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Experimental investigation of rheological and filtration properties of water-based drilling fluids in presence of various nanoparticles

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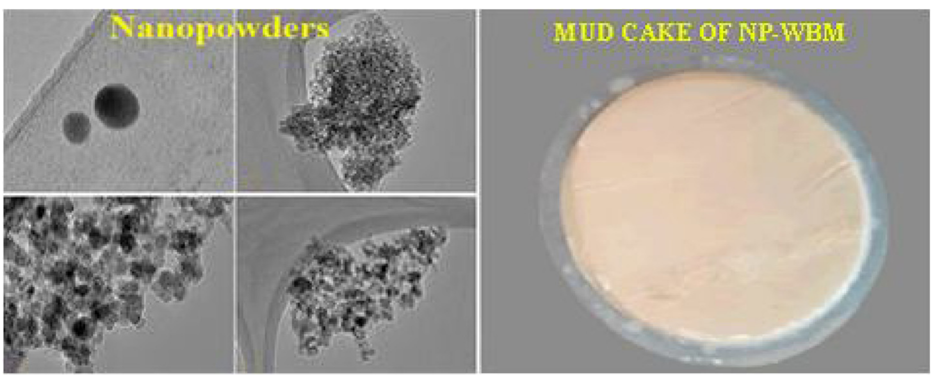
GRAPHICAL ABSTRACT



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ABSTRACT

For the past decades, considerable attention has been focused on the manufacture of a high-performance, environmentally compliant water-based mud system to be a better choice than oil and synthetic-based muds (OBM/SBM). However, the improvement of WBMs has not reached the satisfactory level yet and attempts in this regard should be continued. Accordingly, in this study, an attempt was made to improve the performance of a Bentonite-WBM by adding four types of hydrophilic nanoparticles (NPs), namely aluminum oxide (Al_2O_3), titanium dioxide (TiO_2), silicon dioxide (SiO_2), and copper oxide (CuO). The NPs were dispersed in the drilling fluid with concentrations of 0.01, 0.05, 0.1 and 1 wt%. The results revealed that the Al_2O_3 NPs increased the amount of mud filtration up to 80% while the mud cake quality became poorer as compared to the based mud. In contrast, the amount of mud filtration had a decreasing trend when SiO_2, TiO_2 and CuO NPs were applied especially at the concentration below 0.5 wt%. Rheological properties and gel strength were also improved in the presence of TiO_2, Al_2O_3 and CuO NPs in comparison with the based mud. Overall, it was concluded that adding of the NPs at concentrations below 0.5 wt% to the Bentonite-WBM has potential to improve rheological and filtration properties.

1. Introduction

Globally growth in energy demand and decline in oil production from the current oil resources has renewed the interest of petroleum engineers to explore new opportunities in deep-water and unconventional hydrocarbon reservoirs. In this regard, the right choice of a

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drilling fluid formulation for specific drilling conditions is a key factor for the success of drilling operations, particularly in unconventional formations. Drilling fluids have various roles which include cooling drilling pipes and bits, carrying drilling cuttings from the bottom of a wellbore to the ground surface, suspending the cuttings from sedimentation during the shutdown, and stabilizing the wellbore [1–3]. Drilling fluids are mainly classified into three types, namely water-base muds (WBM), Oil-based muds (OBM) and synthetic-based muds (SBM). The OBM and SBM have higher operational efficiencies as compared to the WBM. However, the use of OBM and SBM has been declined due to the environmental issues [4–6]. This remains WBMs as the preferred ones over the other two types despite their limitations. Therefore, in order to obtain further achievements in drilling engineering, more studies on WBMs properties are in demand to improve their applications.

The main drawback of applying WBMs emerges in the course of drilling a shale formation due to shale swelling which makes the use of WBMs ineffective. This is mainly due to the fact that shale swelling brings other destructive problems such as wellbore instability, lost circulation, and pipe sticking [7,8] which lower the rate of penetration and raise the drilling operation costs. In the 19^{th} century, OBM was utilized in shale formations. However, in the 20^{th} century, the application of OBM was prohibited due to the environmental issues. Therefore, water became the main and unique fluid to make drilling muds. This caused the researchers focused on the modification of rheological WBM properties to solve the aforementioned problem. It is an important point that the driller of wells be able to control the rheological properties of drilling fluids by using various additives.

