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Evaluation of polyacrylamide-grafted-polyethylene glycol/silica nanocomposite as potential additive in water based drilling mud for reactive shale formation

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A B S T R A C T

This research work discusses the feasibility of polyacrylamide-grafted-polyethylene glycol/SiO_2 nanocomposite as a potential additive for the drilling of troublesome shale formations which may lead to severe wellbore instability problems. The free radical polymerization technique was adopted for the synthesis of the nanocomposite and it was characterized by Fourier transform infrared spectroscopy (FTIR), Field emission scanning electron microscopy (FESEM), Energy dispersive spectroscopy (EDX), Atomic force microscopy (AFM), and thermogravimetric analysis (TGA). Then, it was utilized in the formulation of the water based drilling mud system. Its effect on the rheological parameters and filtration control characteristics of the developed mud system was analyzed thoroughly as per API standard procedures. In addition, its shale inhibition characteristic was investigated with hot rolling shale dispersion tests, and immersion test. Further, Core flooding tests were carried out to study the formation damage caused by developed drilling fluid system. The experimental investigations revealed that synthesized nanocomposite exhibited superior shale inhibition property. The nanocomposite acted synergistically with other additives in the developed system and furnished good rheological properties & filtration characteristics. It also exhibited low formation damage, high shale recovery, and high thermal stability than the partially hydrolyzed polyacrylamide (PHPA) polymer in the developed drilling mud system. Hence, this nanocomposite may be used as a potential drilling fluid additive in the water based drilling fluid system for shale formations.

1. Introduction

Depletion of conventional oil & gas reserves has increased the importance of exploiting unconventional reservoirs like gas/oil shale to bridge the gap between demand and supply of energy worldwide. Traditionally, shale is considered as the source rock; however some shale plays are recognized as major unconventional hydrocarbons reservoirs. The recent advancements in the exploration & production technologies like directional drilling, multilateral drilling, hydraulic fracturing etc have opened new frontiers for the development of shale gas plays. But, wellbore instability is the major problem associated with the drilling of reactive shale formations. Generally, water based drilling fluid accelerates physical and chemical reactions with the reactive shale formations inside the wellbore. The situation becomes more severe in the presence of smectite and illite clay minerals as they get hydrated easily in presence of water and causes swelling and dispersion of shale (Liang et al., 2014; Oort, 2003; Deville et al., 2011; Patel, 2007; Simpson et al., 1961). Studies on the interaction between the shale and drilling mud confirm that wellbore instability is due to the water adsorption, osmotic swelling, and disintegration of the cuttings which in result alter the in-situ stress regime of shale formations and properties of the drilling mud (He et al., 2014; Lyons, 2010; Lummus and Azar., 1986). However, the swelling properties of the clay/shale are the function of its structure, chemical composition and the type of exchangeable cations (Mahto and Sharma., 2008).

The various wellbore instability problems can be mitigated by the selection of proper drilling mud to drill shale formations. Oil based muds (OBM) give greater shale stability than the water based mud system, however high performance water-based muds are the good alternative to drill troublesome shale formations as these

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contain relatively lower concentration of the organics and may result in favorable conditions for the fluid disposal at the drilling sites, especially in marine environment. Different polymers are added during the formulation of the water based muds in order to provide desired rheological properties, filtration characteristics, and shale inhibition to the system (Khodja et al., 2010; Mahto and Sharma, 2004; Mahto et al., 2013; Caenn and Chilingarian, 1996; Chilingarian and Vorabutr, 1981). Partially hydrolyzed polyacrylamide (PHPA), sodium silicate, glycols etc are manly used to improve the shale instability during the drilling of shale formations (Hale and Mody, 1993; Bland, 1994). The most common polymer used for shale encapsulation and borehole stabilization is the partially hydrolyzed polyacrylamide (PHPA). The polymer based mud having PHPA as a mud constituent has tendency to form thin impermeable filter cake at the wellbore, which is advantageous to mitigate wellbore instability problems. In addition, polyethylene glycol (PEG) and silicate mud systems are also preferred for the shale inhibition. The inhibition mechanism in case of PEG is governed by pore plugging phenomenon, thus reducing the dispersion of the shales. The other prevailing theories for glycol inhibition are their cloud point effect; and interference with the hydrogen between water & shale surfaces. Glycols can also form hydrogen bonds and may compete with the water, so disrupting the hydrogen bond network (Aston and Elliott, 1994). The silicate mud systems, used in conjunction with potassium salt may also help in good shale inhibition characteristics by forming a protective film on the shale surface which can prevent the invasion of filtrate and solid particles of drilling muds into the micro-fractures of the shale (Guo et al., 2006).

