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Research paper

Clay nanoparticles modified drilling fluids for drilling of deep hydrocarbon wells

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ABSTRACT

Projections of continued growth in hydrocarbon demand are driving the oil and gas industries to explore new or under-explored areas that are often challenging. Oman, being an oil reliant country, is also striving to go deep for exploration of non-conventional and deep lying oil reserves, as most of the existing fields are approaching maturity. Deep drilling poses a great challenge as the current performance of drilling fluids deteriorate due to high temperature and pressure (HPHT) conditions faced during extended reach drilling operations. Keeping in view the decisiveness of drilling fluids' impact on drilling efficiency, this work presents an approach to stabilize the drilling fluid rheology in HPHT conditions by making use of nanoparticles. Abundantly available in Oman, palygorskite (Pal) (natural hydrous clay mineral with fibrous rod-like microstructure) was purified, synthesized, characterized, functionalized, and tested for the first time in nano-form (10–20nm diameter) for its effectiveness to tailor the rheology of drilling fluids swiftly. The nanoparticles are able to retain the properties over a wide range of operating temperatures and pressure, thus ensuring efficient operation in versatile formations and operating conditions. After successive laboratory investigations, an absolute proportion of water, regular montmorillonite (Mt), and Pal nanoparticles provided consistent results at various temperatures and pressures, i.e., stable drilling fluid rheology at HPHT environment. The best-recorded results are reported in this paper and the properties focused here are the plastic viscosity, yield point, gel strength, density, shear thinning, spurt lost, fluid lost, and Lubricity index.

1. Introduction

Over the next three decades, global energy demand is projected to rise almost 60%, a challenging trend that may be met only by revolutionary breakthroughs in energy science and technology (Saeid et al., 2006). The demand is widespread geographically and influences all energy sources. The growing concerns about maintaining the future adequacy of oil and gas resources have urged the drilling technologists to look for going beyond the current methods and technologies for oil and gas extractions from both onshore and offshore reservoirs. Industry needs great discoveries in underlying core science and engineering as the search for hydrocarbon sources has become extreme in terms of going deeper and hence higher pressure and temperature. Oman, being an oil reliant country, is now striving hard to go beyond conventional ways for maximum upturn of oil by accessing deep lying reservoirs and cost effective drilling operations for feasible recovery from small reservoirs and exploring new fields since all of the existing fields are now approaching maturity.

The benefits of improving tools, materials, skills, use of down-hole rotation tools and any other innovation for improving drilling operations are almost ineffectual if they are not used in the presence of an accurate drilling fluid. The drilling fluid circulation has to be maintained throughout the drilling process during which it has to perform certain crucial tasks like hole cleaning, maintaining effective lubrication between the bore-hole and drill string, cooling of the bit, and maintaining appropriate drilling pressure hence weight on bit. These functions have to be performed consistently throughout the operation regardless of the type of formation and operating conditions. These functions are purely dependent on the rheological properties of the drilling fluids, particularly, viscosity, density and gel strength. Lack in performing any of these functions leads to severe drilling problems like: lost circulation, high torque and drag, instability with changing conditions, and stuck pipe events (Adriana et al., 2009; George and Scott, 1951; Mendes et al., 2003; Ryan and Douglas, 2008; Yarim et al., 2007). These problems, if happen, lead to huge financial losses since there will be a need for expensive additives, huge non-productive time in resolving the problem and in the worst cases, may lead to abandonment of the well. The problem becomes more severe in deep drilling due to the considerable increase in temperature and pressure, which results in the deterioration of fluid properties, limiting tool and downhole equipment selection, downhole pressure determination, lost circulation, low penetration rates, acid gases, and compliance with safety and environmental regulations.

Clays which are mined from surface pits as relatively pure deposits are used among many uses in drilling fluids (Anderson et al., 2010; İşçi and Turutoğlu, 2011; Neaman and Singer, 2004). Clays, such as

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claystones, shales intermixed with sands and sandstones make up the largest percentage of minerals drilled while exploring for oil and gas (Khodja et al., 2010). Mt is a useful additive for increasing the density of drilling muds. Pal had been used by industry for more than 40years before it was recognized as a distinct clay mineral. It derives its non-swelling needle-like morphology from its three-dimensional crystal structure. The shape and size of the needles result in unique colloidal properties, especially resistance to high concentrations of electrolytes, give high surface area and high porosity particles when thermally activated. Pal is currently used in drilling fluids as viscosifier improves drilling fluid's ability to remove cuttings from the wellbore and to keep the cuttings and weighing materials dispersed during periods of no circulation.

Clay minerals form an important group of the phyllosilicate family of minerals, which are distinguished by layered structures composed of polymeric sheets of SiT_4tetrahedra linked to sheets of (Al,Mg,Fe)(O,OH)$_6$octahedra. The geochemical importance of clay minerals stems from their ubiquity in soils and sediments, high specific surfaces, and ion-exchange properties. Consequently, clay minerals tend to dominate the surface chemistry of soils and sediments. Furthermore, these properties have given rise to a wide range of industrial applications throughout history (Kloprogge et al., 1999).

