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Research paper

Predictive modelling of the impact of silica nanoparticles on fluid loss of water based drilling mud

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ABSTRACT

Research into the use of nanoparticles for drilling mud formulation is gaining momentum but a key challenge involves predicting the effect of nanoparticles on the properties of the modified mud. Mathematical models used in the description of drilling muds allow for a generalised computation of drilling performance. In other words, such models cannot quantitatively capture the contributions of nanoparticles to the overall performance of the nano-modified drilling mud. In this work, a new model was derived which describes the fluid loss of nanoparticle enhanced water based drilling mud under static filtration. This was done taking into account the structural kinetics of the bentonite suspension and colloidal behaviour of the nanoparticles. The new fluid loss model was compared with the known API static fluid loss model using statistical measures, Root Mean Square Error (RMSE) and Coefficient of Determination (R^2). The new model compares favourably with the API static model with RMSE and R^2 values of 0.41–0.81 cm^3 and 99.3–99.89% respectively. The new fluid loss model was able to predict a value for the maximum fluid loss. It also accounted for variation in mud cake permeability and solid fraction, which could not be explained by the API fluid loss model.

1. Introduction

Drilling activities for oil and gas is made possible with a drill bit attached to an extended string of drill pipes. The function of the drill bit is to break the rock into cuttings and this is lifted to the surface with the aid of the drilling mud (Sehly et al., 2015; Vryzas and Kelessidis, 2017). At the surface, separation of the cuttings from the drilling mud takes place in an equipment after which the drilling mud is circulated back to the wellbore (Mahmoud et al., 2016; Afolabi et al., 2017a). Additional functions performed by drilling muds include; stabilizing the bare rock surface, regulate subsurface pressures, provide buoyancy, lubricate and cool the drill bit, and prevent contamination of subsurface hydrocarbon fluids (Vryzas and Kelessidis, 2017). As a result, drilling muds must be properly formulated to carry out these functions efficiently in unfavourable downhole environments (Abdo and Danish-Haneef, 2012; Hoelscher et al., 2012; Ismail et al., 2016; Afolabi et al., 2017b; Vryzas and Kelessidis, 2017). Development of new oil and gas fields in difficult subsurface environments entails the formulation and use of sophisticated and unique drilling muds. These drilling muds must be able to preserve their fluid loss and rheological attributes even at harsh downhole conditions (William et al., 2014). In light of this, there has been increased research into the use of new technologies in advancing oil and gas exploration into these complex terrains and nanotechnology has been at the frontline of new techniques been considered (Vryzas and Kelessidis, 2017). This will open new frontlines in the development of the several hydrocarbon bearing basins (Jain et al., 2015; Taha and Lee, 2015; Ismail et al., 2016). Recent technological advancements made in certain industries such as pharmaceuticals can be attributed to nanotechnology, which has been at the forefront of scientific research and development in the past decade (Afolabi, 2017; Vryzas and Kelessidis, 2017). Nanotechnology covers the engineering of functional systems at the molecular scale. Research into the use of nanotechnology for drilling activities is not an exception to this technological advancement (Vryzas and Kelessidis, 2017). Nanoparticles are essentially made to have dimensions of about 1–100 nm. Colloidal suspensions formed from the dispersion of various nanoparticles in a continuous medium are known to have distinguishing properties for potential applications in various sectors ranging from biomedical to cosmetics, energy and aerospace industries (Vryzas and Kelessidis, 2017). The uniqueness of the physio-chemical properties of these nanoparticles makes them suitable for application in the formulation of drilling mud (Zhang et al., 2012; Jung et al., 2013; Vryzas and Kelessidis, 2017). This is due to their small size alongside the