Several studies were carried out on the WBMs during past decades to modify their properties by adding different additives such as soda ash and calcium carbonate [9,10]. Recently, the use of nanoparticles (NPs) has been introduced for modification of drilling fluid properties [11]. Through chemical and physical processes, researchers have shown an ability to create nanomaterials with improved thermal, mechanical, electrical, and rheological properties. The positive effects of different types of NPs on the properties of drilling fluids are documented by some researchers [1,10,12–18]. For example, Hou et al. [16] and Mohammadi et al. [15] evaluated the effects of nanopowders on the rheological properties of clay based-muds at high temperature and pressure conditions. They could enhance the penetration or plastic deformation. Rosso et al. [12] determined the effect of zinc oxide NPs to remove H_2S productive on the wells to improve the WBM performance and maximizes the porosity. Abdo and Haneef [1] came up with an approach to stabilize the drilling fluid rheology in high-pressure, high-temperature (HPHT) conditions by making use of NPs. They claimed that NPs 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. Mohammed [10], Amanullah et al. [13], Mao et al. [14], and Aftab et al. [17] have studied the effect of various concentration Nano iron oxide on the enhancement of Bentonite-WBM rheological properties such as yield point, plastic viscosity and apparent viscosity. Chai et al. [19] and Amarfio [20] studied the effect of Al_2O_3 NPs on the WBM at varying temperature conditions that have shown increasing procedure of shear rates. Sadeghalvaad and Sabbaghi [21] and Zhou et al. [22] studied the effect of TiO_2 NPs on the WBM properties and the results indicated that the additive contributes in increasing the base mud viscosity and decreasing the fluid loss and filter cake thickness. Wang et al. [18] introduced modified Fe_3O_4 NPs with Poly (sodium p-styrene sulfonate) into water-based drilling fluids as effective additives. Their rheological tests indicated a significant improvement of the drilling fluids against salt (KCl) tolerance even under high temperature and high salinity. They, therefore, concluded that their modified water-based drilling fluids are potential candidates for drilling in deep and salty formations. A few research studies have also been conducted on thermal stability and hydrate inhibition by metal oxide NPs [23–28]. It was found that heat transfer properties have been improved extensively through the addition of metal NPs. With the use of NPs, thermal conductivity increases over 50% for some cases, and filtration loss decreases with increasing NPs concentration for nearly all studies. Accordingly, it can be concluded that NPs may have the potential of solving technical challenges associated with the drilling operation.

The performance of a nano system in water based drilling fluid has shown promising potential in shale formations stability. The main mechanism through which the nano system reduces the shale permeability is by physically plugging of the nanometer sized pores [29]. The right sized NPs in combination with the correct fluid loss system can minimize the fluid-rock interaction.

As mentioned above, although there are some studies on the effects of NPs applications on the rheology of WBM, the number of NPs utilized in the previous studies was limited and more studies are in demand in this area of research to completely understand the roles of various NPs types and concentrations on the WBM. Thus, the objective of this study is to determine the rheology properties of a Bentonite-WBM in the presence of various metal oxide NPs namely Al_2O_3, TiO_2, CuO, and SiO_2. Moreover, finding the optimum concentration of the above mentioned NPs was another task in the current study. For this purpose, the Bentonite-WBM was first made and then the above mentioned NPs were added at different concentrations to the base mud. Thereafter, plastic viscosity, yield point, gel strength, filtration loss and filter cake thickness were evaluated and the results were compared to each other.

2. Materials and methods

2.1. Materials

In this study, four commercial NP types, namely TiO_2 (40 nm, purity 99.5%, specific surface area 50–100 m^2/g), SiO_2 (40 nm, purity 99.5% and specific surface area 160 m^2/g), CuO (40 nm, purity 99% and specific surface area 50 m^2/g), and Al_2O_3 (40 nm, purity 99% and specific surface area 60 m^2/g) were Procured from SkySpring Nanomaterials, Inc., (Houston, TX). X-ray diffraction (XRD, model D5000, SIMENS) and transmission electron microscopy (TEM, model JEM-2100/HR, JEOL, Acc.200.00 kV) analyses were carried out to evaluate the NPs crystalline compositions, sizes, and morphologies. Sodium carbonate (also known as soda ash, Na_2CO_3, purity > 99%) was obtained from Merck chemicals. Bentonite (size 40 μm and density of 2.68 g/cm^3) powder received from SunClayTherapy, Inc. (Florida, US) and was utilized without further purification. To determine the morphology of Bentonite, Field Emission Scanning Electron Microscope (FESEM; HITACHI-SU8020) image was prepared from the powder. Furthermore, energy dispersive X-ray (EDX) analysis was also carried out to determine the Bentonite compositions.

2.2. Water-based mud preparation

To make a based mud, 22.5 g Bentonite was slowly added to 350 mL of distilled water and put them in a mixer for 10 min. Then, 2 g of sodium carbonate was added to the suspension to maintain the filtration rate and increase the viscosity of the drilling fluid. The suspension was mixed by the mixer for 5 min. to achieve a uniform suspension. The prepared mud was put in the room at ambient condition (27 °C) for 16 h according to the API standard (API 1608). Accordingly, the bentonite crystallized completely in the suspension. After 16 h, before any testing the mud was put further in the mixer for 2 min. to recombine the mud contents. To determine the influence of NPs on the mud rheology, the base mud was placed into a balloon and the NPs in concentrations of 0.05, 0.1, 0.5 and 1 wt% were added to the prepared base mud. The muds were then agitated for 1 h using an orbital shaker at 220 rpm and ultrasonicated by an ultrasonic bath for a period of 15 min. to obtain homogeneous muds prior to each test. It should be noted that API 13D has been meticulously used for conducting the experiments. The