Renewable and Sustainable Energy Reviews 76 (2017) 1301–1313

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Nanoparticles based drilling muds a solution to drill elevated temperature wells: A review

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ARTICLE INFO

Keywords:
Drilling additives
Nanoparticles
Nanocomposite
Drilling muds
Rheological properties
Shale

ABSTRACT

Demand of the oil and gas energy is increasing very drastically. Conventional hydrocarbon reservoirs contain below the sealing cap rock (shale) and easily move towards wellbore are at the depletion stage. Therefore, drilling engineers in collaboration with mud engineers, geologists and geophysicists are looking for innovative materials to drill unconventional hydrocarbons reservoir which are distributed at the basin scale and cannot approach easily. Geo-thermal energy wells and most of unconventional reservoirs are occurred at high pressure high temperature (HPHT) conditions. Conventional micro-macro organic drilling mud additives with heat insulator in nature can minimize efficiency while drilling HPHT wells. Oil-based muds (OBM) are strictly restricted due to high toxic level and poor emulsion stability at HT. However, this review suggests that addition of macro size organic particles and inorganic nanoparticles can enhance rheological performance, reduce filtrate loss volume and improve shale inhibition characteristics of environmental friendly water-based mud (WBM). Despite an impressive amount of experimental work has been done over drilling additives and their effect over rheological and shale inhibition, taking into account their literature review are rare. In addition, there is no review work of the knowledge gained to date. This work will hope fully trigger further development and new research topics in the area of drilling muds system.

1. Introduction

The primarily resources of energy in the world for survival of human life are non-renewable in particular oil, methane gas, and coal. Oil contributes about 31%, methane gas 21%, coal 29%, nuclear 4.8% and sum of all renewable energies contribute 10.6% to total primary energy supply [1]. Global hydrocarbon energy demand increased by 8% from 2004 to 2012. Expertise projected that the two-quarters of world's energy demand will continue to be fulfilled primarily by fossil fuels through 2040 [2]. Most possible way to overcome the fossil fuels energy crisis is to explore and drill more oil and gas wells by 2020 [3]. Exponential decline in conventional oil and gas reservoirs is boosting the interest among investors and wildcatters to drill unconventional reservoirs which are located under HPHT downhole conditions. Additionally, for renewable sustainable energy development various geo-thermal energy wells are drilled using high temperature drilling fluids system. Drilling muds play a very significant role in drilling process [4]. The first historic cable tool well drilled in 1859, and first rotary well drilled in 1863 by using WBM [5]. However, some studies reported first oil well is drilled by China in around 2000 BCE [6]. Oil and gas well drilling process depends on behaviour of drilling muds. Drilling muds are typically composed of liquids, solids, and chemical

Abbreviations: AAM, anodic alumina membrane; CMC, carboxy methyl cellulose; CoF, coefficient of fiction; HPA, hidroxypropylamide; HPHT, high temperature high pressure; KCl, potassium chloride; MBCA, 4,4′-methylenebis-cyclohexanamine; Mont, montmorillonite; NA, not available; NaCl, sodium chloride; NADF, non-aqueous drilling fluids; NG, natural gas; OBM, oil-based mud; PAC, polyanionic cellulose; PAM, polyacrylamide; PEG, polyethylene glycol; $PEI_{70,000}$, polyethyleneimine; PG, polyglycerol; PHPA, polyhydrolytic polyacrylamide; PPG, polypropylene glycol; ROP, rate of penetration; SBM, synthetic-based mud; TPEC, total primary energy consumption; TKKP, tetra-potassium pyrophosphate; TPES, total primary energy supply; WBM, water-based mud

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http://dx.doi.org/10.1016/j.rser.2017.03.050
Received 23 January 2016; Received in revised form 29 January 2017; Accepted 8 March 2017
1364-0321/

Nomenclature

lb/bbl	pound per barrel
°C	centigrade
°F	Fahrenheit
μm	micron
Ca^+	calcium
$CaCl_2$	calcium chloride
cp	centipoise
Cr3+	chromium
CuO	copper oxide
ft	foot
K	potassium
KCOOH	potassium formate
M	molarities
Mg+	magnesium
ml	mililitre
mPa.s	mili pascal's
Mtoe	metric tonnes of oil equivalent
MWCNT	multi-walled carbon nanotube
nm	nanometer
Pa	Pascal's
pH	power of hydrogen
ppg	pound per gallon
TiO_2	titanium dioxide
ZnO	zinc oxide