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exceptionally high surface-to-volume ratio they possess. This makes nanoparticles most favourable for the formulation of drilling muds, which have appropriate properties to meet demands of challenging downhole conditions (Zakaria et al., 2012; Contreras et al., 2014; Barry et al., 2015). The drilling activities in the oil and gas industry can thus benefit significantly from the use of nanoparticles. Some encouraging prospects in the use of nanoparticles in drilling muds is that it imparts on them excellent characteristics under varied range of environmental conditions (Vryzas and Kelessidis, 2017). In addition, the encouraging prospects in manufacturing specific-type nanoparticles will be pivotal towards advancing nanoparticle-based drilling muds (Vryzas and Kelessidis, 2017). This is because such modified drilling muds can be formulated to meet the requirements of drilling operations in handling diverse downhole conditions (Ismail et al., 2016; Kang et al., 2016; Vryzas and Kelessidis, 2017). Adoption of new technologies often comes with pronounced risks and this may have been what has limited the use of nanoparticles to laboratory studies with ongoing research for field deployment (Vryzas and Kelessidis, 2017). Modelling the rheological and fluid loss behaviour of nanoparticle-enhanced drilling muds are important when designing and planning for economical drilling operations involving nanoparticles (Vryzas and Kelessidis, 2017). Past research efforts have been channelled towards examining the use of different types of nanoparticles such as iron oxide nanoparticles, aluminium oxide nanoparticles, silicon oxide nanoparticles, polymeric coated nanoparticles and titanium nitride nanoparticles in the preparation of drilling muds. The properties of the modified mud were investigated at different downhole conditions obtainable during drilling operations (Abdo and Danish-Haneef, 2012; Jung et al., 2013; Vegard and Belayneh, 2017; Vryzas and Kelessidis, 2017). The known properties of drilling muds, which can be altered with the use of nanoparticles are wellbore and shale stabilisation, rheology and fluid loss control, wellbore strengthening, cuttings suspension, thermal properties of the drilling muds and magnetic properties (Vryzas and Kelessidis, 2017). Production of a drilling mud custom-made with nanoparticles to withstand particular environmental and downhole requirements with adjustable properties can transform the drilling industry (Fazelabdolabadi and Khodadadi, 2015; Taha and Lee, 2015; Vryzas and Kelessidis, 2017). Promising attempts have been reported with respect to modelling the modified rheological and fluid loss behaviour of nano-drilling muds (Gerogiorgis et al., 2017). This goes to confirm their prospect for describing multifaceted nano-drilling mud systems towards viable application. The known models used in the characterisation of bentonite-based muds allow for a generalised description of mud behaviour (Gerogiorgis et al., 2017). In such approach for example, rheological models describing shear stress and viscosity are expressed as a data driven correlation or explicit function of shear rate (Gerogiorgis et al., 2017). This does not allow for customisation of such models to explicitly express the aforementioned viscosity and shear stress as a function of multiple independent variables including the contribution of nanoparticles (volume fraction) to the overall model (Gerogiorgis et al., 2017; Vryzas and Kelessidis, 2017). The same applies when describing the fluid loss behaviour of drilling muds treated with nanoparticles. The well-known API static fluid loss model is simply a function of time and parametrised approach is taken when describing the fluid loss of nanoparticle enhanced drilling muds. The contributory effect of nanoparticles in the fluid loss reduction is not captured in the model. In this work, a new model, which describes the fluid loss behaviour of nanoparticle enhanced water based drilling mud formulated from bentonite clay, was derived. This was done taking into account the structural kinetics of the bentonite suspension and colloidal behaviour of the nanoparticles. The developed fluid loss model was compared with the known API static fluid loss model using statistical tools such as the coefficient of determination (R^2) and Root Mean Square Error (RMSE) values.

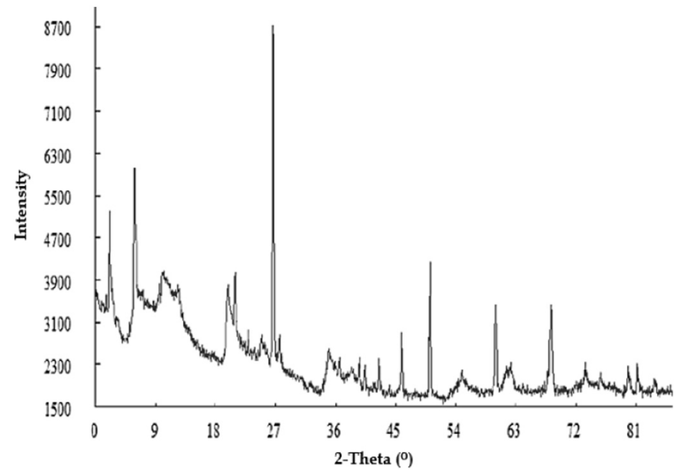

Fig. 1. X-Ray Diffraction (XRD) pattern of bentonite clay.

2. Material and methods

2.1. Materials

2.1.1. Bentonite clay

The local bentonite clay used for this study was sourced from Equilab Solutions in Nigeria. The bentonite clay consist of the montmorillonite mineral. The mineralogical analysis was carried out using the PAN Analytical X-Pert Pro diffractometer operating at 30 kV and 40 mA. The X-Ray Diffraction (XRD) pattern is shown in Fig. 1 with the mineral composition contained in Table 1. Investigation of elemental composition of the bentonite clay was done using Energy Dispersive X-Ray (EDX) spectroscopy. This was carried out using the Phenom® ProX desktop Energy Dispersive X-Ray (EDX) machine. The analysis showed high silica content and the presence of oxides of alkali and alkaline earth metal (Table 2).

2.1.2. Silica nanoparticles

Silica (SiO_2) nanoparticles were also acquired from Equilab Solutions Limited in Nigeria. The nanoparticles were manufactured by Sigma Aldrich and have the following physical properties; appearance: white powder, size: 50 ± 4 nm (TEM), purity: 99.8%, surface area (BET): 60.2 m^2/g.

2.2. Statistical design of experiment

A 2^2 (2-Level, 2-Factors) central composite design was used to create a statistical model to study the quadratic effects and interaction effects between the nanoparticles and bentonite clay particles. MINITAB® 17 (PA, USA) statistical software was used in the design of experiment and statistical analysis of the experimental data. The fluid loss and mud cake thickness (response variables) of the nanoparticle modified water base mud was studied at different concentrations of silica nanoparticles. Nanofluids of varying concentrations were prepared by adding 2–10 g of silica nanoparticles in 350 mL of distilled water. The dispersed nanoparticles were stirred using a Hamilton beach mixer at a speed of 11,000 RPM until silica nanofluids were obtained. These nanofluids acts as the base fluids for the preparation of the drilling mud. 20–40 g of the bentonite clay were added to the prepared nanofluid and stirred for 20 min after which the nanoparticle-enhanced water based drilling mud was obtained. The various quantities of nanoparticles and bentonite were selected after preliminary beneficiation experiment. The response variables were fitted by a second-order polynomial in Eq. (1):