (CMC) (Sehly et al., 2015) have been reported to improve the rheological properties of drilling fluids. Polymers are heat insulators in nature and cannot be applied at extreme downhole conditions (Jeon and Baek, 2010; Mao et al., 2015). Moreover, these macro-size polymers cannot seal the nanopore throats of the wellbore. Therefore, oil and gas researchers are focusing to use physical small and enhanced heat transfer drilling fluids additives for better progress of drilling fluids rheology (Amanullah et al., 2011; Amanullah and Al-Tahini, 2009; Hoelscher et al., 2012; Zakaria et al., 2012).

Nanoparticles have enhanced the performance drilling fluids because of its distinctive type such as highly enhanced physicochemical, electrical, thermal, and hydrodynamic properties (Amanullah et al., 2011). Multifunctional applications of nanoparticles attract a variety of industries for instance biomedical technology, electronics, coating industry and material composite (Saidur et al., 2011). Similarly, successive efforts are also taken by the petroleum institutions to develop advanced material for nano sensing or nanorobots to collect the underground reservoir valuable data for the investigation of reservoir performance and deliverability (Hoelscher et al., 2012). Materials added in drilling fluids ranging in size between 1 and 100 nm are called nanoparticles (Amanullah and Al-Tahini, 2009; Hoelscher et al., 2012; Zakaria et al., 2012). Nanoparticles compared to their bulk phase materials offer many potential applications to oil and gas industry (Amanullah et al., 2011). Various applications of nanoparticles in drilling fluids have been reported in the literature such as controlling the mud filtrate volume (Contreras et al., 2014; Srivatsa and Ziaja, 2011; Barry et al., 2015), minimizing differential pipe sticking (Javeri et al., 2011), drilling and production at HPHT conditions (Nguyen et al., 2012; Singh et al., 2010; William et al., 2014) and enhancing shale stability (Hoelscher et al., 2012; Li et al., 2012; Riley et al., 2012).

More recently nanocomposites have been introduced as an alternative to polymers and clays to improve rheological properties of the drilling fluids (Jain and Mahto, 2015; Mao et al., 2015; Sadeghalvaad and Sabbaghi, 2015). It has been identified that the applicability of the nanocomposites is novel in drilling fluids with better effects over rheological performance of drilling fluids. In this study, nanoparticles such as MWCNT, nanosilica and micronmaterial such as GBs (90–150 µm) and GBs (250–425 µm) are used in WBDF to examine their effects over the rheological performance.

2. Methodology

The methodology discussed in this paper was based on the laboratory work. All the drilling fluid testing work was carried out as per recommended practice *API RP 13B-1* for investigating WBDF. The experimental design is given in Fig. 1.

2.1. Material selection

MWCNT (21 nm), nanosilica (12 nm), GBs (90–150 µm), GBs (250–425 µm) and Tween 80 surfactant were purchased. Drilling fluids additives potassium chloride (KCl), flowzan, caustics soda (NaOH), poly anionic cellulose (PAC), partial hydrolytic polyacrylamide (PHPA) and barite were provided by a drilling fluid service company.

2.2. Formulation of basic water-based drilling fluid

350 cc of basic WBDF was prepared by adding fresh water (FW), KCl, NaOH, flowzan, PAC, PHPA and barite. The formulation was designed to achieve mud weight of 12 ppg. 290 ml of freshwater was added with 39 g of KCl and stirred for 3 min. After 3 min, 0.13 g of NaOH was added into the solution and stirred for another 2 min. Then, 0.43 g of flowzan was added into the solution and stirred for 5 min. 1.3 g of PAC was added into the solution and stirred for another 5 min. Later, PHPA with 3.9 g was added into the solution and stirred for 10 min. Lastly, 180 g of barite was added and stirred for another 30 min.