Units conversion

1 cp	1 mPa s
1 lb/100 ft^2	0.4788 Pa
1 metric ton	1000 kg
1 ppb	1 g/350 ml

components. Primary functions of drilling muds are to cleaning the wellbore, transporting the drill cuttings, cooling and lubricating the drill bit, maintaining wellbore stability, controlling the formation pressure, preventing reservoir fluids inflows, forming thin and impermeable filter cake [5,7,8]. Furthermore, in petroleum production, permeability of rock is preserved during earlier to late life of well such as drilling to final assisted recovery operations. Therefore, drilling muds are designed to avoid damage to permeability near-well region [9,10]. Inappropriate size of bridging material used for prevention of filtrate loss and pore throat plugging of shale in drilling muds can plug the producing channels and reduce the productivity of hydrocarbon due to formation damage. Thus, formulation of drilling mud plays a very important role in productivity of oil and gas. Formation damage due to filtrate invasion can adversely block the producing channels, thereby contributes to decline productivity of oil and gas. Anyanwu and Mustapha [11]. examined the effect of birding materials in particularly mica and alumina nanoparticles over filtrate loss and formation damage. Mica and alumina nanoparticles can reduce filtrate loss volume thereby formation damage was minimized. Mahmoud et al. [12] demonstrated that ferric oxide nanoparticles and nanosilica improved the drilling muds properties with less formation damage. Drilling muds have two different types WBM, and non aqueous drilling fluids (NADF) such as OBM and synthetic-based mud (SBM) [13]. OBM showed better shale inhibition, and rheological performance but it has high toxicity level, lower emulsion stability at HPHT and affect well logging performance.

Among various drilling muds, WBM is considered most inexpensively, widely and environmentally friendly mud [14–17]. WBM can be a better option to drill water sensitive shale with inhibitors which may provide better shale inhibition and require lower disposal cost. Addition of potassium chloride (KCl) in WBW is frequently well accepted and commonly adopted by oil and gas industry to control rheological properties and better hydrate-resistant particularly in shale [18]. Santoyo [19] modeled numerical equations for the behaviour of 11 WBM at high temperature used in drilling of geo thermal wells located in Mexico. Serpen et al. [20] demonstrated various high temperature WBM for drilling geo-thermal wells through laboratory work. Besides the fact that WBM has great potential for drilling fossil fuels wells, it is also used for drilling geo-thermal wells. Clark et al. and other researchers [21,22] all highlighted in their studies that high concentration of KCl in conjunction with polymer can improve performance of drilling fluid. However, high concentration of KCl in WBM can separate the mud into two phases such as liquid and sediments [23]. Therefore, application of polymers were broadened to improve rheological [24] and shale inhibition [25,26] characteristics of drilling muds.

Polymers contribute to drilling oil and gas wells at HPHT downhole conditions [27–29]. Synthetic polymers are formulated for viscosity [30], lubricity [31], shale stability [32,33], filtrate loss reducer [34–36] and improve yield value [37] as per their particular characteristics. Polymers were shown to have a broad utility. However, thermal gradient increases with the well depth. Behaviour of these polymers considered to be very important functional characteristic at high temperature [38]. Moreover, field results showed that behaviour of the polymers are not stable at high temperature to perform certain operational task that are essential in challenging drilling environment [39]. Because, polymers have not appropriate thermal, mechanical, chemical and physical properties [14,38,39]. Polymers like carboxymethyl cellulose (CMC), and xanthan gum are commonly added in WBM for improvement of viscosity and reduce filtration loss. These polymers are expensive and cannot be used at HPHT conditions [14,40]. Moreover, their difference with anionic additives limits the polymers applications at field scale [41]. Therefore, oil and gas industry is searching the new ways for physically small, multi-functional, environmental friendly, thermally and chemically stable polymers or natural products for formulation of efficient colloidal drilling mud system to employ virtually in all areas of drilling operation [42–44].

Applications of nanotechnology in petroleum industry are very diverse and can open the new doors for exploration phase particularly for oil and gas well drilling. Rheological, thermal, and mechanical properties of drilling muds can improve with incorporation of nanotechnology [45]. Various applications of nanoparticles in drilling muds have been reported, such as stabilizing viscosity and preventing loss circulation at high temperature, minimizing water invasion into wellbore, reducing clay swelling, preventing differential pipe sticking, controlling filtrate loss, and wellbore strengthening in shale [46–53]. Variety of nanoparticles have been studied for enhancing the performance of rheological properties and shale inhibition of drilling muds namely nanosilica [44,50,54–59], nanographite [59], graphene oxide [60], carbon nano tubes [44,58], zinc oxide [46], copper oxide [46]. Nanoparticles in drilling muds as a nanoscale additive can sustain HPHT, and provide shale inhibition.

Shale mainly consists of three clay minerals such as montmorillonite, kaolinite and illite. Montmorillonite average size is lying between 10 to 1000 nm, illite is 20–2000 nm, and kaolinite is 500–5000 nm [61]. Monohar [62]. investigated that average pore throat of shale was 3–100 nm. Moreover, shale gas reservoirs are divided into three pore systems, in particular microspores (pore diameter less than 2 nm), mesopores (pore diameter between 2 nm and 50 nm), and macrospores (pore diameter more than 50 nm) [63]. Thus, bentonite, barite, shale stabilizers and polymers have greater particle diameter in the range of 0.1–10 μm [48]. However, drilling muds additives are in macro sizes