One major emerging application of nanotechnology in oil reservoir engineering is in the sector of developing new types of smart fluids for improved/enhanced oil recovery and drilling (Igor et al., 2006). Due to totally different and highly enhanced physio-mechanical, chemical, electrical, thermal, hydrodynamic properties and interaction potential of nano-materials compared to their parent materials, the nano-materials are considered the most promising material of choice for smart fluid design for oil and gas field applications (Amanullah and Al-Tahini, 2009). One of the pioneering works of Paiaman and Al-Anazi (2009) presents useful results by using carbon black nanoparticles in drilling fluid. The significance of the use of nanoparticles in drilling fluids has also been reported for the first time by Abdo and Danish (2010, 2012) and Abdo et al. (2010).

The work presents a novel solution to acquire a set of rheological properties by using a combination of regular Mt and Pal extracted in nano-form. A schematic procedure for purification and breaking down Pal to nano-level and using it in drilling fluids for uniform dispersion and stability at HPHT environment is established. The properties focused on are the plastic viscosity, yield point, gel strength, density, shear thinning behavior, spurt lost, fluid lost, and lubricity index.

2. Methods

2.1. Montmorillonite (Mt)

Montmorillonite $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$ is a member of the smectite family. Mt is the main constituent of bentonite. Much of Mt's usefulness in drilling and geotechnical engineering industry comes from its unique rheological properties. Relatively small quantities of Mt dispersed in water form a viscous shear thinning material.

2.2. Palygorskite (Pal)

Ideal palygorskite $Si_8O_{20}(Al_2Mg_2)(OH)_2(OH_2)_4 \cdot (H_2O)_4$ has dioctahedral character. The elongate shape of Pal results in unique colloidal properties, especially the resistance to high concentrations of electrolytes (Bergaya et al., 2006). This elongate needle shape (Fig. 1) is in contrast to the flake-shaped of Mt which leads to some unique applications.

Pal has very good colloidal properties such as specific features in dispersion, high temperature endurance, salt and alkali resistance, and high adsorbing and de-coloring capabilities and hence is suitable for many commercial applications.

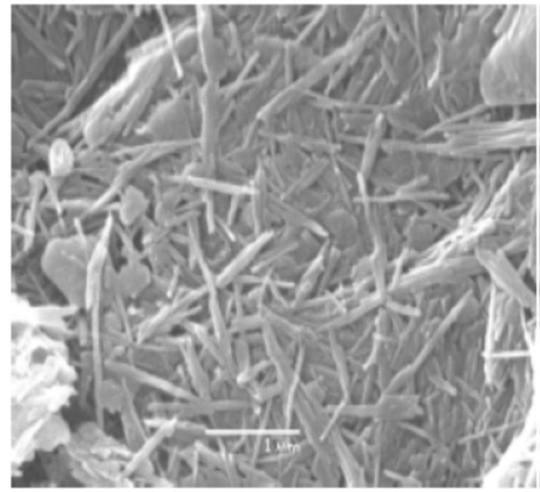

Fig. 1. SEM image of regular Pal (needle like clusters).

2.3. Use of palygorskite and montmorillonite in drilling fluids

The drilling mud circulated through a well serves the primary function of removing bit cuttings from the hole. In addition, it lubricates the bit, prevents hole sloughing, and forms an impervious filter cake on the walls of the hole, thus preventing loss of the fluid to porous formations. Of utmost importance among the characteristics of clays for a drilling mud is the ability of the clay to build up a suitable viscosity at relatively low solid levels and to maintain the desired viscosity throughout the drilling operation.

Mt has been widely used for this purpose, but it can be used only with the help of expensive chemical treatments in areas where contaminants such as salt, calcium sulfate, or magnesium sulfate are encountered. Mt based drilling fluids have the limitation of flocculation and instability at high temperature and pressure conditions. Because of high water absorption capability and swelling characteristics the dispersion behavior of Mt is non-uniform and has a huge problem of flocculation, which results in insufficient and inconsistent rheology of drilling fluids.

On the other hand, Pal has excellent colloidal properties, such as specific features in dispersion, high temperature endurance, salt and alkali resistance, and high adsorbing capabilities (Emilio and Singer, 2011). The special nanorod structure and large specific surface area can endow Pal with many unique physical and chemical properties; therefore, Pal attracted the interest to be used as efficient and stable rheology modifier for drilling fluids.

2.4. Expected performance of nanoparticles in drilling fluids

The onset of nanotechnology has revolutionized the science and engineering faction, and due to its huge domain of applicability, the drilling industry can also benefit from nanotechnology one of which is the use of nanoparticles in drilling fluids in order to have a definite operational performance, stability and suitability to adopt well with a wide range of operating conditions with minor changes in composition and sizes (Igor et al., 2006). The use of nanoparticles in drilling fluids will enable the drilling technologists to swiftly modify the drilling fluid rheology by changing the composition, type or size distribution of nanoparticles to suit any particular situation, discourage use of other expensive additives, and improved functionality. The use of nanoparticles synthesized from different materials has been used to achieve certain targets and are reported in the literature (Cai et al., 2012; Jimenez, 2003; Paiaman and Al-Anazi, 2009). Hence, by controlling the rheology of drilling fluid by using nanoparticles, severe drilling problems can be avoided by modifying the properties to suit particular drilling conditions, i.e., type of formation, surrounding temperature and pressure, formation pressure, required operating pressure etc.