The applications of the nanotechnology in the oil & gas industry are extremely diverse and can lead to open new frontiers in the exploration and development of the various hydrocarbons bearing sedimentary basins. The extraordinary properties like rheological, filtration, mechanical and thermal properties of the drilling muds can be enhanced for optimum drilling performance with the incorporation of this technology (Abdo and Haneef, 2013). Recently, Sadeghalvaad and Sabbagh have reported the application of the TiO_2/polyacrylamide nanocomposite as an effective mud additive in the water based drilling fluid (Sadeghalvaad and Sabbaghi, 2015). William et al. has shown the effect of the nanofluids on the various properties of drilling fluids (William et al., 2014). Husein et al. observations showed that the addition of nanoparticles reduces the fluid loss volume of the drilling fluids (Husein et al., 2013). Authors have also observed the effect of nanoparticles like silica and carbon black in reducing circulation loss and mud cake thickness at elevated temperatures and pressures inside the wellbore (Paiaman and Al-Anazi, 2009; Javeri et al., 2011). Bicerano has a patent on the application of the nanocomposites in the development of drilling fluid as fluid loss control additive and wellbore strengthening additive (Bicerano, 2009). Several researchers has also revealed about the application of nanoparticles in improving wellbore instability arising mainly due to swelling/hydration of reactive shales (Akhtarmanesh et al., 2013; Li et al., 2012; Cai et al., 2012). The presence of nanoparticles aids in sealing of the pores and micro-cracks near the wellbore surface during the drilling of shale formations. The synergistic effects of polymers and reinforcing nano-fillers in the nanocomposite result in good mechanical strength, and high thermal stability (Hussain et al., 2006). The large surface area and smooth morphological characteristics of the fumed silica nanoparticles have got more attention for the synthesis of polymer/SiO_2 nanocomposite (Zou et al., 2008).

In the present study, polyacrylamide-grafted-polyethylene glycol/silica nanocomposite is synthesized by free radical polymerization technique using potassium persulfate (KPS) as an initiator. The morphological and thermal characteristics of the nanocomposite using conventional techniques have also been studied. Further, this research work also focuses on the application of the synthesized nanocomposite as potential drilling fluid additive in the developed inhibitive drilling mud system. The rheological and filtration studies, salt tolerance, shale inhibition, and formation damage studies were carried out for the evaluation of synthesized nanocomposite as a potential additive in the developed water based drilling fluid system. As per our knowledge, this is the first report on the applicability of polyacrylamide-g-polyethylene glycol/silica nanocomposite as a potential drilling fluid additive in water based system.

2. Experimental

2.1. Materials

Silicon oxide nanopowder (20–30 nm) was purchased from Intelligent Nanoshel LLC (United States). Synthesis grade acrylamide, potassium persulfate, potassium chloride salt; methanol, and acetone were obtained from the Merck Pvt. Ltd., Mumbai and CDH. Chemicals Ltd., India respectively. Xanthan gum (XG), pregelatinized starch and partially hydrolyzed polyacrylamide (PHPA) were procured from Oil & Natural Gas Corporation Ltd. (ONGC), India. Shale sample was collected from Damodar Valley basin, India.

2.2. Synthesis of polyacrylamide-grafted-polyethylene glycol/silica nanocomposite

The polyacrylamide-grafted-polyethylene glycol/SiO_2 nanocomposite was synthesized via free radical polymerization technique in inert nitrogen gas atmosphere. Prior to the polymerization process silica nanoparticles were dispersed completely by stirring an aqueous solution of silica nanoparticles for 30 min in ultrasonic bath (Fisherband model FB 15101, UK) at room temperature. Different silica to monomer ratios (0.0006–0.0025) were used to get completely dispersed polymer matrix with silica (SiO_2) nanoparticles. Amount of polyethylene glycol (1.5–2.5 g) was also varied to obtain the optimum grade of the synthesized nanocomposite. Silica to monomer ratio was kept to 0.0006. 20 ml aqueous solution containing 0.11 mol of monomer was poured into 3-neck round bottom (RB) flask having dispersed polyethylene glycol-silica solution and was stirred for 45 min. This step will aid in the homogenous distribution of the particles in the solution. Afterward, KPS was added to initiate free radical polymerization process. The temperature was maintained at 68 °C during the synthesis. The final synthesized product was precipitated, and washed several times with solvents to remove any impurities and dried. Afterward, the synthesized product is processed for its evaluation as a potential drilling fluid additive in the developed water based mud.

2.3. Characterization of polyacrylamide-grafted-polyethylene glycol/silica nanocomposite

2.3.1. Fourier transform infrared spectroscopy (FTIR)

The silica nanoparticles, polyethylene glycol, polyacrylamide and nanocomposite were dried in oven and stored in air tight micro-centrifuge tubes before FTIR measurements. The FTIR spectra (450–4000 cm^{-1}) were measured with Perkin–Elmer Spectrum Two, FT-IR instrument (USA).

2.3.2. Field emission scanning electron microscopy (FESEM) and energy dispersive spectrometry (EDX)

FESEM analysis was carried out to study the morphology of the samples with FE-SEM Supra 55 model, Carl Zeiss (Germany) after platinum coating to get clear images. EDX is a widely used